

Urban Heat Risk in Kigali: Remote Sensing Evidence (2015–2024) for Informed Policy and Planning

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Abstract

The Urban Heat Island (UHI) effect exacerbates thermal stress in rapidly urbanizing cities, yet detailed temporal and spatial assessments remain limited in many African urban centers. This study examines UHI patterns in Kigali from 2015 to 2024 using satellite-derived Land Surface Temperature (LST) and Normalized Difference Vegetation Index (NDVI) data. The findings present significant spatial heterogeneity in vegetation cover, with greener sectors such as Jali and Kanyinya contrasting sharply with densely urbanized areas like Kicukiro, which exhibit higher surface temperatures and limited vegetation. A consistent negative correlation between NDVI and LST underscores the cooling influence of urban vegetation on surface temperatures. Persistent UHI hotspots are concentrated in highly built-up zones, highlighting the urgent need for targeted green infrastructure interventions. Statistical analyses confirm significant temporal changes in both thermal and vegetative patterns, offering critical evidence to support climate-resilient urban planning and sustainable development in Kigali and other rapidly growing African cities

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1. Introduction

Urbanization continues to reshape the physical and climatic structure of cities around the world, with particularly rapid and often unplanned growth occurring across many parts of sub-Saharan Africa (Grimm et al., 2008; Seto, Guneralp, & Hutya, 2012). One of the most visible and measurable consequences of this transformation is the Urban Heat Island (UHI) effect, in which urban areas experience significantly higher temperatures than their rural surroundings due to land cover alterations and anthropogenic heat emissions (Oke, 1982; Rizwan, Dennis, & Liu, 2008). The reduction in vegetation cover, expansion of impervious surfaces, increased surface albedo, and waste heat from buildings and transport all contribute to the intensification of urban thermal environments (Arnfield, 2003; Voogt & Oke, 2003).

Guided by the Urban Surface Energy Balance (USEB) framework, which emphasizes the interaction between surface characteristics and thermal energy fluxes (Abunnasr et al., 2022), this study focused on understanding how Kigali's urban expansion has contributed to UHI dynamics over the past decade. While the USEB model is well established (Oke, 1982), its application to African cities, especially those with hilly topographies and emerging green agendas, remains underdeveloped in empirical literature. Green infrastructure plays a central role in the regulation of surface energy exchanges and microclimatic moderation, yet it remains underprioritized in rapidly growing cities like Kigali (Gill et al., 2007; Bowler et al., 2010).

Although previous research has highlighted land cover changes in Kigali (Mutambara, Mapuranga, & Mushore, 2021; NISR, 2022), these studies have generally not addressed how such changes influence thermal conditions or spatial temperature patterns. In contrast, our study undertook a decadal temporal-spatial analysis of the UHI effect using remote sensing tools, including satellite-derived Land Surface Temperature (LST) and Normalized Difference Vegetation Index (NDVI), to map and quantify Kigali's urban heat trends between 2015 and 2024. These tools enabled us to track changes in thermal intensity across different urban zones and to assess how vegetation loss and land use transitions have influenced the distribution and severity of heat accumulation in the city (Weng, Lu, & Schubring, 2004; Dash, Manna, & Panda, 2019; Zhang et al., 2021).

The results demonstrate a significant intensification of the UHI effect in Kigali over the last decade, particularly in high-density neighborhoods and rapidly urbanizing peripheries. Areas with decreased vegetation cover and increased impervious surfaces showed pronounced increases in LST, corroborating findings from other African cities such as Addis Ababa and Nairobi (Feyisa, Dons, & Meilby, 2014; Onyango et al., 2022). These results suggest that, despite Rwanda's policy aspirations to become a green and climate-resilient nation (MININFRA, 2020), urban growth in Kigali continues to outpace the integration of adequate green infrastructure. This study fills an important gap in Rwanda's urban climate literature by offering both spatial and temporal insights into the progression of urban heat and its link to land cover dynamics, providing actionable knowledge to inform sustainable urban planning and adaptation strategies.

1.2 Objectives of the Study

The research sought to address the following specific objectives:

- 1) To analyze spatial and temporal variations in Urban Heat Island (UHI) intensity in Kigali City from 2015 to 2024 using satellite-derived Land Surface Temperature (LST) data.
- 2) To assess vegetation cover changes using NDVI (Normalized Difference Vegetation Index) and their relationship with UHI patterns over the same period.
- 3) To identify consistent urban heat hotspots and examine their spatial association with land use and urban zones.
- 4) To interpret UHI patterns to inform urban planning and climate-resilient policy strategies in Kigali.

3. Materials and Methods

Study Area

Kigali City, the capital and largest urban center of Rwanda, is geographically located between latitudes 1.90°–1.99° South and longitudes 30.0°–30.2° East, encompassing an area of approximately 730 km² (NISR, 2022). The city is located in the center of the country and is administratively divided into three districts: Gasabo, Kicukiro, and Nyarugenge, each exhibiting diverse urban characteristics. Topographically, Kigali is characterized by rolling hills and valleys with elevations ranging from 1,300 to 1,800 meters above sea level, which influence local microclimates (MININFRA, 2020). The city experiences a tropical highland climate marked by distinct wet and dry seasons that affect vegetation phenology and surface energy balance (Nkurunziza et al., 2018). Over the past decade, Kigali has undergone rapid urbanization, driven by strong economic growth and rural-to-urban migration, resulting in significant land cover changes, vegetation loss, and expansion of impervious surfaces (Douglas et al., 2011; NISR, 2022). These transformations contribute to the intensification of the Urban Heat Island effect, making Kigali an ideal study site to analyze spatial and temporal variations in land surface temperature and vegetation indices through remote sensing approaches. Figure 1 displays the baseline map; which this study has employed for zoned analysis of the Urban Heat island effect.

Data Sources

This study utilized multi-temporal satellite data from the Landsat program, specifically Landsat 8 Operational Land Imager (OLI) and Thermal Infrared Sensor (TIRS), as well as Landsat 9, accessed via the cloud-based platform Google Earth Engine (GEE) (Gorelick et al., 2017). The choice of Landsat imagery was informed by its moderate spatial resolution (30 m for reflective bands and 100 m resampled to 30 m for thermal bands), which is well suited for urban heat island (UHI) analysis at city scale (Voogt & Oke, 2003; Weng et al., 2004). Four representative years (2015, 2018, 2021, and 2024) were selected at three-year intervals to assess temporal changes in land surface temperature (LST) and vegetation indices. Imagery acquisition was restricted to the dry season months of June to August to minimize atmospheric noise from moisture and cloud cover, with only scenes containing less than 10% cloud cover being selected to ensure data reliability (Dash et al., 2019). Administrative boundary shapefiles of Kigali City were sourced from the GADM database (GADM, 2024), while population and urbanization statistics were obtained from the National Institute of Statistics of Rwanda (NISR, 2022).

Image Preprocessing and LST Calculation

Image preprocessing was performed directly within the GEE environment using its standardized routines and JavaScript-based API. Raw Landsat surface reflectance imagery underwent radiometric calibration and atmospheric correction through GEE's Landsat Collection 2 Level-2 processing pipeline, which provides surface reflectance and brightness temperature products (Roy et al., 2014). Cloud and shadow artifacts were masked using the Quality Assessment (QA_PIXEL) band with bitwise operations, effectively isolating high-quality pixels (Zhu & Woodcock, 2012). Each image was clipped to the Kigali City administrative boundary to maintain spatial consistency and to eliminate extraneous pixels beyond the study area. This preprocessing ensured spatial alignment, radiometric consistency, and comparability across all years analyzed, forming a reliable basis for calculating Normalized Difference Vegetation Index (NDVI) and Land Surface Temperature (LST) (Weng et al., 2004; Zhang et al., 2021).

UHI Analysis Approach

The Urban Heat Island (UHI) effect was assessed using the Land Surface Temperature (LST) derived from Landsat thermal bands (Band 10 for Landsat 8 and 9). Surface temperature retrieval was conducted using the mono-window algorithm implemented in Google Earth Engine (GEE), which accounts for atmospheric and emissivity corrections. Vegetation indices such as the Normalized Difference Vegetation Index (NDVI) were also computed to examine the spatial relationship between vegetation cover and LST. Temporal comparisons were made across the selected years (2015, 2018, 2021, and 2024) to identify the intensity and spatial extent of UHI in Kigali City. Hotspot zones were identified by mapping high-LST areas in relation to urban land use and built-up density.

NDVI and LST Classification Thresholds

Table 1. Classification scheme for Normalized Difference Vegetation Index (NDVI) values used to categorize vegetation cover across the study area.

Class	NDVI Range	Interpretation
1	-0.06 – 0.00	Water / Built-up
2	0.01 – 0.10	Barren / Bare Soil
3	0.11 – 0.20	Sparse Vegetation
4	0.21 – 0.30	Moderate Vegetation
5	0.31 – 0.40	Dense Vegetation
6	0.41 – 0.48	Very Dense Vegetation

Source: QGIS Development Team (2025). QGIS Geographic Information System. Open Source Geospatial Foundation Project.

Table 2. Classification scheme for Land Surface Temperature (LST) values applied to categorize thermal conditions across the study area.

Class	LST Range (°C)	Interpretation
1	≤ 24	Very Cool
2	24.1 – 27	Cool
3	27.1 – 30	Moderate
4	30.1 – 33	Warm
5	33.1 – 36	Hot
6	≥ 36.1	Very Hot

Source: QGIS Development Team (2025). QGIS Geographic Information System. Open Source Geospatial Foundation Project.

NDVI and LST Change Detection Thresholds

Table 3. Threshold values defining the categories of NDVI change between 2015 and 2024, used to assess vegetation dynamics over the study period.

NDVI Change Range	Interpretation
≤ -0.05	Vegetation Loss
-0.05 to 0.05	No Significant Change
> 0.05	Vegetation Gain

Table 4. Threshold values defining categories of Land Surface Temperature (LST) change (°C) between 2015 and 2024, used to evaluate thermal variations over the study period.

LST Change Range	Interpretation
$\leq -1.5\text{ }^{\circ}\text{C}$	Significant LST Decrease
-1.5 to +1.5 °C	No Significant LST Change
$> +1.5\text{ }^{\circ}\text{C}$	Significant LST Increase

Source: QGIS Development Team (2025). QGIS Geographic Information System. Open Source Geospatial Foundation Project.

LST Change Categories for Hotspot Mapping

Table 5. Categorization of Land Surface Temperature (LST) changes used for hotspot mapping, detailing the classification thresholds and their corresponding change categories.

Category	LST Change Condition
Very High	$\geq 1.0\text{ }^{\circ}\text{C}$
High	0.5 – 0.99 °C
Moderate	0.0 – 0.49 °C
Low	$< 0.0\text{ }^{\circ}\text{C}$

Source: QGIS Development Team (2025). QGIS Geographic Information System. Open Source Geospatial Foundation Project.

3. Results

Temporal and Spatial Patterns of NDVI and LST across Kigali City

NDVI Spatial Distribution and Temporal Trends

The Normalized Difference Vegetation Index (NDVI) values across Kigali City sectors reveal notable spatial differences and temporal patterns in vegetation health and density from 2015 through 2024. The average NDVI values vary considerably between sectors, reflecting the diversity of land use and vegetation cover within the urban landscape. Throughout the three years

analyzed, sectors such as Jali, Kanyinya and Rutunga consistently demonstrate higher average NDVI values (Table 6-9), ranging approximately between 0.22 and 0.25. This suggests these areas maintain relatively dense and healthy vegetation cover. In contrast, sectors like Rwezamenyo, Gitega, and Kicukiro exhibit lower average NDVI values, typically below 0.13, indicating more sparse vegetation, which may be attributed to higher urbanization levels and limited green spaces.

As shown in Figures 2, 3 & S1, S2); examining temporal trends, the NDVI values appear relatively stable with only minor fluctuations observed across most sectors over the ten-year period. For instance, sectors such as Bumbogo and Jabana show a slight increase in NDVI, from around 0.21 in 2018 to approximately 0.22 in 2024, implying modest improvements or maintenance of vegetation cover. On the other hand, some sectors like Gatsata and Gisozi record small decreases in NDVI values over the same period, which might be linked to urban development or land cover changes. These subtle variations likely reflect the interplay of seasonal influences, land management practices, and ongoing urban expansion.

Variability within sectors, as indicated by standard deviation and range of NDVI values (Table S1-S4), highlights the heterogeneous nature of vegetation cover in the city. Sectors such as Nyakabanda and Muhima demonstrate higher variability, with standard deviations reaching up to 0.08 in 2024, pointing to fragmented vegetation patches interspersed with built-up areas. Conversely, sectors like Rwezamenyo, which have lower variability, suggest more homogeneous land cover dominated by urban infrastructure with limited green vegetation.

It is also noteworthy that the Masaka sector recorded the highest NDVI range, around 0.50 in 2021, indicating a significant difference between areas of dense vegetation and bare or built surfaces within the sector. The maximum NDVI values across most sectors generally exceed 0.35, indicating the presence of relatively dense vegetation patches such as parks or remnant forest fragments within the urban matrix. Despite the overall stability in NDVI values, slight declines observed in some sectors may reflect ongoing pressures from urbanization, leading to a gradual reduction in vegetation cover (Figure 4). In general, the NDVI analysis across Kigali City sectors from 2018 to 2024 shows a relatively stable but spatially diverse vegetation pattern. While certain sectors maintain or slightly increase their vegetation cover, others experience small declines, underscoring the importance of urban greening and conservation initiatives to sustain the ecological benefits and enhance urban livability. NDVI maps for intermediate years [2018&2021] can be found in the supplementary information for more year-wise details.

Table 6. Mean NDVI values in 2015 for the top five sectors in Kigali City exhibiting the highest vegetation cover.

Sector	Mean
Rutunga	0.26794
Kanyinya	0.25591
Jali	0.25271
Nduba	0.2515

Gikomero	0.25142
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Source: QGIS Development Team (2025). QGIS Geographic Information System. Open Source Geospatial Foundation Project.

Table 7. Mean NDVI values in 2018 for the top five sectors in Kigali City exhibiting the highest vegetation cover.

Sector	Mean
Gikomero	0.29523
Rutunga	0.28977
Nduba	0.28541
Jali	0.27228
Bumbogo	0.26666

Source: QGIS Development Team (2025). QGIS Geographic Information System. Open Source Geospatial Foundation Project.

Table 8. Mean NDVI values in 2021 for the top five sectors in Kigali City exhibiting the highest vegetation cover.

Sector	Mean
Kanyinya	0.2534
Mageregere	0.24478
Jali	0.24366
Gikomero	0.24287
Rutunga	0.24105

Source: QGIS Development Team (2025). QGIS Geographic Information System. Open Source Geospatial Foundation Project.

Table 9. Mean NDVI values in 2024 for the top five sectors in Kigali City exhibiting the highest vegetation cover.

Sector	Mean
Kanyinya	0.2448
Jali	0.244
Mageregere	0.2381
Nduba	0.2343
Rutunga	0.2328

Source: QGIS Development Team (2025). QGIS Geographic Information System. Open Source Geospatial Foundation Project.

LST Spatial Distribution and Temporal Trends

The analysis of Land Surface Temperature (LST) data over the period 2015 to 2024 reveals distinct spatial patterns and temporal trends across Kigali’s sectors. (Figure 5, 6 & S1, S4) illustrate temperature variations that are strongly influenced by urban morphology, land use, and vegetation cover. As highlighted in Table 10-13; Highest mean LST values are consistently observed in sectors such as Kimisagara, Muhima, Gikondo, Niboye, and Rwezamenyo, with temperatures frequently exceeding 35°C. These sectors correspond to densely urbanized areas characterized by impervious surfaces, low vegetation cover, and intense anthropogenic activities, contributing to elevated surface heating. Conversely, peripheral sectors like Jali, Kanyinya, and Kigali show relatively lower mean LST values, often below 32°C, reflecting a combination of more open spaces, vegetation presence, and lower built-up density. LST maps for intermediate years [2018&2021] can be found in the supplementary information for more year-wise details.

Over the decade, the LST data indicates overall stability in sector-level average temperatures, with minor fluctuations likely tied to seasonal and climatic variability. While some urban hotspots maintain consistently high LST values, the spatial extent of elevated temperature zones appears to have marginally expanded, potentially reflecting ongoing urban expansion and densification. Temperature ranges within sectors vary, with Jali and Bumbogo exhibiting the widest LST ranges (over 18°C), suggesting heterogeneous land cover types and microclimatic variability. In contrast, sectors like Rwezamenyo and Gitega show relatively narrow temperature ranges (under 5°C), indicative of more uniform land surface characteristics (See Figure 7). The interplay between LST and vegetation health is further highlighted when combined with NDVI data. Sectors with lower NDVI values tend to correspond with higher LST, underscoring the cooling effect of vegetation in urban heat mitigation. Overall, these findings emphasize the need for targeted urban greening and sustainable land use planning to manage urban heat islands and improve climate resilience in Kigali.

Table 10. Mean Land Surface Temperature (LST, °C) values in 2015 for the top five sectors in Kigali City exhibiting the highest temperatures.

Sector	Mean
Rwezamenyo	38.2899
Gikondo	36.94
Kicukiro	36.8399
Muhima	35.5194
Niboye	35.207

Source: QGIS Development Team (2025). QGIS Geographic Information System. Open Source Geospatial Foundation Project.

Table 11. Mean Land Surface Temperature (LST, °C) values in 2018 for the top five sectors in Kigali City exhibiting the highest temperatures.

Sector	Mean
Rwezamenyo	36.69503
Kicukiro	35.65349
Gikondo	35.4922
Niboye	35.16892
Muhima	34.86435

Source: QGIS Development Team (2025). QGIS Geographic Information System. Open Source Geospatial Foundation Project.

Table 12. Mean Land Surface Temperature (LST, °C) values in 2021 for the top five sectors in Kigali City exhibiting the highest temperatures.

Sector	Mean
Muhima	36.2
Kimisagara	36.17
Kicukiro	35.96
Gikondo	35.52
Niboye	35.4

Source: QGIS Development Team (2025). QGIS Geographic Information System. Open Source Geospatial Foundation Project.

Table 13. Mean Land Surface Temperature (LST, °C) values in 2024 for the top five sectors in Kigali City exhibiting the highest temperatures.

Sector	Mean
Rwezamenyo	35.7185
Niboye	34.8328
Kicukiro	34.6805
Gikondo	34.3239
Nyarugunga	34.1962

Source: QGIS Development Team (2025). QGIS Geographic Information System. Open Source Geospatial Foundation Project.

Annual Correlation between NDVI and LST

Understanding the relationship between vegetation cover and land surface temperature (LST) is critical for assessing urban heat dynamics and ecological sustainability. In this study, the annual Pearson correlation coefficients between NDVI and LST were calculated to evaluate the vegetation cooling effect across Kigali City for the selected years: 2015, 2018, 2021, and 2024.

The results reveal a consistently strong negative correlation (see correlation Matrix in Figure 8) between NDVI and LST over all four years (see Table 14), with coefficients ranging from -0.795 in 2021 to -0.919 in 2018 (as visualized in Figure 10). This inverse relationship indicates that areas with higher NDVI values (denser or healthier vegetation) are generally associated with lower land surface temperatures. The strongest vegetation cooling effect was observed in 2018, suggesting a relatively better vegetative cover during that year.

These findings are visually supported by the scatterplot graphic (Figure 9), which demonstrates a clear downward trend in LST values with increasing NDVI for a representative year. Such patterns align with well-established urban climatology theories that link vegetation to reduced surface heat, particularly through processes like evapotranspiration and shading. At the zonal level, the Outskirts/Rural Fringe zone, which consistently shows the highest NDVI values across all years (e.g., 0.281 in 2018), records the lowest mean LST (e.g., 29.98°C in 2018). In contrast, the City Center and Dense Residential zones show relatively lower NDVI and higher LST values, especially in years with reduced vegetation cover like 2021. These trends further emphasize the spatial significance of green spaces in urban heat mitigation.

For additional insights into the relationship between NDVI and LST over time, readers are referred to Figure S5, which presents the temporal trend of the correlation between NDVI and LST from 2015 to 2024, illustrating how the strength and direction of this relationship have evolved throughout the study period. Furthermore, Figure S6 displays annual scatterplots of NDVI versus LST for each selected year, highlighting the inter-annual variability in vegetation cover and surface temperature dynamics across Kigali. In addition, Figure S9 presents multi-panel bar charts comparing mean LST and NDVI values by year and by urban zone, providing a clearer view of spatio-temporal patterns in both surface temperature and vegetation. While Figure S9 may also stem from correlation-based analysis, it primarily supports the interpretation of spatial and temporal variability in these key environmental indicators.

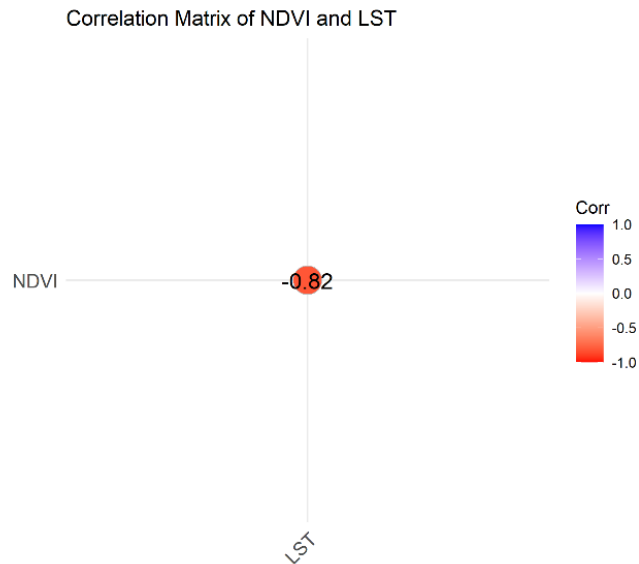


Figure 8. Correlation matrix illustrating the strength and direction of relationships between NDVI and LST across all zones and study years. **Source:** RStudio Team (2024). RStudio: Integrated Development Environment for R. Posit Software,PBC

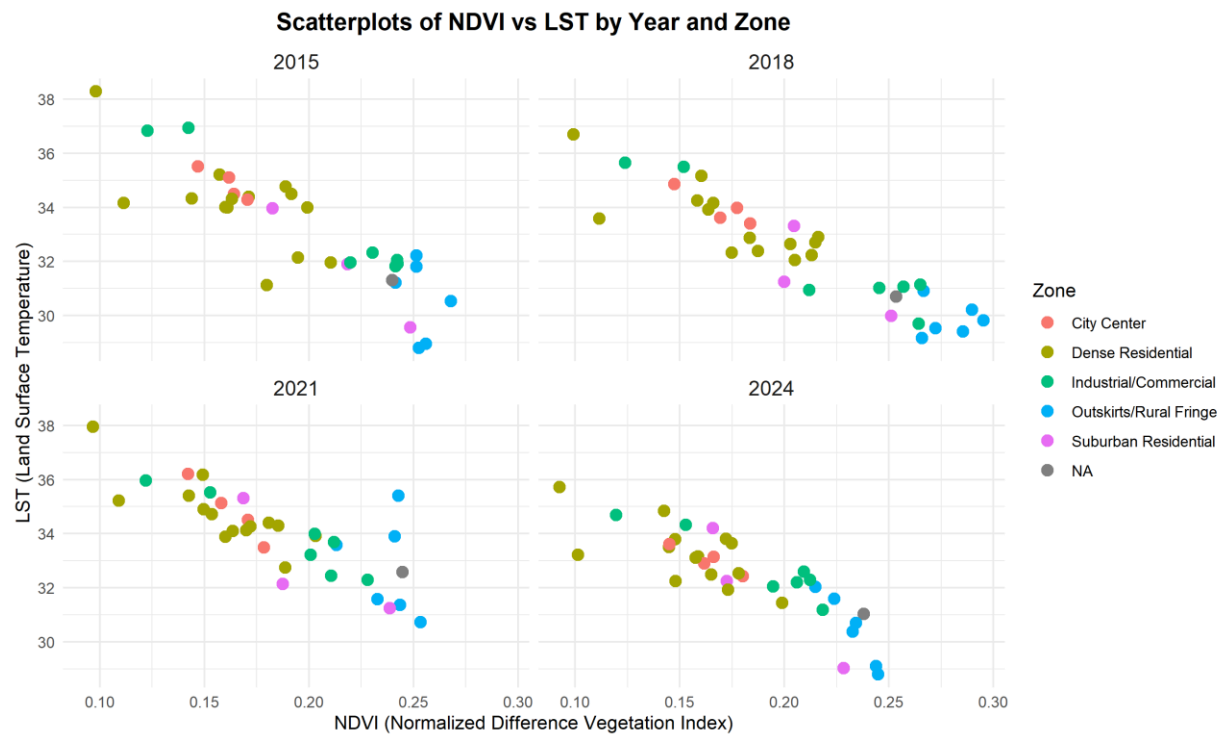


Figure 9. Combined scatterplots illustrating the relationship between NDVI and LST across different years and zones, highlighting temporal and spatial correlation patterns. **Source:** RStudio Team (2024). RStudio: Integrated Development Environment for R. Posit Software,PBC

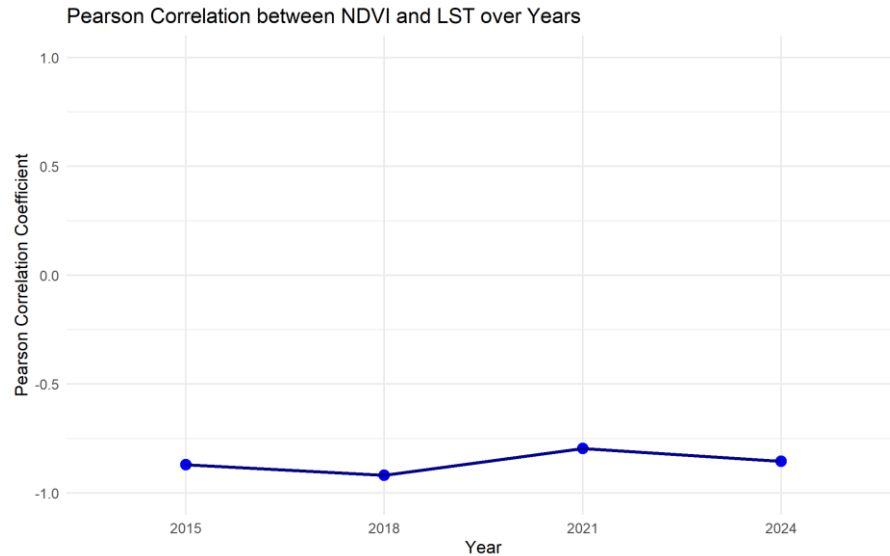


Figure 10. Pearson correlation coefficients between NDVI and LST, disaggregated by zone and year, indicating the strength and direction of their relationship across spatiotemporal scales.
Source: RStudio Team (2024). RStudio: Integrated Development Environment for R. Posit Software,PBC

Table 14. Summary statistics of NDVI and Land Surface Temperature (LST) by urban zone from 2015 to 2024, including annual Pearson correlation coefficients between NDVI and LST.

Year	Zone	Mean NDVI	SD NDVI	Mean LST (°C)	SD LST	Pearson r (NDVI vs. LST)
2015	City Center	0.1609	0.0100	34.85	0.57	-0.869
2015	Dense Residential	0.1665	0.0322	34.08	1.68	
2015	Industrial/Commercial	0.2134	0.0448	32.57	2.52	
2015	Outskirts/Rural Fringe	0.2530	0.0095	30.92	1.34	
2018	City Center	0.1695	0.0158	33.96	0.65	-0.919
2018	Dense Residential	0.1755	0.0363	33.42	1.32	
2018	Industrial/Commercial	0.2219	0.0486	31.70	2.19	
2018	Outskirts/Rural Fringe	0.2819	0.0120	29.98	0.61	
2021	City Center	0.1624	0.0159	34.83	1.14	-0.795
2021	Dense Residential	0.1589	0.0293	34.72	1.23	
2021	Industrial/Commercial	0.1980	0.0385	33.32	1.75	
2021	Outskirts/Rural Fringe	0.2347	0.0128	33.17	1.69	
2024	City Center	0.1633	0.0144	33.02	0.49	-0.855
2024	Dense Residential	0.1540	0.0287	33.24	1.13	
2024	Industrial/Commercial	0.1931	0.0368	32.14	1.94	
2024	Outskirts/Rural Fringe	0.2300	0.0110	30.76	1.14	

Source: RStudio Team (2024). RStudio: Integrated Development Environment for R. Posit Software,PBC

Identification and Mapping of Urban Heat Island Hotspots

Key to this research; the analysis of Land Surface Temperature (LST) data from 2015, 2018, 2021, and 2024 was conducted to identify and map Urban Heat Island (UHI) hotspots across Kigali City’s sectors. The sectors in Kigali City exhibited considerable variability in mean surface temperatures, with values ranging from 28.79°C in Kanyinya to 35.72°C in Rwezamenyo. Notably, sectors such as Kicukiro (mean LST = 34.68°C), Niboye (34.83°C), and Gikondo (34.32°C) demonstrated some of the highest average surface temperatures, consistent with their dense built environments and limited vegetation cover. The observed temperature ranges within sectors, varying between approximately 3.7°C and 18.6°C, reflect the heterogeneous land use and microclimatic conditions influencing localized heat retention.

To understand the temporal persistence of hotspots, Table 15 & Figure 11 detail sectors frequently classified as UHI hotspots across the study period. Both Kicukiro and Rwezamenyo maintained hotspot status during all four years (2015, 2018, 2021, 2024), representing permanent heat accumulation zones in Kigali. Gikondo was identified as a hotspot for three of the four years, suggesting strong but somewhat variable heat island effects.

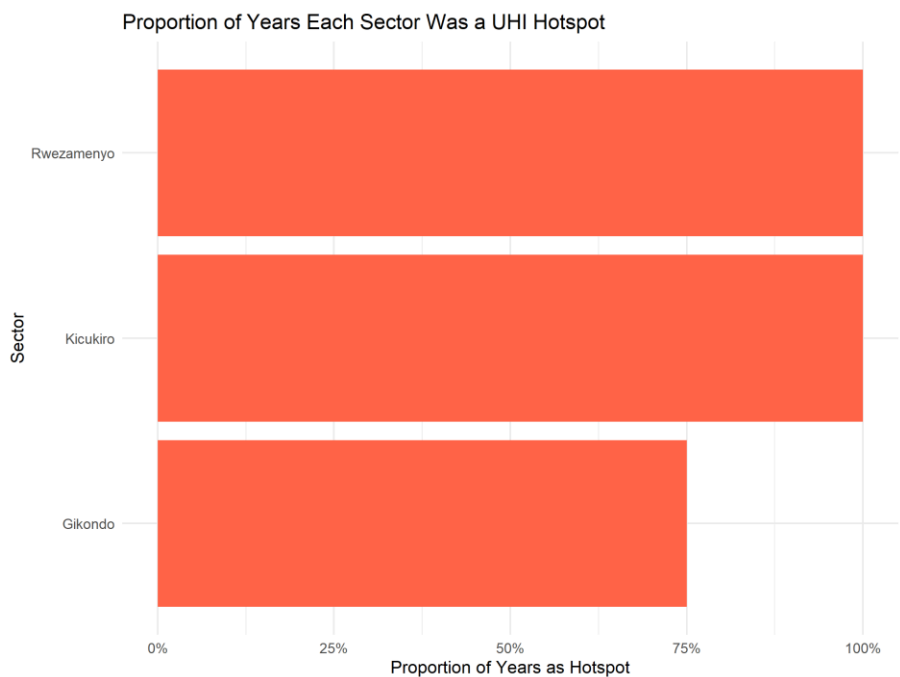


Figure 11. Proportion of sectors exhibiting Urban Heat Island (UHI) hotspots across the study area, highlighting the spatial distribution and relative intensity of heat-affected zones. **Source:** RStudio Team (2024). RStudio: Integrated Development Environment for R. Posit Software,PBC

Table 15. Frequency of Urban Heat Island (UHI) Hotspot Occurrence by Sector (2015–2024). Shows the number and percentage of years each Kigali sector experienced UHI hotspots between 2015 and 2024, indicating spatial patterns of urban heat stress.

Sector	Years Identified as Hotspot	Total Years	Proportion of Years as Hotspot
Kicukiro	4	4	1.00
Rwezamenyo	4	4	1.00
Gikondo	3	4	0.75

Source: RStudio Team (2024). RStudio: Integrated Development Environment for R. Posit Software,PBC

Furthermore, land use-based grouping of LST data reveals that the City Center and Dense Residential zones experienced the highest mean LST values of 34.16°C and 33.87°C respectively, highlighting the influence of urban density and impervious surfaces on heat retention (Table 16 & Figure 12). Lower mean temperatures were found in the Outskirts/Rural Fringe zones, with an average LST of 31.20°C, indicative of greater vegetative cover and less built infrastructure.

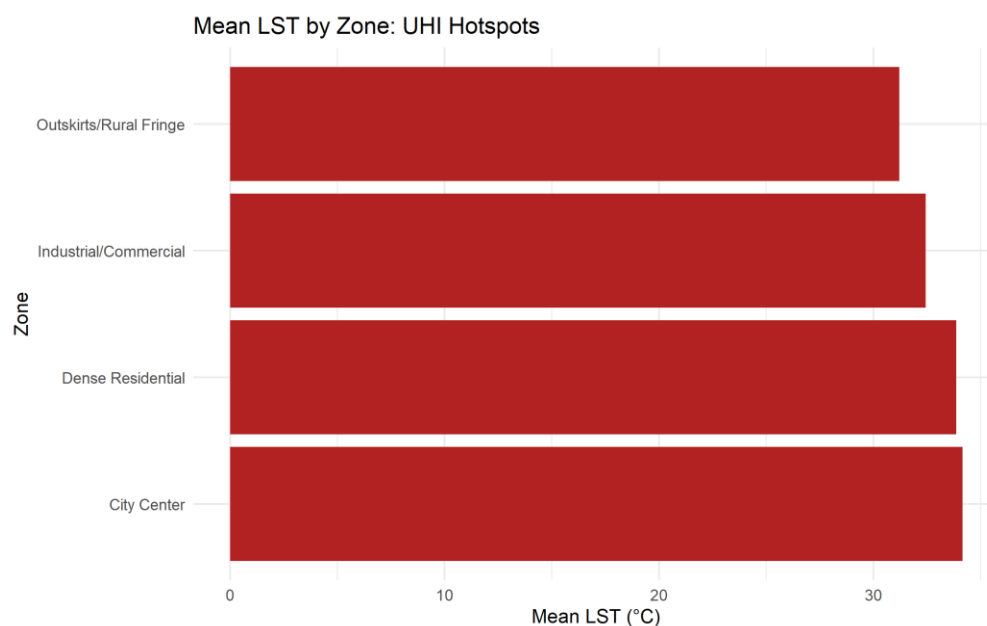


Figure 12. Frequency distribution of Urban Heat Island (UHI) hotspots by zone, derived from horizontal bar chart analysis to illustrate spatial patterns of heat concentration. **Source:** RStudio Team (2024). RStudio: Integrated Development Environment for R. Posit Software,PBC

Table 16. Mean Land Surface Temperature (°C) by Urban Zone (2015–2024). Annual average LST values for each urban zone in Kigali City from 2015 to 2024, highlighting spatial and temporal thermal variations.

Urban Zone	Mean LST (°C)	Count of Observations
City Center	34.16	16
Dense Residential	33.87	56
Industrial/Commercial	32.43	44
Outskirts/Rural Fringe	31.20	20

Source: RStudio Team (2024). RStudio: Integrated Development Environment for R. Posit Software,PBC

Further mapping showed that Gisozi shows the highest urban heat intensity throughout the decade (Figure 13), with Bumbogo sector following. Both sectors have a common characteristic; being among the top sectors that have received numerous settlements throughout the study period. Generally, these findings demonstrate a clear spatial pattern in Kigali’s UHI dynamics, with concentrated hotspots in specific sectors linked to urban form and land use. The persistent high temperatures in sectors like Kicukiro and Rwezamenyo warrant focused urban planning and greening strategies to mitigate UHI impacts and improve urban thermal comfort.

Statistical Significance of NDVI and LST variations across Years

To assess the spatial and temporal variations in Land Surface Temperature (LST) and Normalized Difference Vegetation Index (NDVI) across Kigali City, Analysis of Variance (ANOVA) tests were performed considering factors such as year, sector, and urban zones. Table 17 illustrate the results by zone and year.

Significant differences in LST were found among sectors ($F(33,102) = 11.54$, $p < 0.001$), indicating substantial spatial heterogeneity within Kigali. Temporal differences in LST across the four analyzed years (2015, 2018, 2021, 2024) were also significant ($F(3,132) = 5.60$, $p = 0.0012$), suggesting a clear warming trend consistent with intensifying Urban Heat Island (UHI) effects (Figure 14). Further, when analyzing the combined effects of year and urban zone (City Center, Dense Residential, Industrial/Commercial, Outskirts/Rural Fringe), both year ($F(3,120) = 7.66$, $p < 0.001$) and zone ($F(3,120) = 18.48$, $p < 0.001$) significantly influenced LST, while their interaction was not significant ($F(9,120) = 0.57$, $p = 0.82$) (Figure 15). This indicates that although LST varies distinctly over time and space, the pattern of change over years is similar across zones.

As shown in Figure 16; Regarding NDVI, which serves as a proxy for vegetation cover and health, significant variation was detected both across years ($F(3,120) = 4.46$, $p = 0.005$) and zones ($F(3,120) = 41.29$, $p < 0.001$), while their interaction effect was non-significant ($F(9,120) = 0.38$, $p = 0.94$). This highlights the spatial differentiation in vegetation density within Kigali and temporal shifts possibly linked to urban expansion and seasonal variability. The statistically significant results underscore the dynamic nature of the UHI effect and the role of vegetation in mitigating urban warming. Generally, these findings confirm that Kigali’s urban environment

experiences marked spatial and temporal variations in surface temperature and vegetation, reinforcing the need for targeted urban greening and climate adaptation strategies. Additional visualizations supporting the main findings are provided in the supplementary material. Figure S7 presents a comparative analysis of LST and NDVI variations by year, illustrating temporal trends in surface temperature and vegetation dynamics over the study period. Complementarily, Figure S8 complements this by showing the spatial variability of LST and NDVI across urban zones, providing insights into how these environmental indicators differ within the study area.

Table 17. Summary of ANOVA Results. Analysis of variance (ANOVA) testing the statistical significance of NDVI and LST differences across urban zones and years.

Variable	Factor	Df	F-value	p-value	Significant?
LST	Sector	33	11.54	<0.0001	Yes
LST	Year	3	5.60	0.0012	Yes
LST	Zone	3	18.48	<0.0001	Yes
LST	Year × Zone Interaction	9	0.57	0.823	No
NDVI	Year	3	4.46	0.0053	Yes
NDVI	Zone	3	41.29	<0.0001	Yes
NDVI	Year × Zone Interaction	9	0.38	0.942	No

Source: RStudio Team (2024). RStudio: Integrated Development Environment for R. Posit Software,PBC

4. Discussion

Interpretation of NDVI Spatial Distribution and Temporal Trends

The spatial and temporal distribution of NDVI across Kigali’s sectors from 2018 to 2024 reveals persistent intra-urban disparities in vegetation health and coverage. Sectors such as Jali, Kanyinya, and Kimironko consistently exhibited higher NDVI values, indicating relatively dense and healthy vegetation. These patterns are likely associated with lower urbanization pressures, the presence of forested areas, or localized conservation practices. In contrast, sectors like Rwezamenyo, Gitega, and Kicukiro consistently recorded low NDVI values, corresponding to highly built-up environments with minimal green cover.

These trends are consistent with previous findings in urban environments, where NDVI tends to remain relatively stable over time in the absence of major land use transformation (Buyantuyev & Wu, 2009; Zha et al., 2003). The slight positive trends observed in sectors such as Bumbogo

suggest either successful greening interventions or a deceleration of development pressure, while localized fluctuations in places like Nyakabanda reflect the fragmented nature of vegetation cover in rapidly developing urban zones. The Community-Based Resource Management (CBRM) framework provides a valuable lens for interpreting these spatial differences. Sectors that maintained or improved their NDVI levels may be benefiting from stronger local engagement in greening efforts or more responsive governance mechanisms. Conversely, persistent vegetation decline in other sectors could signal weak institutional enforcement of land use plans, limited community awareness, or a lack of inclusive environmental management.

Relationship between NDVI and LST: Urban Greenness and Heat Mitigation

The observed negative correlation between NDVI and LST across all study years reinforces the well-established cooling function of vegetation within urban environments. The strongest correlation in 2018 ($r = -0.919$) reflects a particularly effective mitigation effect during that year, which could be attributed to favorable weather conditions or relatively intact vegetative cover. Sectors with extensive vegetation—such as Jali and parts of the rural fringe—consistently recorded the lowest mean LSTs. These findings validate the role of vegetation in moderating urban microclimates through evapotranspiration, shading, and surface energy regulation (Oke, 1982; Gill et al., 2007). In contrast, highly urbanized areas such as Kicukiro, Rwezamenyo, and the City Center, where impervious surfaces dominate and green infrastructure is minimal, exhibited significantly elevated LSTs. The inverse relationship between NDVI and LST provides compelling evidence for incorporating green infrastructure into Kigali’s urban climate resilience strategies. By restoring or enhancing urban vegetation in the city’s dense sectors, planners can leverage natural cooling processes to reduce heat exposure and improve thermal comfort, particularly for vulnerable populations.

Urban Heat Island Hotspots and Land Use Influence

The consistent identification of UHI hotspots in Kicukiro, Rwezamenyo, and Gikondo throughout the study period, and particularly Gisozi sector with the leading LST consistency in terms of magnitude, highlights specific zones that require immediate intervention. These areas are typified by dense built environments, limited vegetative cover, and a high proportion of impervious surfaces, all of which contribute to their heat-retaining characteristics. The land use classification further confirms this trend. City Center and Dense Residential zones registered the highest mean surface temperatures, at 34.16°C and 33.87°C respectively, illustrating the thermal impact of urban density and infrastructure concentration. Conversely, the Outskirts and Rural Fringe areas (characterized by sparse development and expansive vegetation) maintained relatively lower LSTs, underscoring the protective effect of natural land cover. These patterns mirror those documented in other global cities facing similar UHI challenges (Voogt & Oke, 2003) and signal a pressing need for targeted green interventions in Kigali’s urban core. These might include the establishment of parks, expansion of street trees, promotion of green roofs, and integration of vertical greenery. Embedding CBRM principles into these strategies can promote local stewardship and long-term sustainability by involving communities in design, implementation, and maintenance efforts.

Statistical Significance of NDVI and LST Variations

The ANOVA results confirm that the spatial and temporal variations in NDVI and LST observed across sectors and land use zones are statistically significant. These findings validate that the differences are not random but stem from structured variations in land cover, development intensity, and likely differing local governance capacities. This statistical significance substantiates the existence of ecological and climatic inequalities across Kigali's urban landscape. Certain sectors appear to be structurally disadvantaged in terms of green space access and exposure to heat stress, which may exacerbate socioeconomic vulnerabilities. Understanding these disparities is essential for directing climate adaptation resources equitably and designing interventions that prioritize historically underserved areas.

Implications for Policy and Planning

The results of this study underscore the urgent need for a comprehensive, equity-focused green infrastructure agenda in Kigali. The observed disparities in NDVI and LST across sectors reinforce the necessity of spatially targeted planning efforts aimed at reversing vegetation loss and mitigating urban heat extremes. This aligns with Rwanda's *National Land Use and Development Master Plan (2020–2050)*, which emphasizes climate-resilient urbanization through ecological corridors, green public spaces, and sustainable zoning practices (MININFRA, 2020).

There is a clear policy imperative to expand and safeguard green spaces in heavily urbanized and heat-vulnerable areas such as Kicukiro and Rwezamenyo. These efforts should be supported by *zoning reforms* that mandate the inclusion of green buffers, tree-lined streets, and corridors in both formal and informal settlements. Integrating satellite-derived indicators like NDVI and LST into urban planning workflows [through platforms such as Rwanda's *Land Administration Information System (LAIS)*]; can enhance evidence-based decision-making and ensure continuous monitoring of urban ecological health (NISR, 2021; REMA, 2019).

Additionally, the *Community-Based Resilience Mechanism (CBRM)* approach can be leveraged to mobilize communities as active participants in greening initiatives, enhancing public ownership, ensuring maintenance, and reinforcing long-term sustainability (World Bank, 2022). This participatory approach is particularly important in areas facing rapid informal settlement growth.

Ultimately, embedding green infrastructure within Kigali's *climate adaptation framework* is not only a technical requirement but also a social necessity. Urban heat vulnerability has direct implications for public health, urban livability, and the resilience of marginalized populations to future climate shocks, making inclusive environmental governance central to Kigali's development future (UN-Habitat, 2020).

Table 18 presents a synthesis of how the key findings of the Urban Heat Island (UHI) analysis—particularly sectoral disparities in NDVI and LST—align with and support the implementation of Rwanda's existing policy frameworks. It highlights the relevance of spatially disaggregated satellite indicators to the National Land Use Master Plan, the Green Growth and Climate Resilience Strategy, and other urban development and environmental policies. The table also underscores how community-based resilience, zoning reforms, and data-driven planning can

contribute to fulfilling national policy goals, thereby translating scientific evidence into actionable urban climate strategies.

Table 18: Linking Study Findings to Existing Policy Frameworks in Rwanda

Study Finding highlight	Policy recommendation	Related National / Kigali City Policy
High LST and low NDVI in sectors like Kicukiro and Rwezamenyo indicate severe UHI effects	Prioritize these sectors for targeted greening interventions and cooling strategies	Kigali City Master Plan (2050) – Green Infrastructure Promotion
Spatial disparities in vegetation cover reveal inequitable access to green infrastructure	Design equitable distribution of green spaces and enhance green public infrastructure	National Land Use and Development Master Plan – Equitable Urban Growth
Year-on-year decline in NDVI in dense urban areas shows weakening of urban ecological resilience	Incorporate greening mandates in zoning and development control regulations	Green Growth and Climate Resilience Strategy – Urban Ecosystem Restoration
Remote sensing can effectively monitor urban heat risk and green space distribution	Institutionalize use of satellite data in planning and decision support systems	Rwanda National Environment and Climate Change Policy (2019)
Green spaces linked to improved urban health and climate resilience outcomes	Frame green infrastructure as a climate adaptation and public health necessity	National Strategy for Transformation (NST1) – Sustainable Cities Goal

Source: Author’s compilation from Secondary Data

5. Conclusion

This study quantitatively assessed the spatial-temporal variations of NDVI and LST in Kigali from 2015 to 2024, confirming significant heterogeneity in vegetation cover and surface temperature across urban sectors. The observed inverse relationship between NDVI and LST validates the

critical role of vegetation in urban heat mitigation and the persistence of Urban Heat Island effects in densely built-up areas such as Kicukiro, Rwezamenyo and Gisozi sector. Statistical analyses demonstrate that variations in vegetation health and thermal patterns are non-random and closely linked to land use intensity and governance structures. Findings highlight the necessity of integrating green infrastructure into urban planning frameworks, particularly in identified UHI hotspots, to enhance climate resilience. The results also underscore the potential of community-based resource management approaches in sustaining urban greening efforts. Incorporating satellite-derived environmental indicators into policy development can improve the targeting and effectiveness of mitigation strategies. This research fills a crucial gap in understanding Kigali's urban thermal environment and provides a scientific basis for informed, equitable urban climate adaptation.

Acknowledgements

The authors sincerely thank the National Institute of Statistics of Rwanda (NISR) for providing the essential shapefiles used in this study. We also acknowledge the Global Administrative Areas (GADM) database for offering comprehensive spatial boundary data that supported the geographical analyses. Our appreciation extends to the Google Earth Engine (GEE) platform for enabling efficient processing and analysis of satellite-derived datasets, and to the MODIS mission for the provision of long-term vegetation data critical to this work. We are also deeply grateful to the experts and colleagues who generously shared their expertise and offered critical insights regarding the methodological framework, data analysis techniques, and overall refinement of the study. Their valuable technical support significantly enhanced the quality of this research.

References

- Abunnasr, Y., Mhawej, M., & Chrysoulakis, N. (2022). SEBU: A novel fully automated Google Earth Engine surface energy balance model for urban areas. *Urban Climate*, 44, 101187. <https://doi.org/10.1016/j.uclim.2022.101187>
- Ahmed, A., & Stephen, K. (2020). Urban Heat Island effect and its implications on sustainable development in African cities: A review. *Environmental Research Letters*, 15(4), 043001.
- Arnfield, A. J. (2003). Two decades of urban climate research: A review of turbulence, exchanges of energy and water, and the urban heat island. *International Journal of Climatology*, 23(1), 1–26. <https://doi.org/10.1002/joc.859>
- Buyantuyev, A., & Wu, J. (2009). Urbanization alters spatiotemporal patterns of ecosystem primary production: A case study of the Phoenix metropolitan region, USA. *Journal of Arid Environments*, 73(4–5), 512–520. <https://doi.org/10.1016/j.jaridenv.2008.12.015>
- Dash, J., Manna, P., & Panda, S. (2019). Assessing the Urban Heat Island intensity using Landsat thermal data: A case study of Bhubaneswar city, India. *Remote Sensing Applications: Society and Environment*, 15, 100230.

- Douglas, I., Alam, K., Maghenda, M., McDonnell, Y., McLean, L., & Campbell, J. (2011). Unjust waters: Climate change, flooding and the urban poor in Africa. *Environment and Urbanization*, 23(1), 17–29.
- Grimm, N. B., Faeth, S. H., Golubiewski, N. E., Redman, C. L., Wu, J., Bai, X., & Briggs, J. M. (2008). Global change and the ecology of cities. *Science*, 319(5864), 756–760. <https://doi.org/10.1126/science.1150195>
- Gorelick, N., Hancher, M., Dixon, M., Ilyushchenko, S., Thau, D., & Moore, R. (2017). Google Earth Engine: Planetary-scale geospatial analysis for everyone. *Remote Sensing of Environment*, 202, 18–27. <https://doi.org/10.1016/j.rse.2017.06.031>
- GADM. (2024). *GADM database of Global Administrative Areas* (Version 4.1) [Shapefile data]. <https://gadm.org/>
- 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*, 33(1), 115–133. <https://doi.org/10.2148/benv.33.1.115>
- MININFRA (Ministry of Infrastructure Rwanda). (2020). *Rwanda urbanization review: Achievements, challenges, and prospects*. Kigali: Government of Rwanda.
- MININFRA. (2020). *National Land Use and Development Master Plan 2020–2050*. Ministry of Infrastructure, Government of Rwanda.
- Mutambara, J., Mapuranga, B., & Mushore, T. D. (2021). Assessing urban heat islands using satellite-derived surface temperature data in rapidly urbanizing African cities: Case of Kigali, Rwanda. *Sustainability*, 13(14), 7621.
- NISR. (2021). *Rwanda Land Use Statistics Report*. National Institute of Statistics of Rwanda.
- NISR (National Institute of Statistics of Rwanda). (2022). *Rwanda population and housing census 2022: Analytical report*. Kigali: NISR.
- Nkurunziza, A., Rwibasira, G., & Habiwaremye, G. (2018). Understanding the impacts of climate variability on vegetation dynamics in Rwanda’s highland zones. *African Journal of Environmental Science and Technology*, 12(6), 231–243. <https://doi.org/10.5897/AJEST2018.2523>
- Oke, T. R. (1982). The energetic basis of the urban heat island. *Quarterly Journal of the Royal Meteorological Society*, 108(455), 1–24. <https://doi.org/10.1002/qj.49710845502>
- REMA. (2019). *State of Environment and Outlook Report: Rwanda*. Rwanda Environment Management Authority.

- Rizwan, A. M., Dennis, L. Y. C., & Liu, C. (2008). A review on the generation, determination and mitigation of Urban Heat Island. *Journal of Environmental Sciences*, 20(1), 120–128. [https://doi.org/10.1016/S1001-0742\(08\)60019-4](https://doi.org/10.1016/S1001-0742(08)60019-4)
- Roy, D. P., Wulder, M. A., Loveland, T. R., Woodcock, C. E., Allen, R. G., Anderson, M. C., ... & Zhu, Z. (2014). Landsat-8: Science and product vision for terrestrial global change research. *Remote Sensing of Environment*, 145, 154–172. <https://doi.org/10.1016/j.rse.2014.02.001>
- Seto, K. C., Guneralp, B., & Hutyrá, L. R. (2012). Global forecasts of urban expansion to 2030 and direct impacts on biodiversity and carbon pools. *Proceedings of the National Academy of Sciences*, 109(40), 16083–16088. <https://doi.org/10.1073/pnas.1211658109>
- UN-Habitat. (2020). *World Cities Report 2020: The Value of Sustainable Urbanization*. United Nations Human Settlements Programme.
- Voogt, J. A., & Oke, T. R. (2003). Thermal remote sensing of urban climates. *Remote Sensing of Environment*, 86(3), 370–384. [https://doi.org/10.1016/S0034-4257\(03\)00079-8](https://doi.org/10.1016/S0034-4257(03)00079-8)
- Weng, Q., Lu, D., & Schubring, J. (2004). Estimation of land surface temperature–vegetation abundance relationship for urban heat island studies. *Remote Sensing of Environment*, 89(4), 467–483. <https://doi.org/10.1016/j.rse.2003.11.005>
- World Bank. (2022). *Rwanda Urban Resilience Project Appraisal Document*. World Bank Group.
- Zha, Y., Gao, J., & Ni, S. (2003). Use of normalized difference built-up index in automatically mapping urban areas from TM imagery. *International Journal of Remote Sensing*, 24(3), 583–594. <https://doi.org/10.1080/01431160304987>
- Zhang, H., Zhou, Y., Wang, H., Li, M., & Liu, H. (2021). Monitoring urban heat islands using Landsat thermal infrared data and MODIS NDVI: A case study in Wuhan, China. *Remote Sensing*, 13(12), 2341.
- Zhu, Z., & Woodcock, C. E. (2012). Object-based cloud and cloud shadow detection in Landsat imagery. *Remote Sensing of Environment*, 118, 83–94. <https://doi.org/10.1016/j.rse.2011.10.02>

APPENDIX

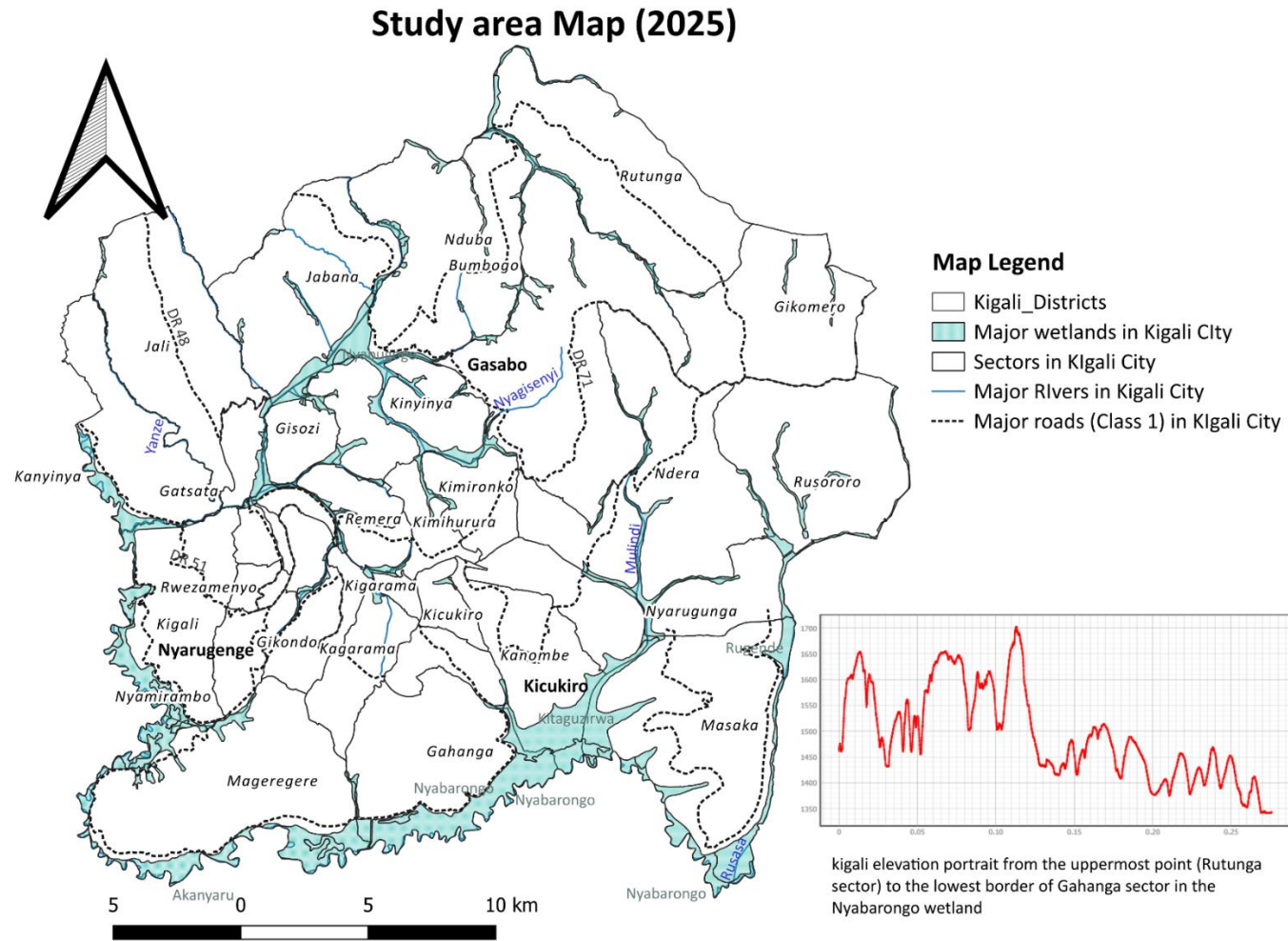


Figure 1. Map of the study area showing Kigali City within Rwanda, including major administrative boundaries (districts and sectors), key rivers, wetlands, and primary roads. The map highlights the spatial context for the analysis of NDVI and LST variations from 2015 to 2024. **Source:** QGIS Development Team (2025). QGIS Geographic Information System. Open Source Geospatial Foundation Project.

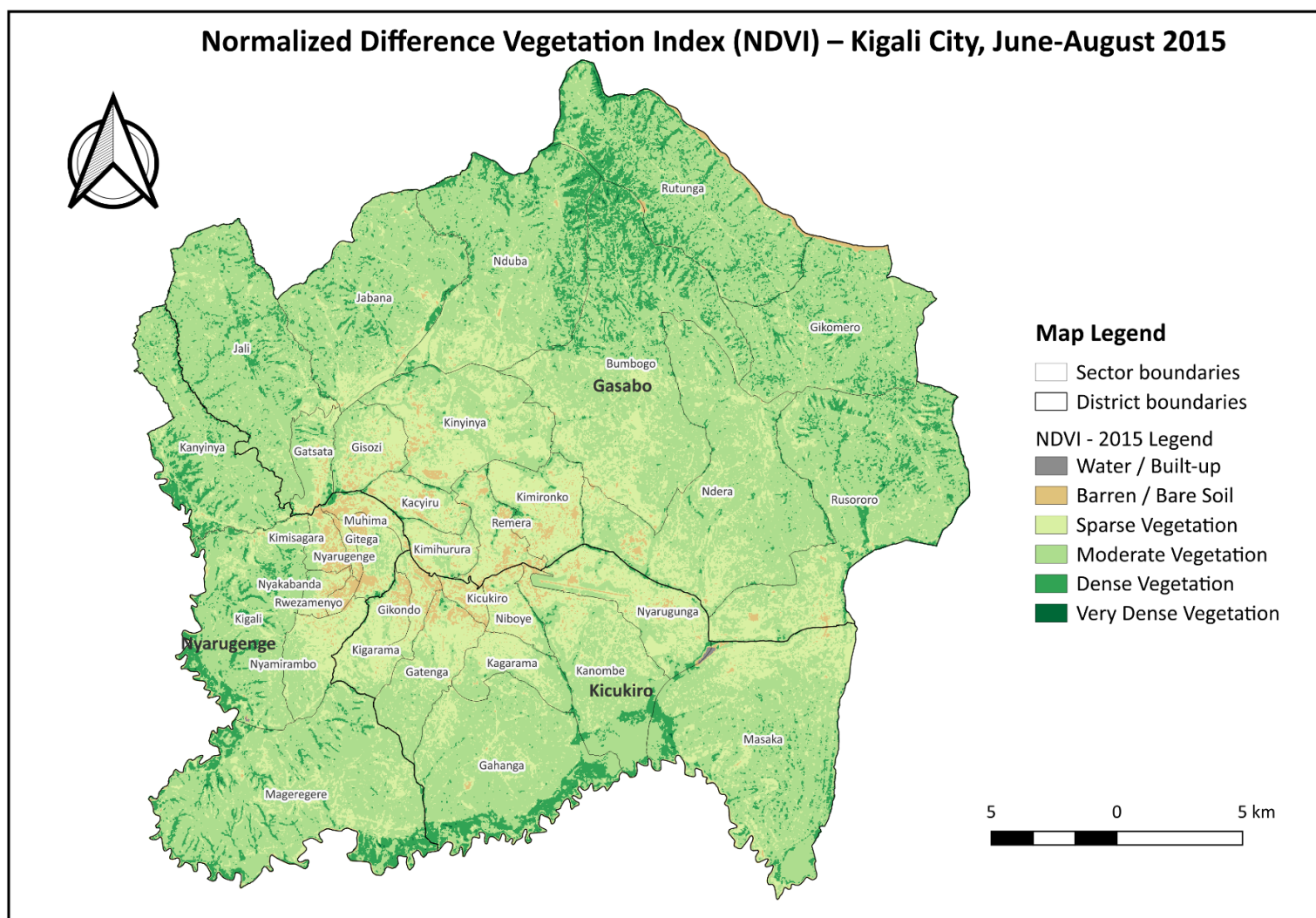


Figure 2. Spatial distribution of Normalized Difference Vegetation Index (NDVI) in 2015 across the study area. Greener areas indicate higher vegetation density, while lighter tones represent sparsely vegetated or built-up surfaces. **Source:** QGIS Development Team (2025). QGIS Geographic Information System. Open Source Geospatial Foundation Project.

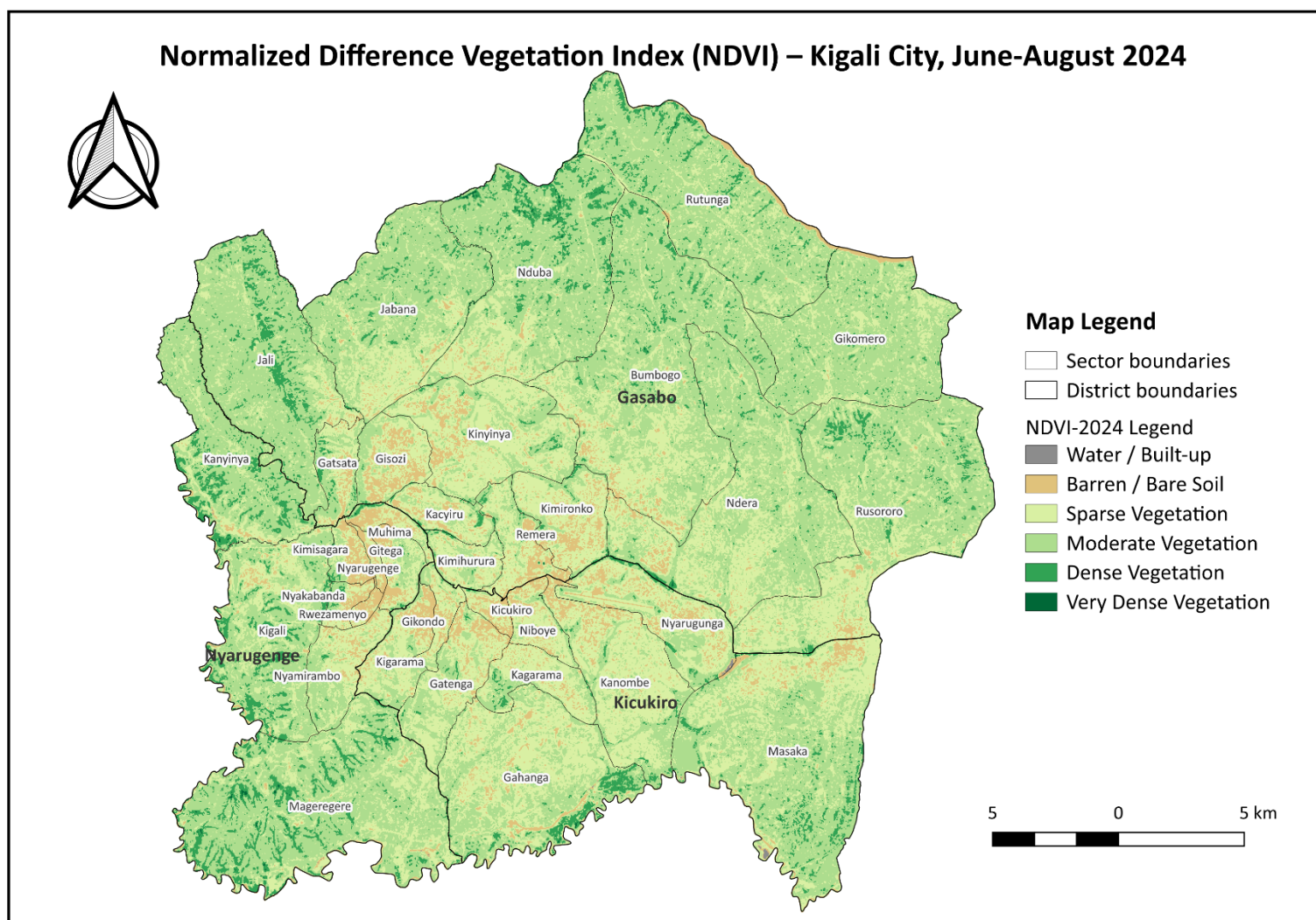
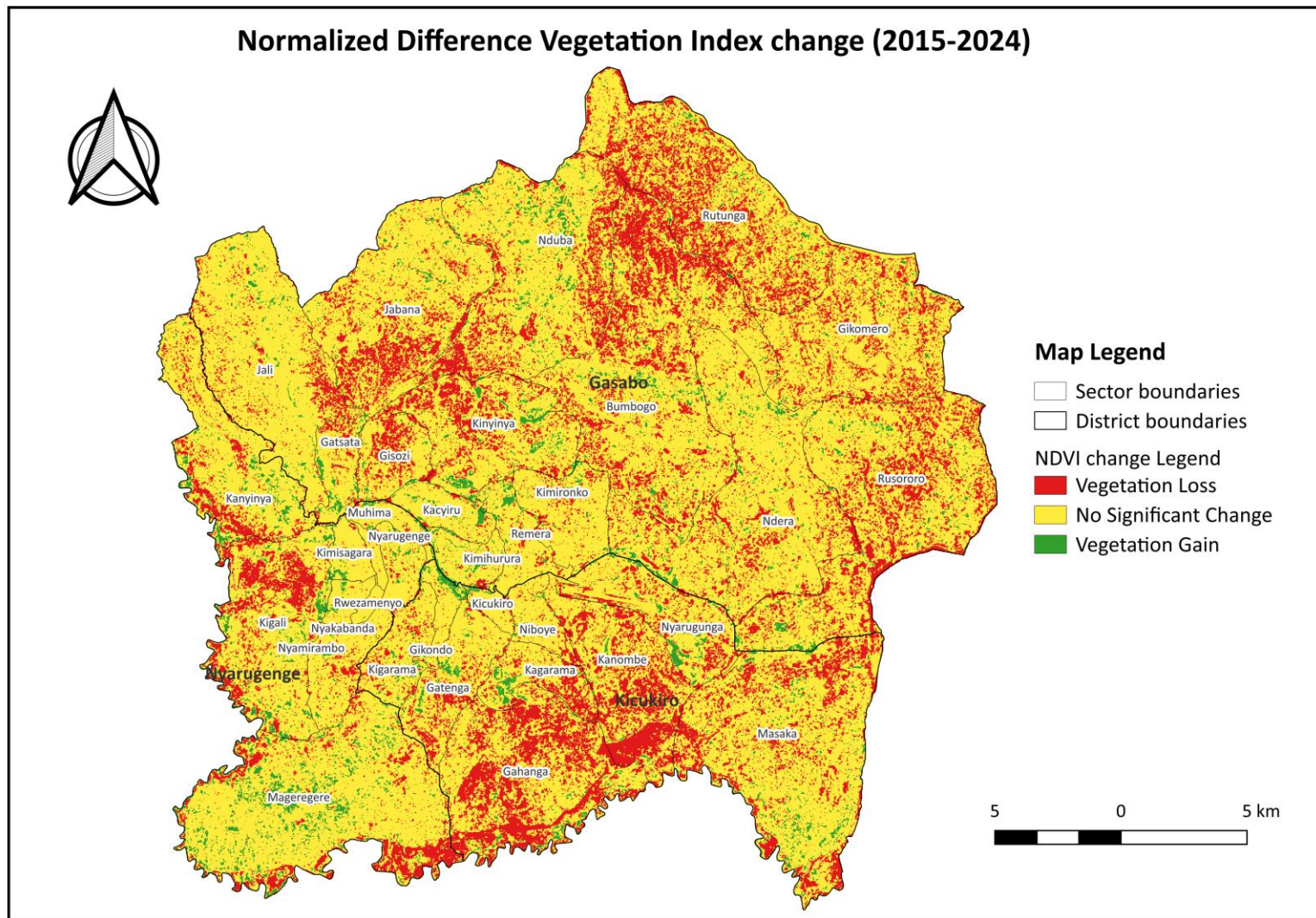


Figure 3. Spatial distribution of Normalized Difference Vegetation Index (NDVI) in 2024 across the study area. Greener areas indicate higher vegetation density, while lighter tones represent sparsely vegetated or built-up surfaces. **Source:** QGIS Development Team (2025). QGIS Geographic Information System. Open Source Geospatial Foundation Project.



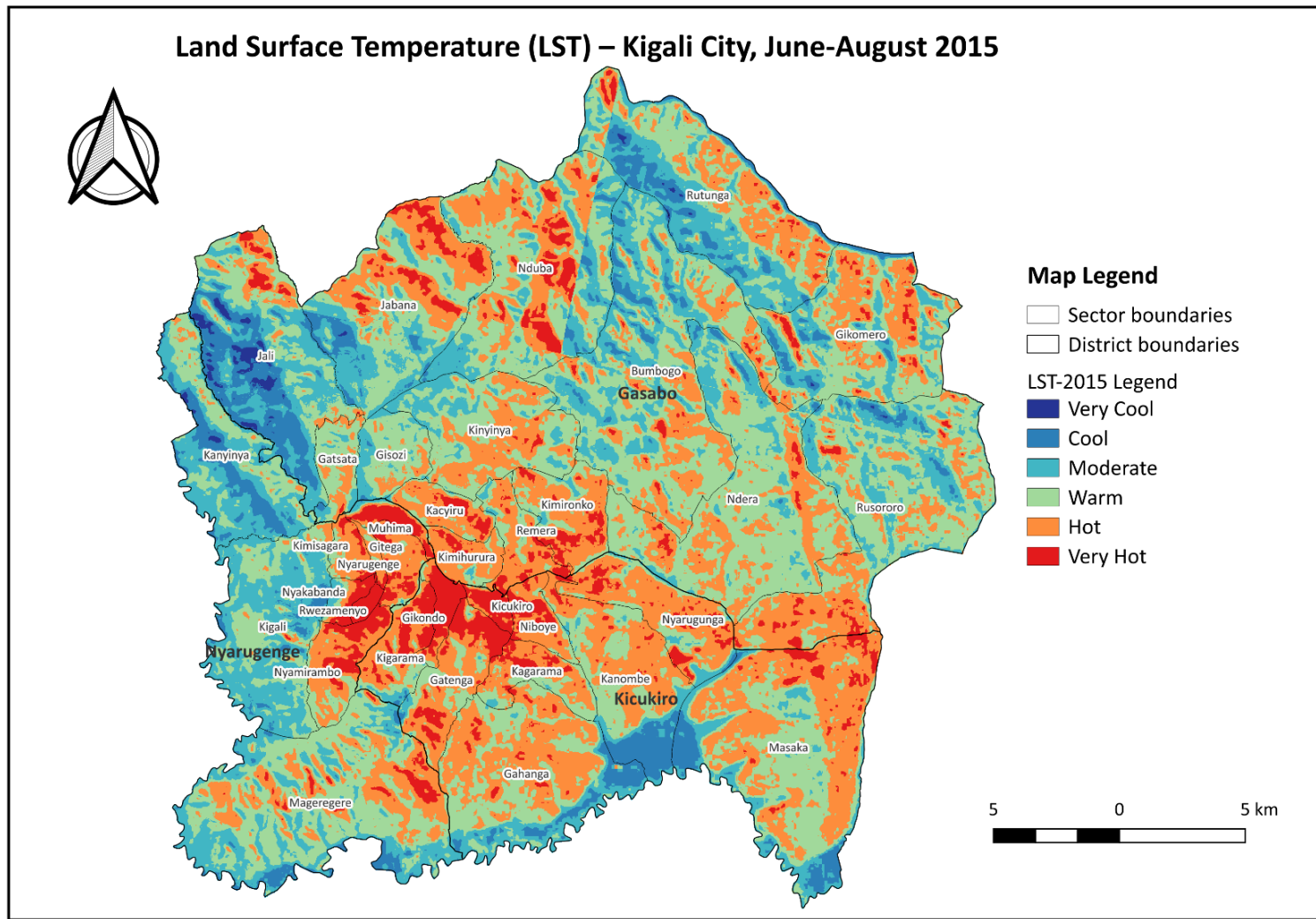


Figure 5. Spatial pattern of Land Surface Temperature (LST) in 2015 over the study area. Warmer colors indicate higher surface temperatures, typically concentrated in urbanized or less vegetated zones. **Source:** QGIS Development Team (2025). QGIS Geographic Information System. Open Source Geospatial Foundation Project.

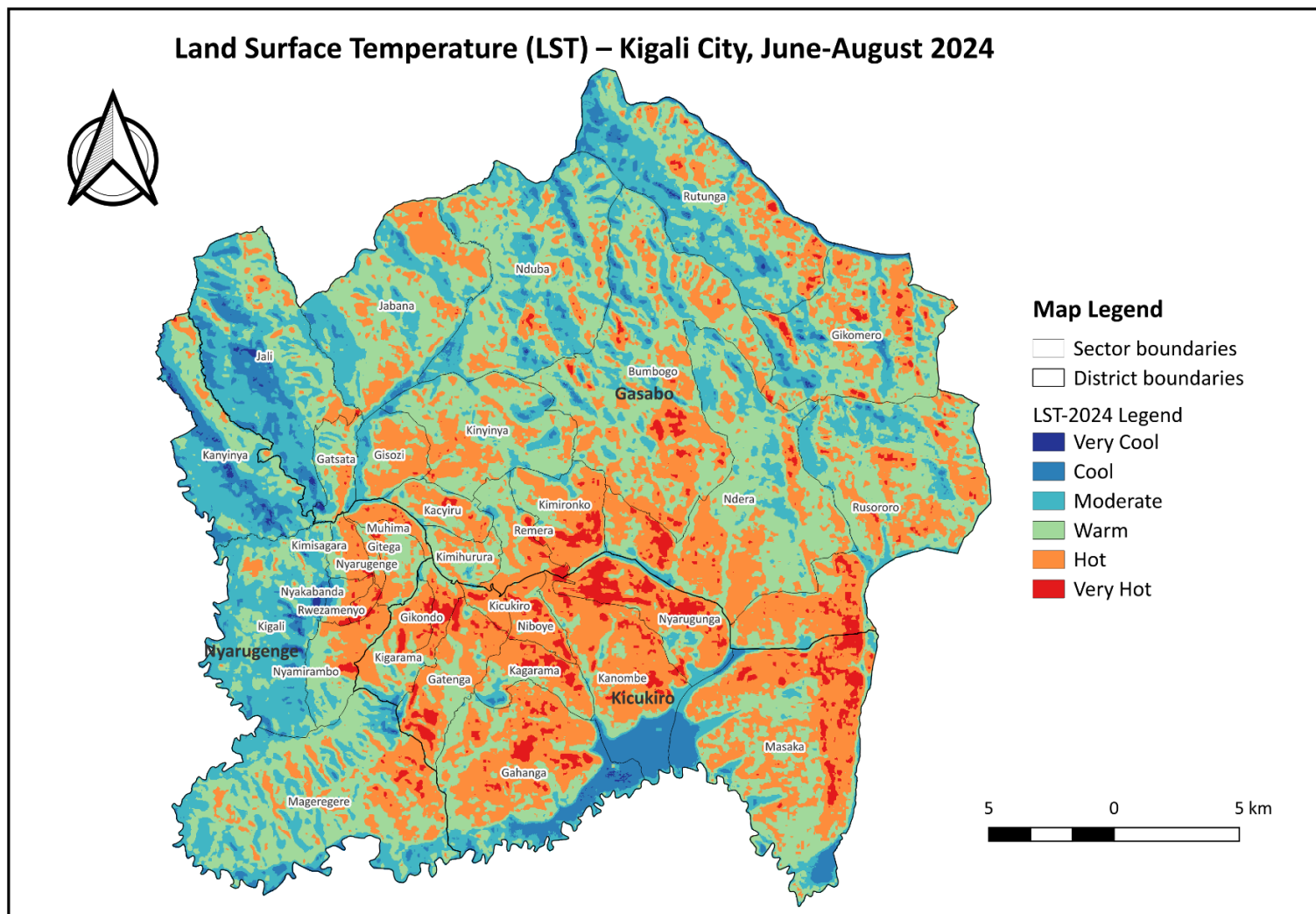


Figure 6. Spatial pattern of Land Surface Temperature (LST) in 2024 over the study area. Warmer colors indicate higher surface temperatures, typically concentrated in urbanized or less vegetated zones. **Source:** QGIS Development Team (2025). QGIS Geographic Information System. Open Source Geospatial Foundation Project.

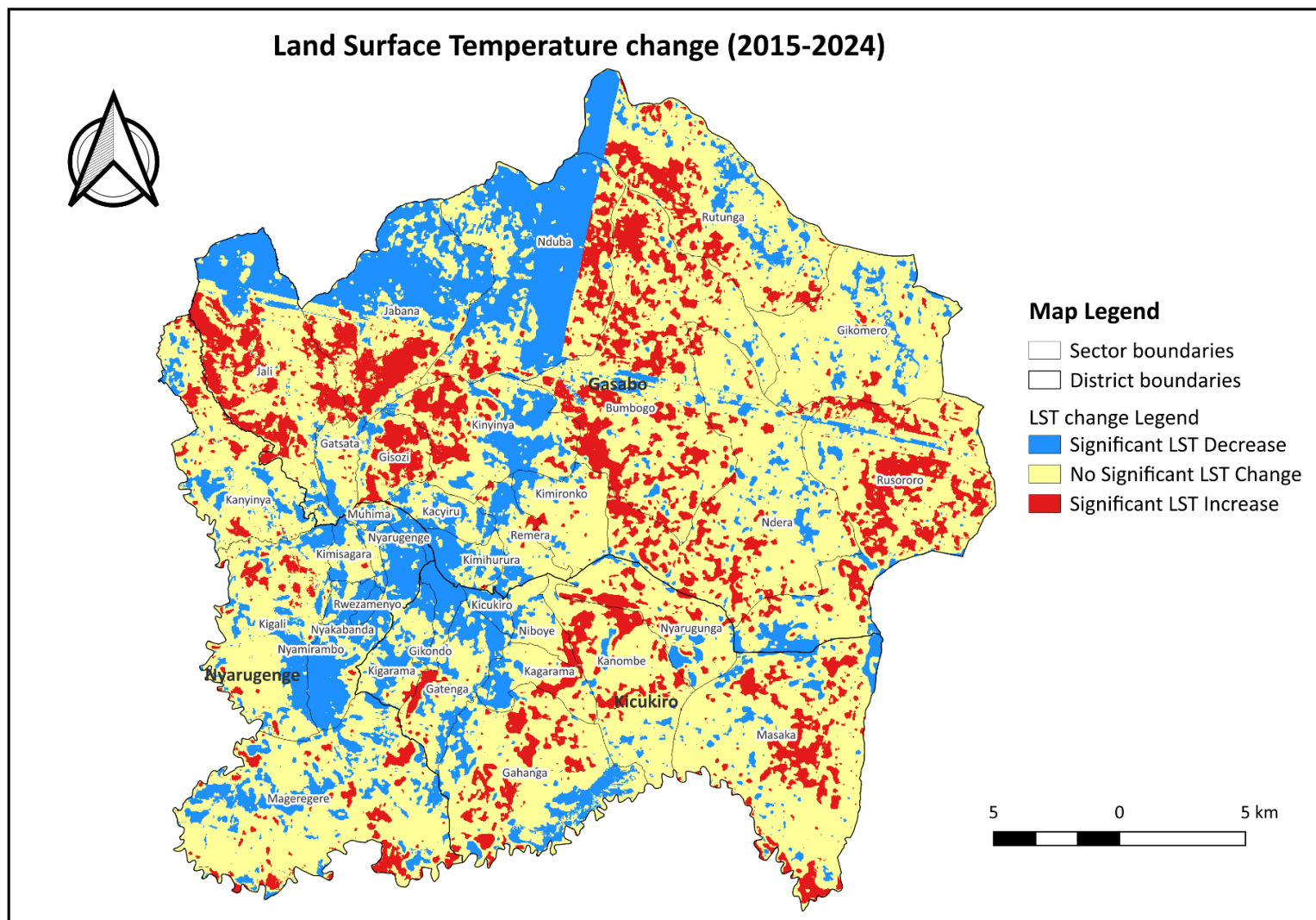


Figure 7. Change in Land Surface Temperature (LST) from 2015 to 2024 across the study area. Red tones indicate areas with increasing surface temperature, highlighting intensified urban heat, while blue tones indicate zones with decreased temperatures. **Source:** QGIS Development Team (2025). QGIS Geographic Information System. Open Source Geospatial Foundation Project.

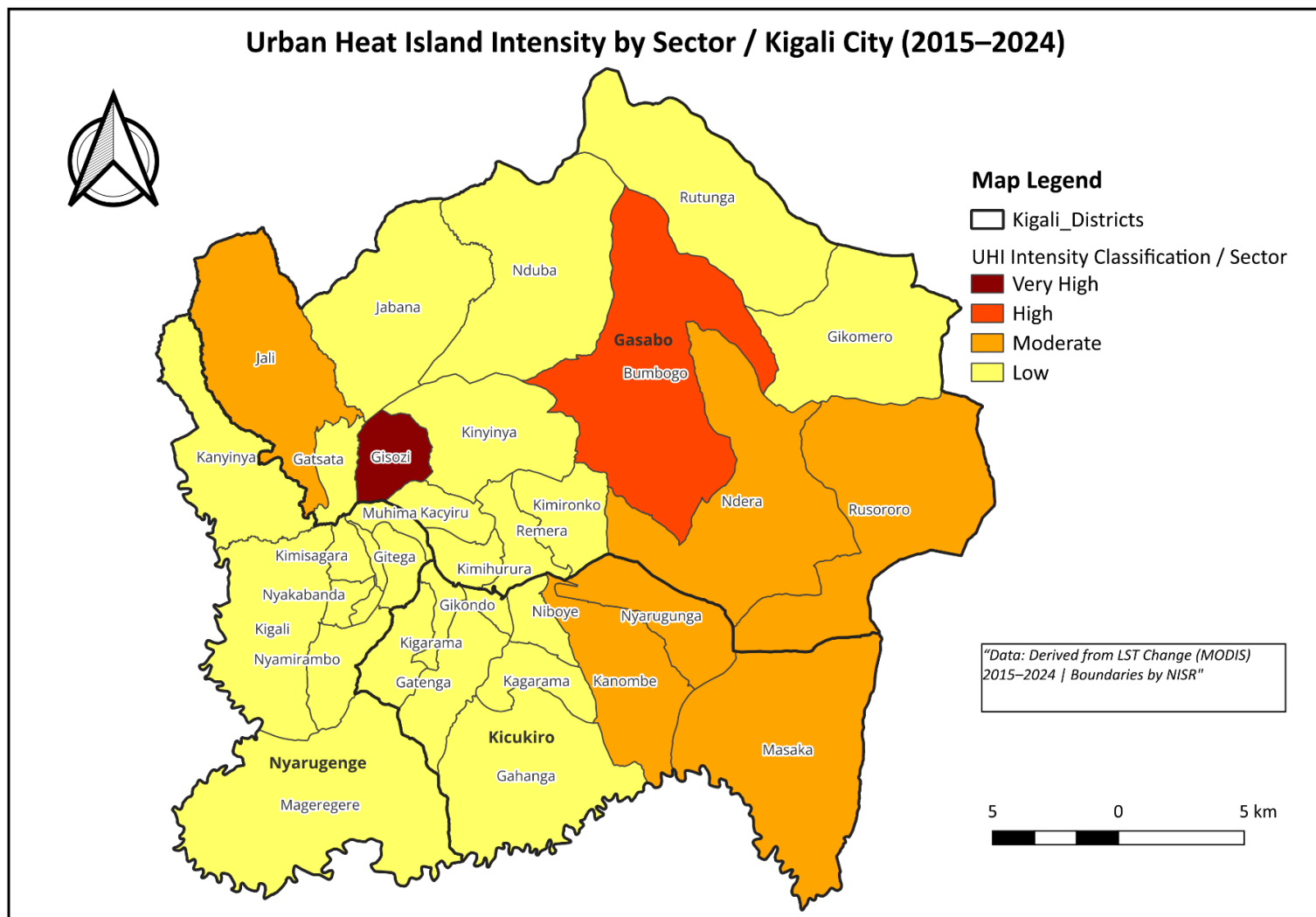


Figure 13. Map showing the spatial distribution of Urban Heat Island (UHI) hotspots in Kigali City, with clustered zones of elevated Land Surface Temperature (LST) visually distinguished from cooler areas. The hotspot analysis highlights intensively urbanized and thermally stressed locations across the study area. **Source:** QGIS Development Team (2025). QGIS Geographic Information System. Open Source Geospatial Foundation Project.

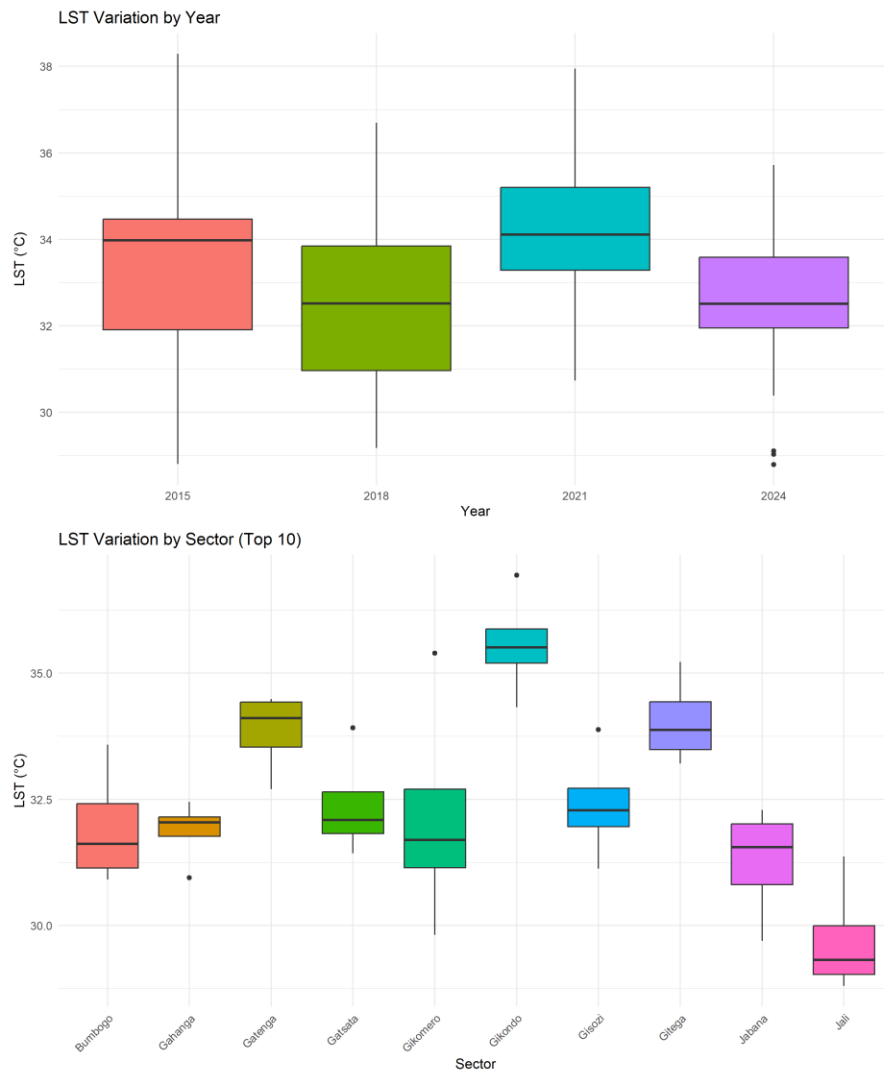


Figure 14. Boxplots showing variation in Land Surface Temperature (LST) across different years and sectors. The figure highlights temporal and spatial variability patterns relevant to urban heat distribution. **Source:** RStudio Team (2024). RStudio: Integrated Development Environment for R. Posit Software,PBC

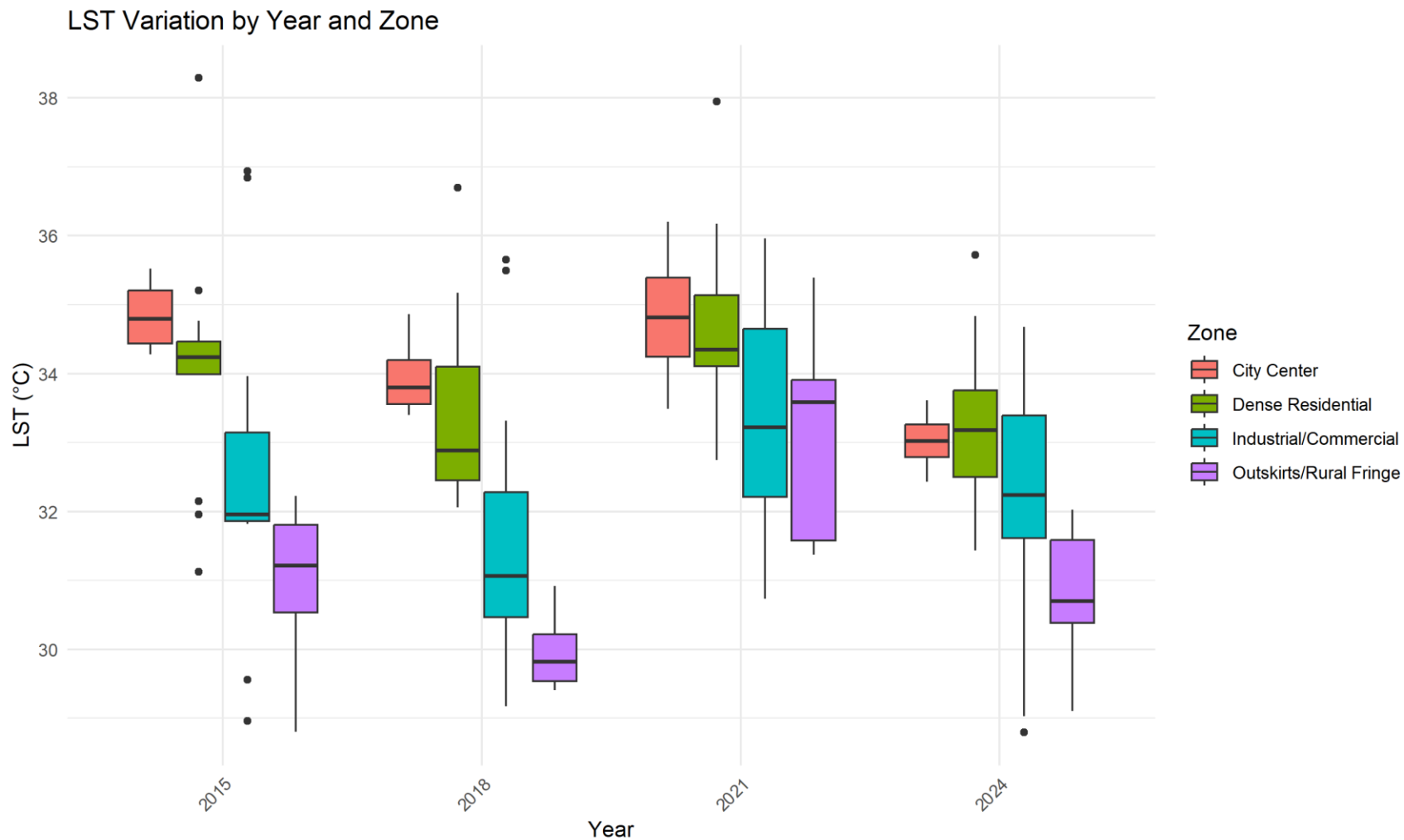


Figure 15. Boxplots showing Land Surface Temperature (LST) variation by year and urban zone, highlighting temporal and spatial differences in thermal patterns across Kigali's planning zones. **Source:** RStudio Team (2024). RStudio: Integrated Development Environment for R. Posit Software,PBC

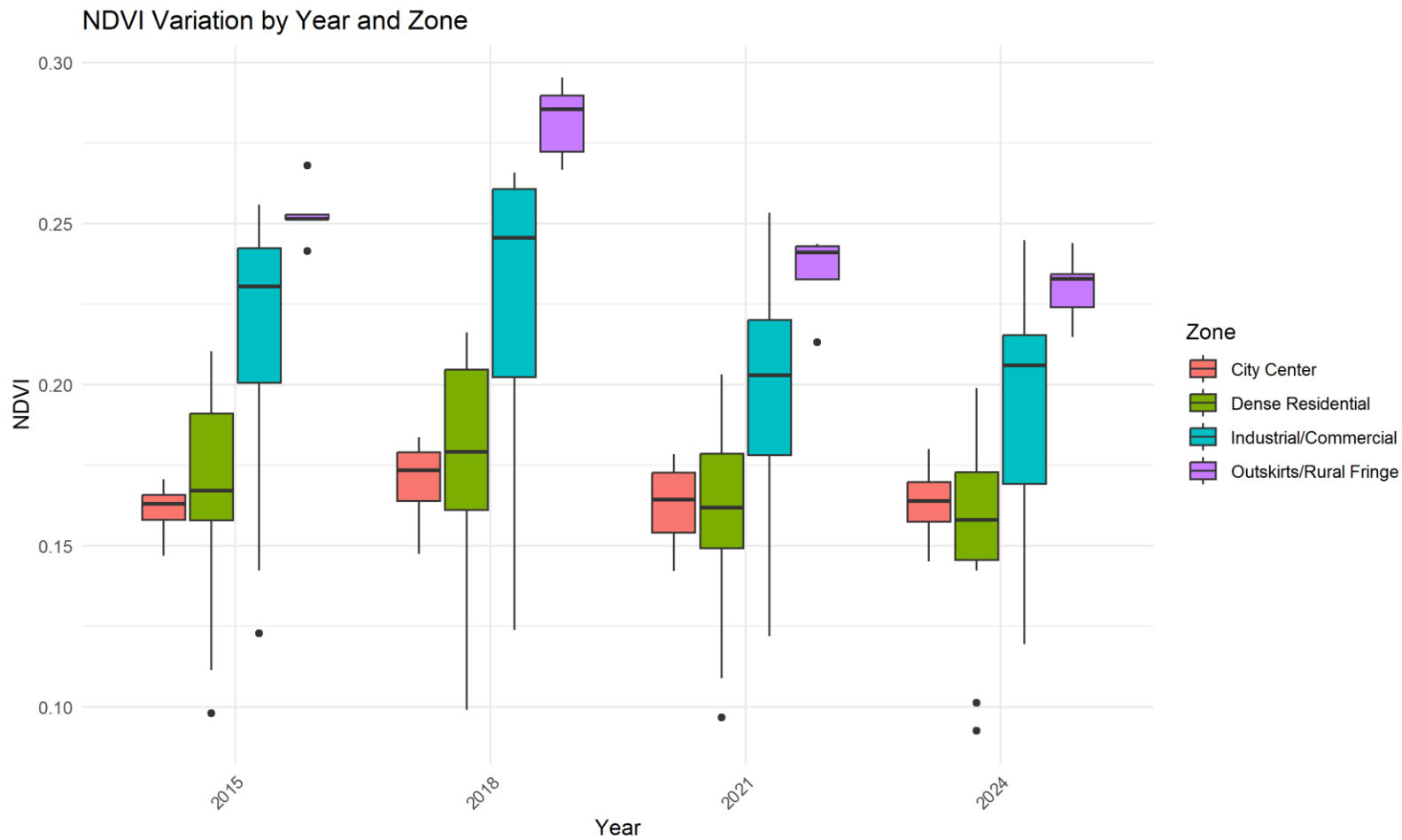


Figure 16. Boxplots showing the variation in NDVI across different years and urban zones, highlighting both temporal changes and spatial differences in vegetation cover within Kigali City. **Source:** RStudio Team (2024). RStudio: Integrated Development Environment for R. Posit Software,PBC

Supplementary Materials

List of Supplementary Materials

N o.	Supplementary Item	File Name	Description
1	Boxplots – LST by Year & Sector	SupplementaryFigure14_LST_Variation_Boxplots.tiff	Boxplots showing variation in Land Surface Temperature (LST) across different years and sectors.
2	Boxplots – NDVI by Year & Urban Zone	SupplementaryFigure16_NDVI_By_UrbanZone_Boxplots.tiff	Boxplots showing NDVI variation by year and urban zones, highlighting spatial and temporal differences.
3	Combined LST and NDVI Scatterplots	SupplementaryFigure6_NDVI_LST_AnnualScatterplots.tiff	Annual scatterplots illustrating the relationship between NDVI and LST across years and zones.
4	Pearson Correlation Matrix	SupplementaryFigure5_NDVI_LST_CorrelationTrend_2015_2024.tiff	Temporal trend of the correlation between NDVI and LST from 2015 to 2024.
5	NDVI vs LST Scatterplots	SupplementaryFigure9_LST_NDVI_MeanValues_BarCharts.tiff	Multi-panel bar charts comparing mean LST and NDVI values across years and urban zones.
6	UHI Hotspot Frequency Bar Charts	SupplementaryFigure12_UHI_Hotspots_Frequency.tiff	Frequency distribution of Urban Heat Island (UHI) hotspots by zone using horizontal bar charts.
7	Summary Statistics – NDVI 2015	SupplementaryTable1_NDVI_Summary_2015.xlsx	Summary statistics of NDVI values for sectors in Kigali City for the year 2015.

8	Summary Statistics – NDVI 2018	SupplementaryTable2_NDVI_Summary_2018.xlsx	Summary statistics of NDVI values for sectors in Kigali City for the year 2018.
9	Summary Statistics – NDVI 2021	SupplementaryTable3_NDVI_Summary_2021.xlsx	Summary statistics of NDVI values for sectors in Kigali City for the year 2021.
10	Summary Statistics – NDVI 2024	SupplementaryTable4_NDVI_Summary_2024.xlsx	Summary statistics of NDVI values for sectors in Kigali City for the year 2024.
11	Summary Statistics – LST 2015	SupplementaryTable5_LST_Summary_2015.xlsx	Summary statistics of LST values for sectors in Kigali City for the year 2015.
12	Summary Statistics – LST 2018	SupplementaryTable6_LST_Summary_2018.xlsx	Summary statistics of LST values for sectors in Kigali City for the year 2018.
13	Summary Statistics – LST 2021	SupplementaryTable7_LST_Summary_2021.xlsx	Summary statistics of LST values for sectors in Kigali City for the year 2021.
14	Summary Statistics – LST 2024	SupplementaryTable8_LST_Summary_2024.xlsx	Summary statistics of LST values for sectors in Kigali City for the year 2024.

Source: Author's computation

These supplementary materials are provided to:

-  Enhance the interpretation of statistical and spatial analyses.
-  Support findings referenced in the main manuscript.
-  Provide a detailed portrait of everything that the researchers have processed in the research process
-  Comply with transparency and reproducibility standards.

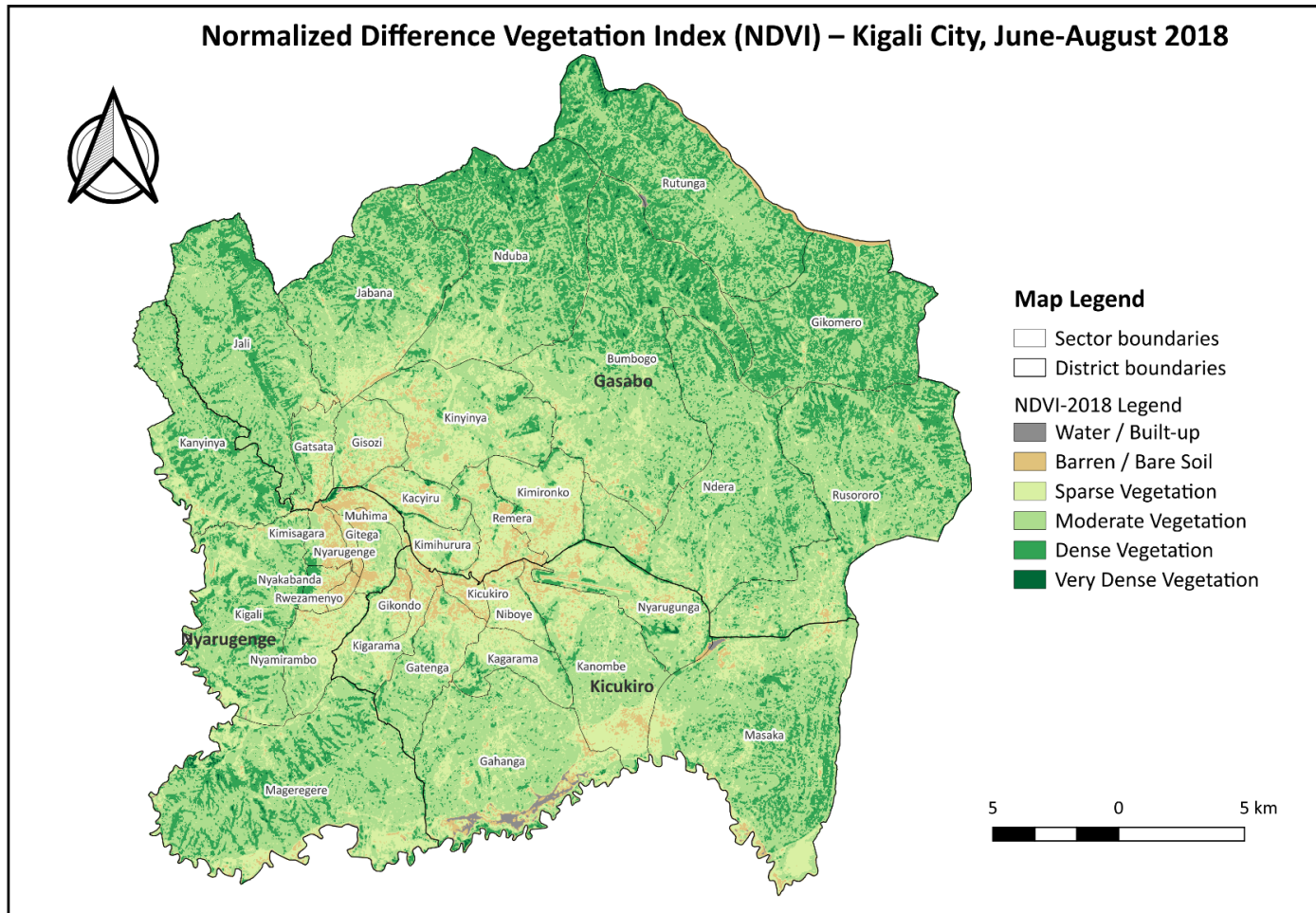


Figure S1. Spatial distribution of Normalized Difference Vegetation Index (NDVI) in 2018 across the study area, illustrating vegetation variability during the mid-study period. **Source:** QGIS Development Team (2025). QGIS Geographic Information System. Open Source Geospatial Foundation Project.

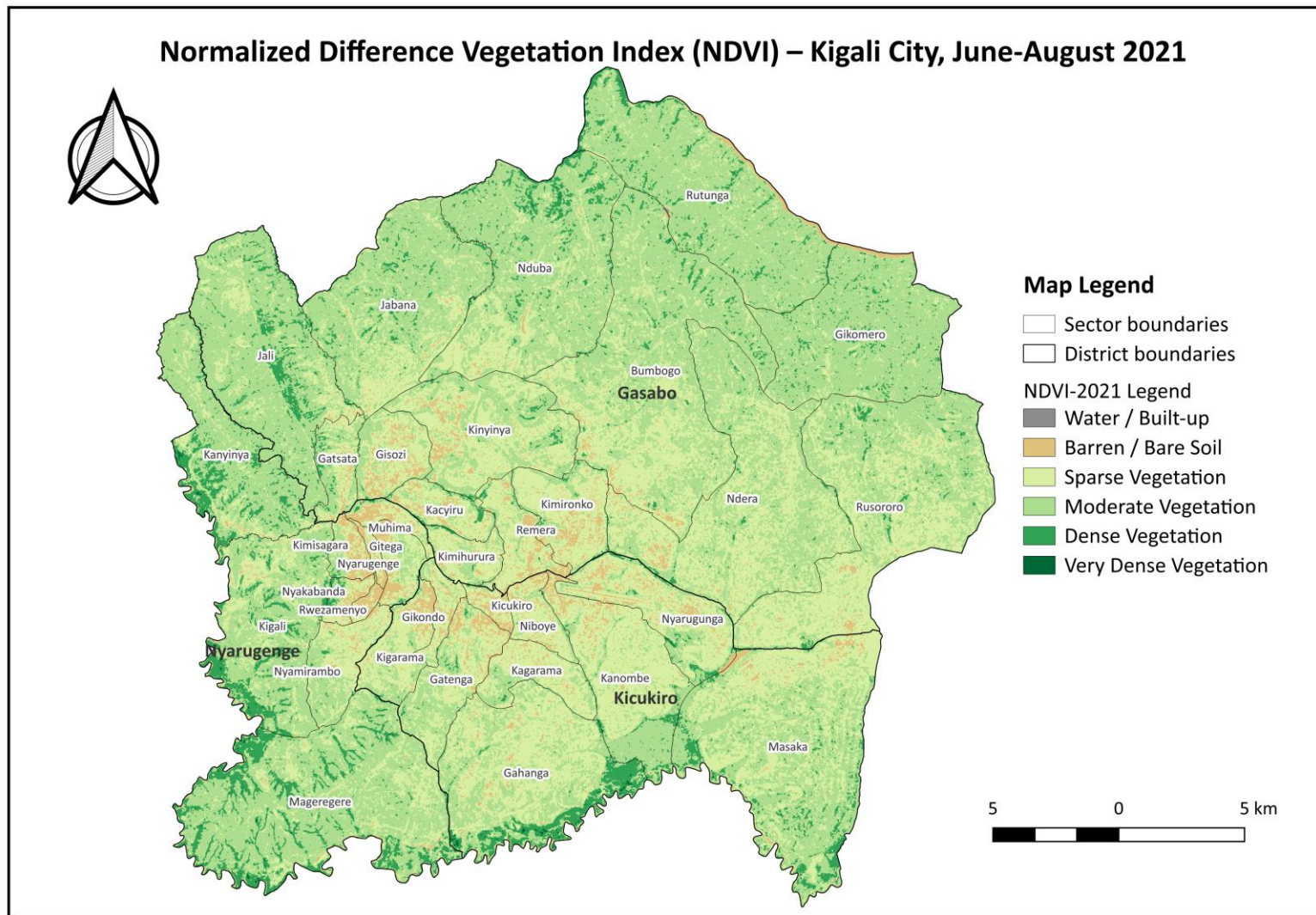


Figure S2. Spatial distribution of Normalized Difference Vegetation Index (NDVI) in 2021 across the study area, highlighting vegetation patterns during the later study period. **Source:** QGIS Development Team (2025). QGIS Geographic Information System. Open Source Geospatial Foundation Project.

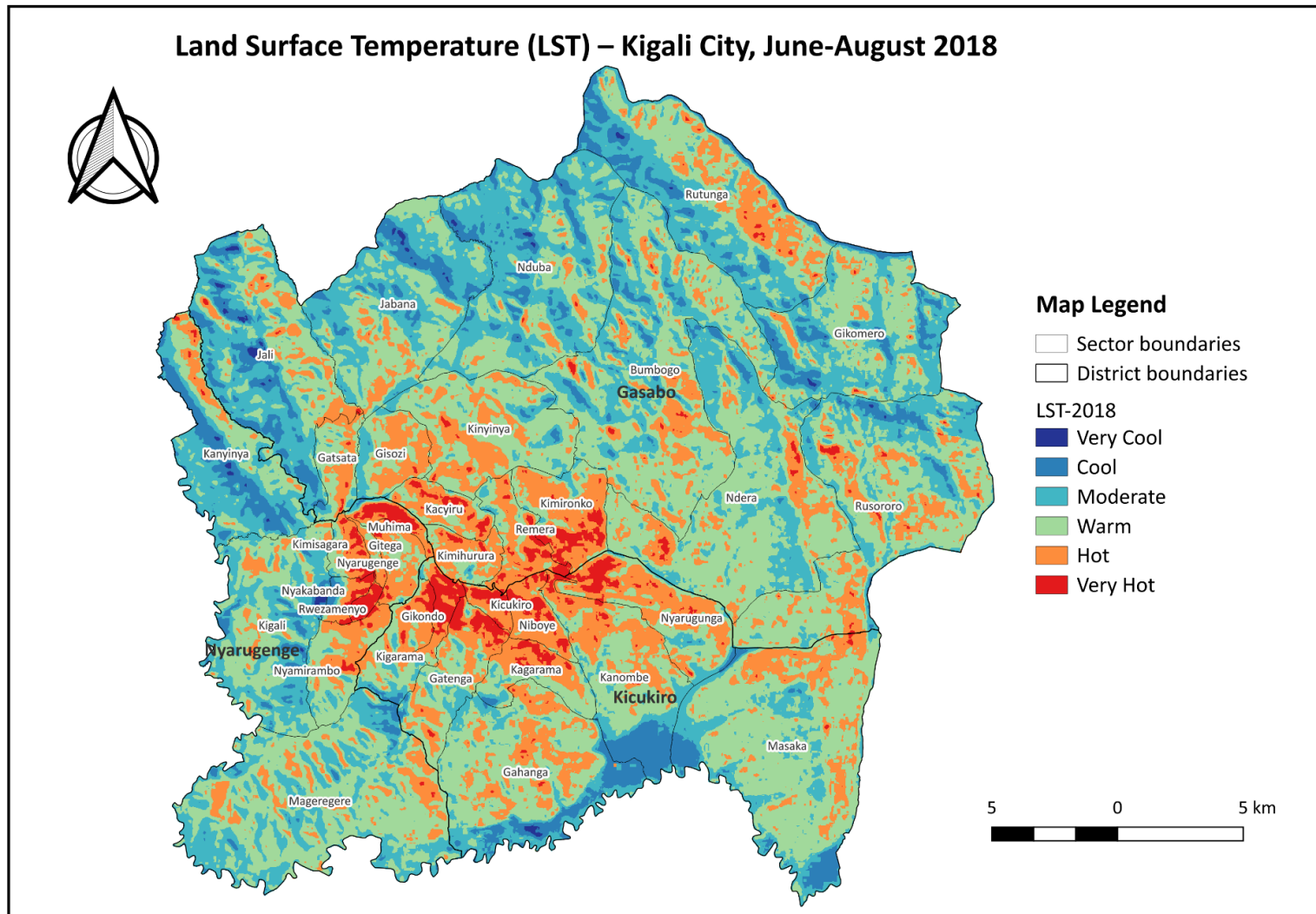


Figure S3. Spatial pattern of Land Surface Temperature (LST) in 2018 across the study area, illustrating the thermal landscape during this year. **Source:** QGIS Development Team (2025). QGIS Geographic Information System. Open Source Geospatial Foundation Project.

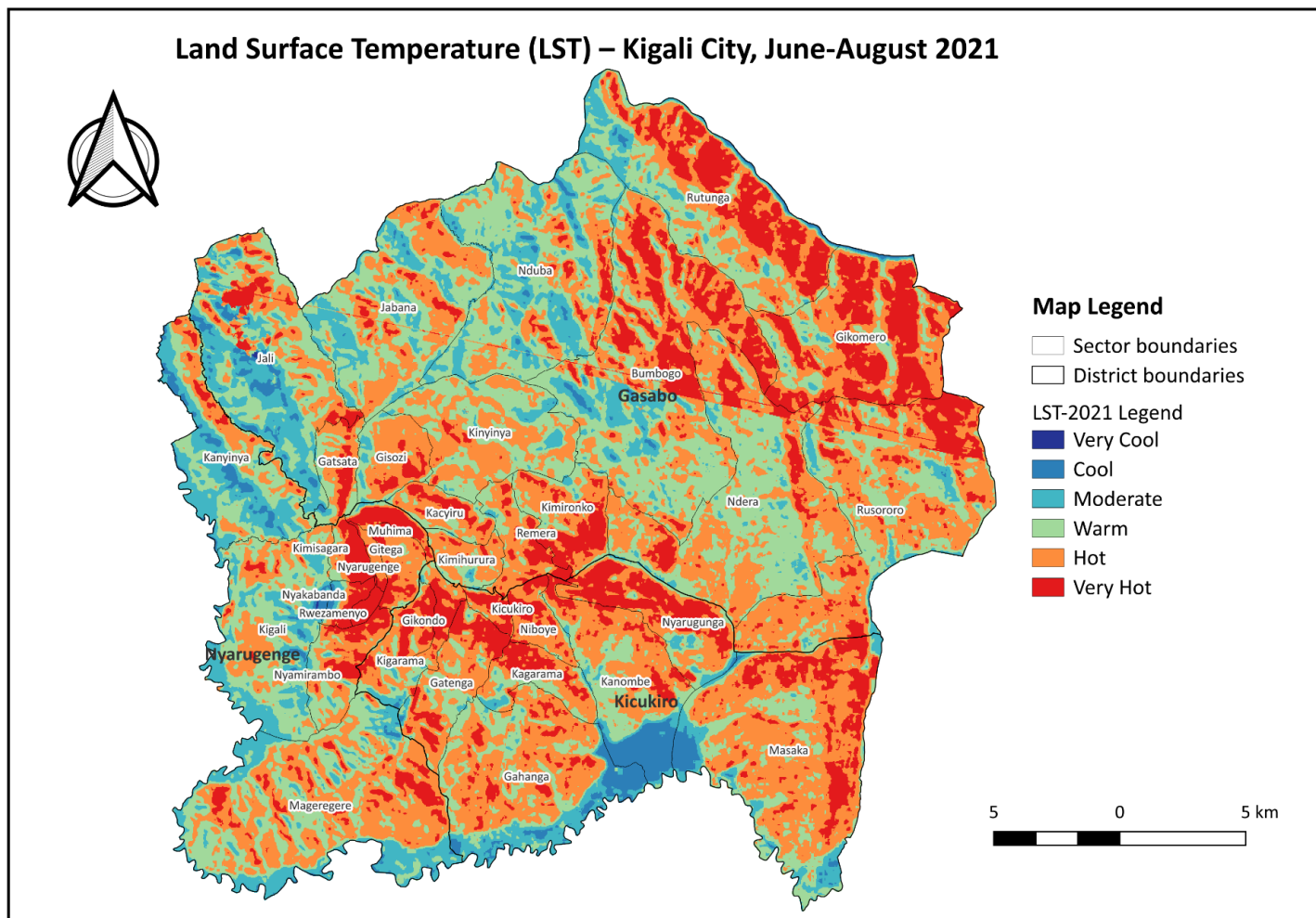


Figure S4. Spatial pattern of Land Surface Temperature (LST) in 2021 across the study area, highlighting the temperature distribution for that year. **Source:** QGIS Development Team (2025). QGIS Geographic Information System. Open Source Geospatial Foundation Project.

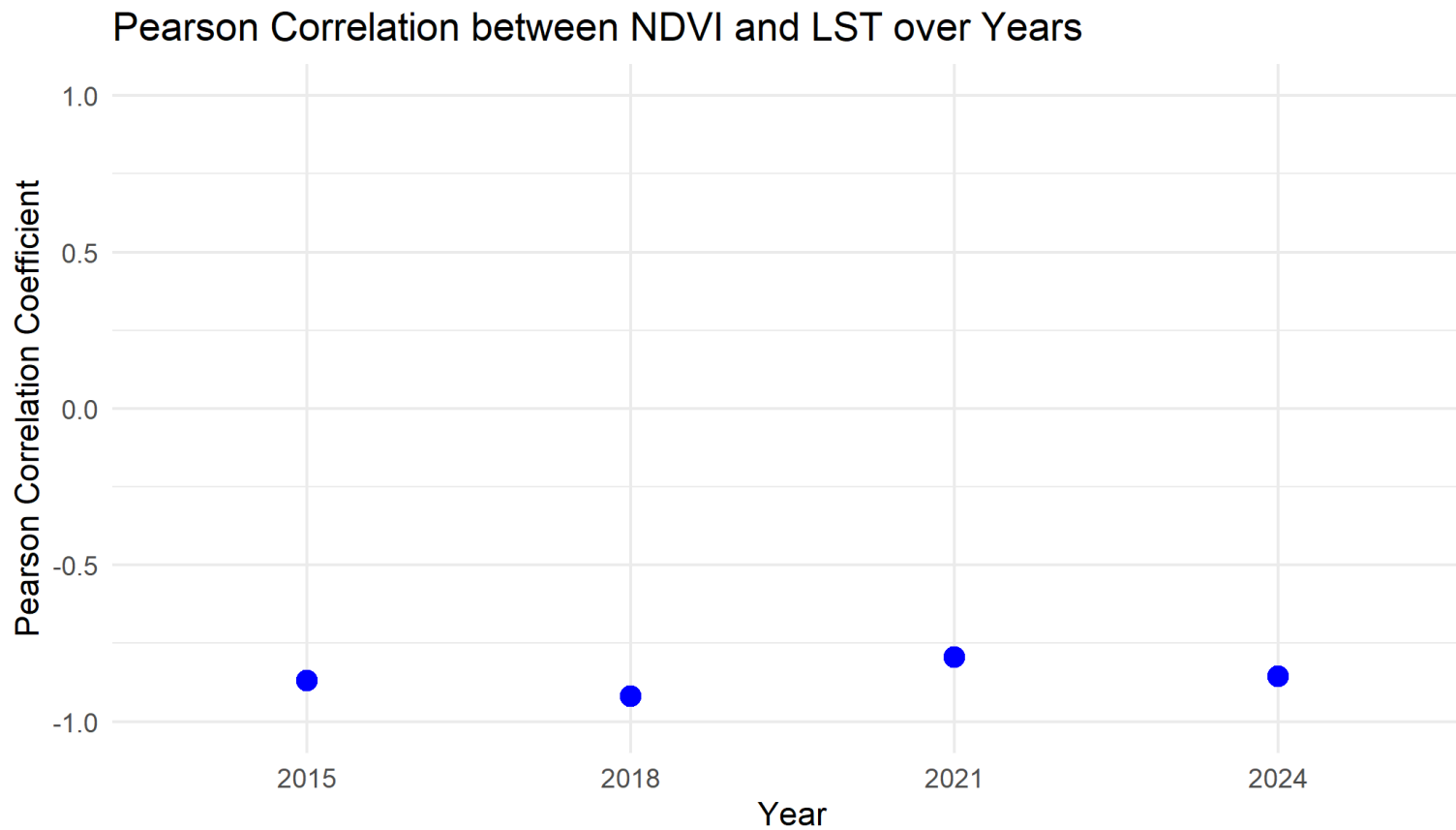


Figure S5. Temporal trend of the correlation between NDVI and LST from 2015 to 2024, illustrating changes in their relationship over the study period. **Source:** RStudio Team (2024). RStudio: Integrated Development Environment for R. Posit Software,PBC

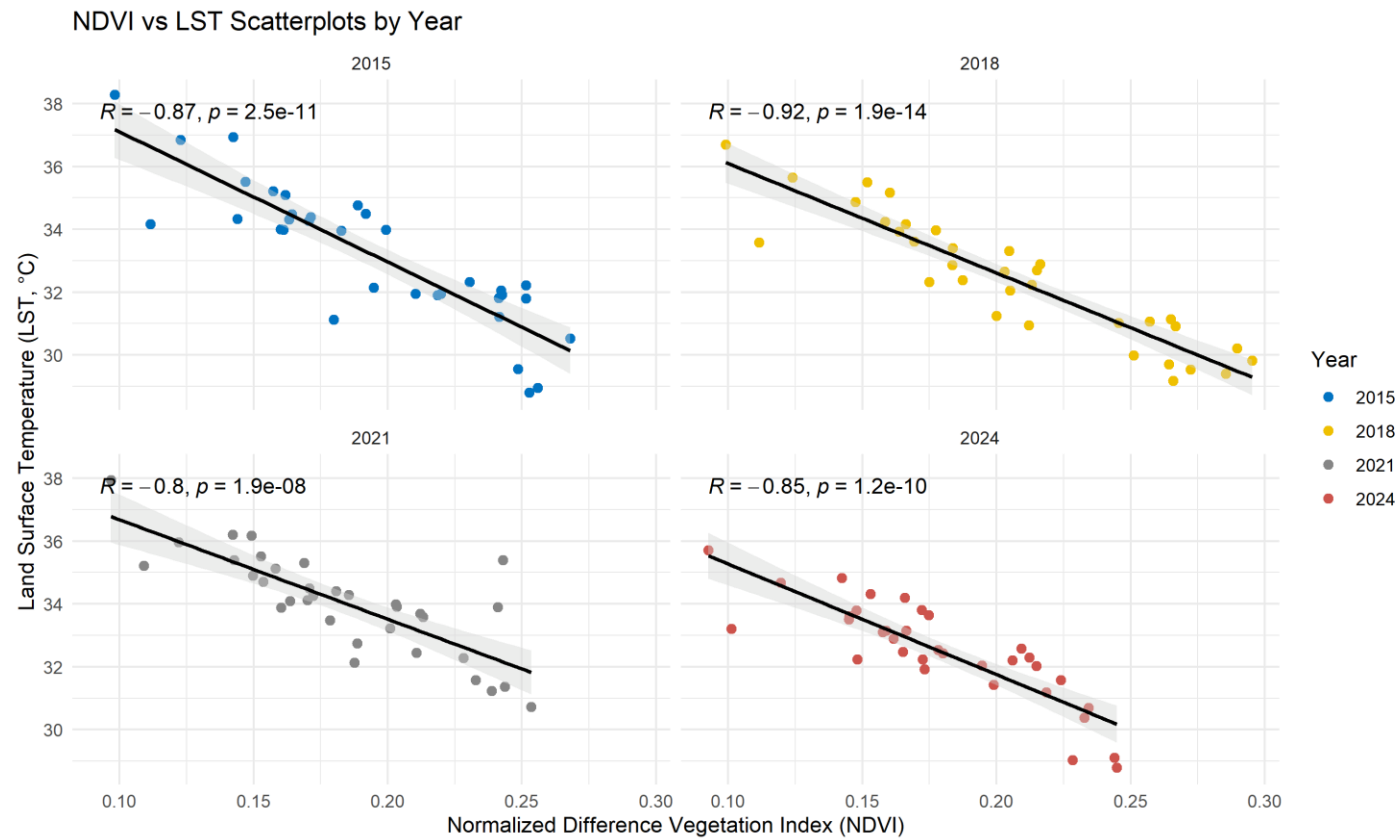


Figure S6. Annual scatterplots illustrating the relationship between NDVI and LST for each selected year, highlighting inter-annual variability in vegetation and surface temperature dynamics. **Source:** RStudio Team (2024). RStudio: Integrated Development Environment for R. Posit Software,PBC

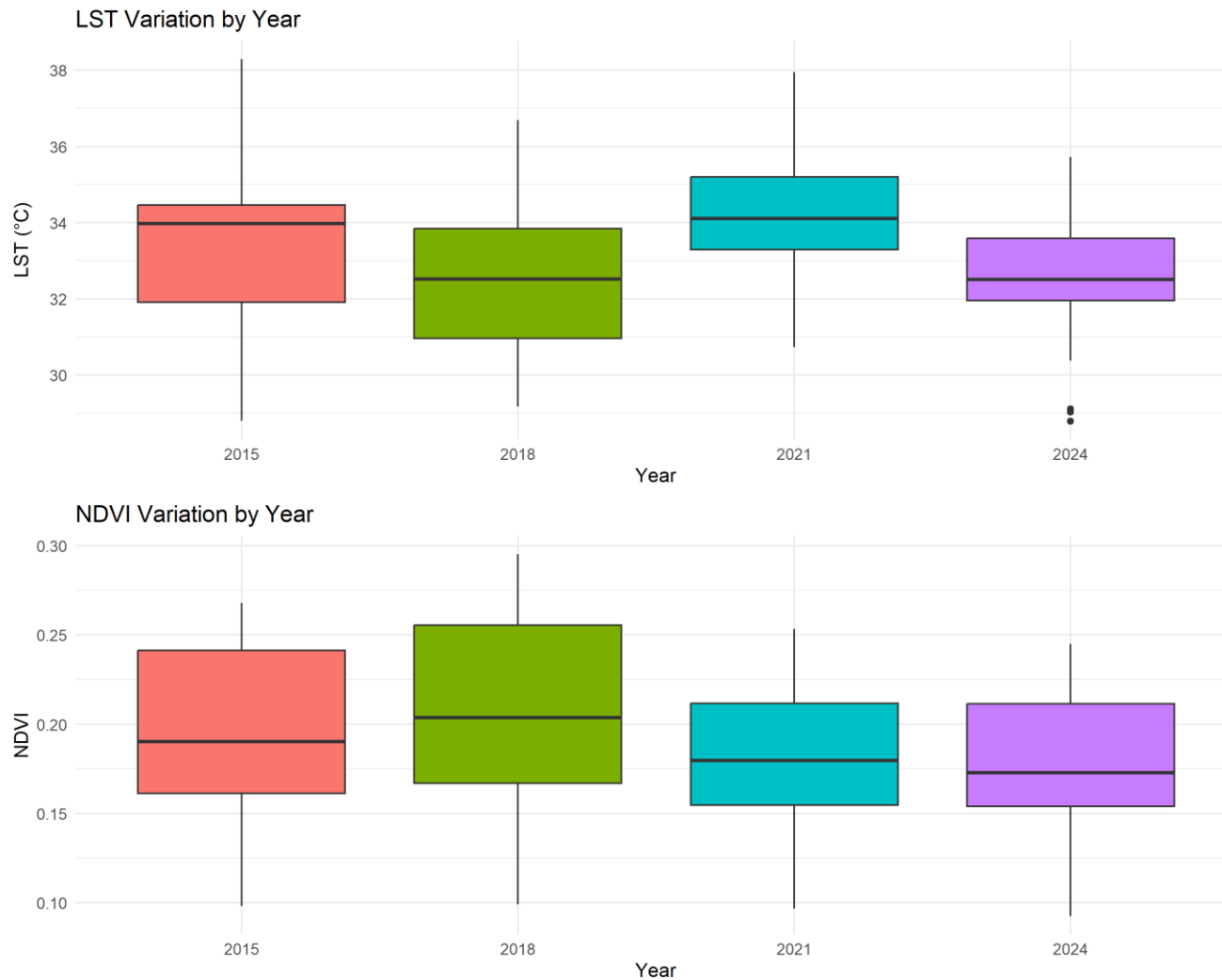


Figure S7. Comparative analysis of LST and NDVI variations by year, illustrating temporal trends in surface temperature and vegetation dynamics. **Source:** RStudio Team (2024). RStudio: Integrated Development Environment for R. Posit Software,PBC

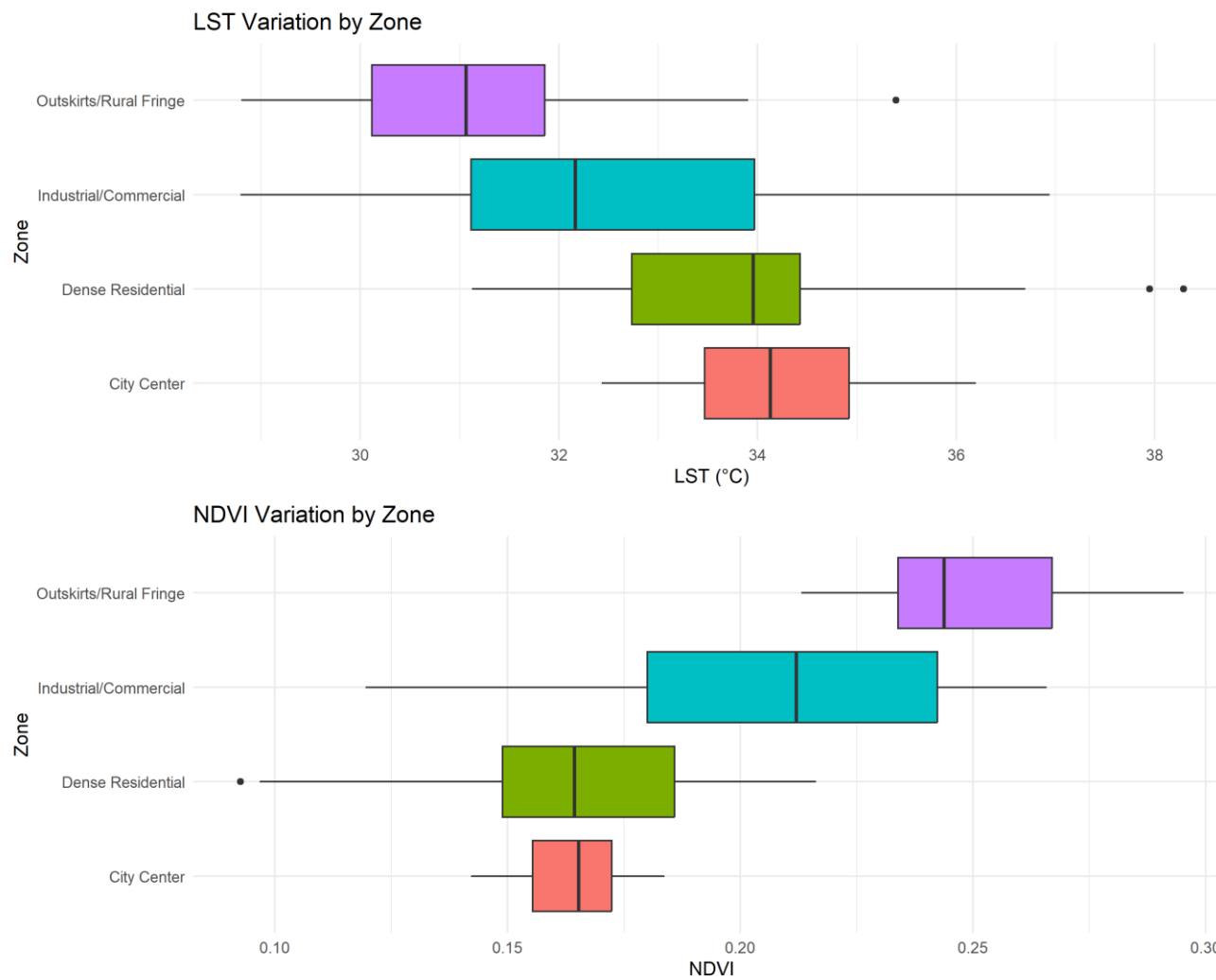


Figure S8. Comparative analysis of LST and NDVI across urban zones, providing insights into spatial variability patterns within the study area. **Source:** RStudio Team (2024). RStudio: Integrated Development Environment for R. Posit Software,PBC

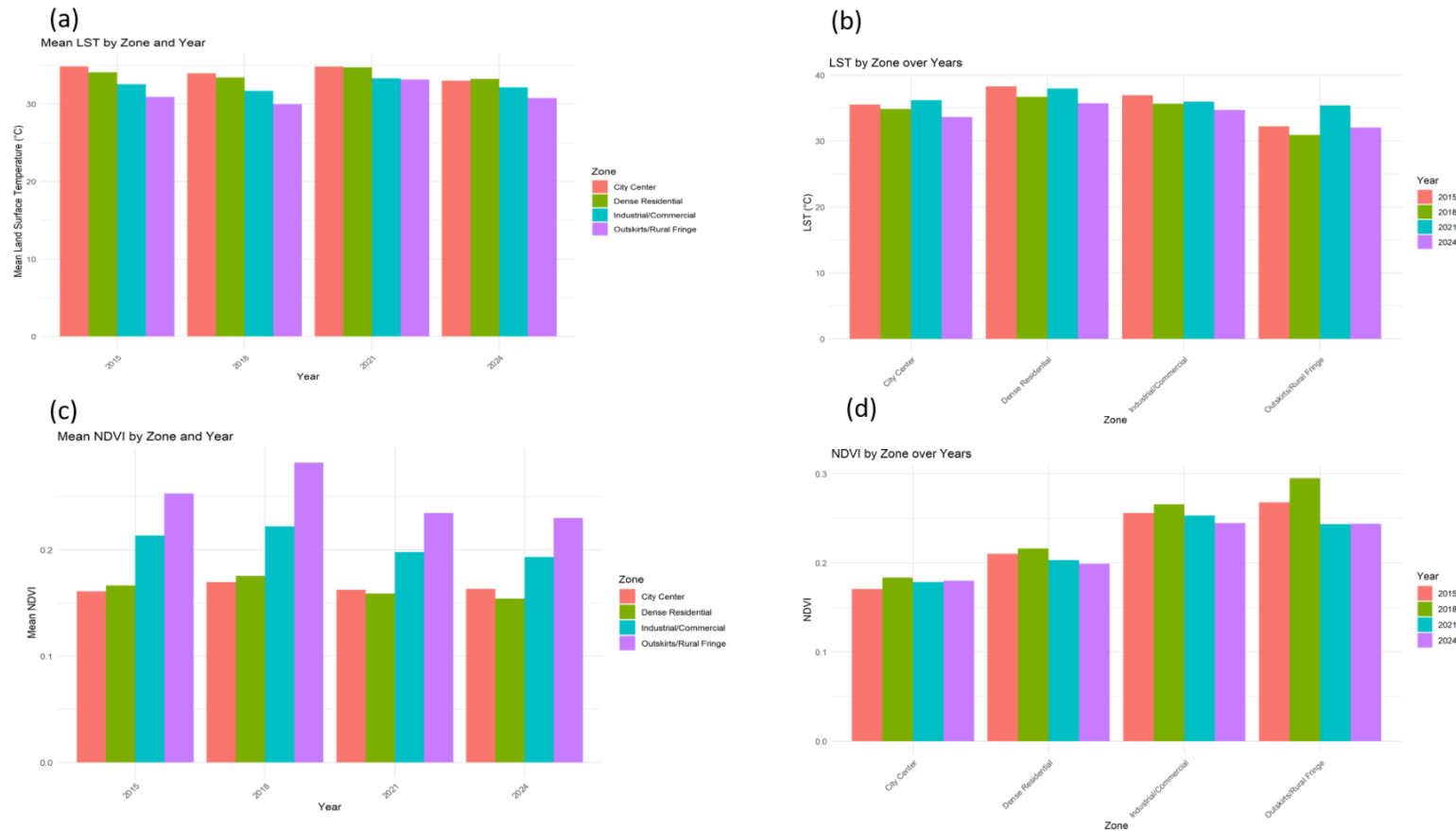


Figure S9. Multi-panel bar charts comparing mean Land Surface Temperature (LST) and Normalized Difference Vegetation Index (NDVI) values across the study area. Panels (a) and (b) show mean LST by year and by urban zone, respectively, while panels (c) and (d) display mean NDVI by year and by urban zone, respectively. These charts highlight spatio-temporal variations in surface temperature and vegetation cover. **Source:** RStudio Team (2024). RStudio: Integrated Development Environment for R. Posit Software,PBC

Table S1: Summary statistics of NDVI values for sectors in Kigali City for the year 2015

Sector	Mean	St. dev	Min.	Max.	Range
Bumbogo	0.24149708	0.05249598	0.000795	0.451587	0.450792
Gatsata	0.21038279	0.06329792	0.049469	0.382843	0.333374
Gikomero	0.25141764	0.04641009	0.006329	0.418483	0.412154
Gisozi	0.17984918	0.05544296	0.041601	0.364098	0.322497
Jabana	0.24248418	0.04516768	0.054487	0.398411	0.343925
Jali	0.25271362	0.03754467	0.070102	0.386974	0.316872
Kacyiru	0.16419939	0.05935674	0.016480	0.385650	0.369171
Kimihurura	0.17061519	0.05450948	0.045656	0.365281	0.319624
Kimironko	0.16002474	0.05683351	0.044629	0.378211	0.333582
Kinyinya	0.19468793	0.04937968	0.021094	0.383867	0.362773
Ndera	0.21980300	0.04041504	0.026867	0.430610	0.403743
Nduba	0.25149692	0.04866900	0.056987	0.460771	0.403784
Remera	0.16107407	0.06213865	0.017149	0.390672	0.373522
Rusororo	0.24141233	0.05003999	0.055508	0.436284	0.380776
Rutunga	0.26794090	0.05544890	-0.001219	0.474483	0.475702
Gatenga	0.19172528	0.05110434	0.044106	0.378898	0.334792
Gikondo	0.14238768	0.04556695	0.043599	0.301508	0.257909
Kagarama	0.19931919	0.04852205	0.060184	0.408161	0.347977
Kanombe	0.21852312	0.05474013	0.013962	0.426346	0.412384
Kicukiro	0.12279863	0.04227042	0.034131	0.332811	0.298680
Kigarama	0.17119304	0.05031452	0.042141	0.380486	0.338345
Masaka	0.23050736	0.05002971	-0.036177	0.436568	0.472745
Niboye	0.15726355	0.05354445	0.050435	0.387311	0.336876
Nyarugunga	0.18257365	0.05717967	-0.015123	0.399178	0.414301
Gitega	0.11147105	0.03525405	0.034568	0.239888	0.205320
Kanyinya	0.25590589	0.04869898	-0.038411	0.414045	0.452456

Kigali	0.24848149	0.05404909	-0.055430	0.418393	0.473823
Kimisagara	0.14398427	0.05981660	0.048147	0.337749	0.289602
Muhima	0.14690708	0.07133791	-0.028373	0.425447	0.453820
Nyakabanda	0.16310704	0.06664219	0.051970	0.317745	0.265775
Nyamirambo	0.18879993	0.04755397	0.049752	0.360260	0.310508
Nyarugenge	0.16184725	0.06314584	0.032769	0.384392	0.351623
Rwezamenyo	0.09810634	0.02678687	0.040488	0.199327	0.158839
Gahanga	0.24225739	0.05086608	-0.039632	0.426803	0.466436
Mageregere	0.23991998	0.05148592	-0.039111	0.427543	0.466655

Source: RStudio Team (2024). RStudio: Integrated Development Environment for R. Posit Software,PBC

Table S2: Summary statistics of NDVI values for sectors in Kigali City for the year 2018

Sector	Mean	St. dev	Min.	Max.	Range
Bumbogo	0.266659026	0.059817183	-0.073009305	0.477113128	0.550122432
Gatsata	0.213143403	0.072979554	0.048039217	0.401757121	0.353717905
Gikomero	0.29523291	0.051377892	-0.001939041	0.45478031	0.456719352
Gisozi	0.174898374	0.061763624	0.027162312	0.377774	0.350611689
Jabana	0.264249884	0.058434907	-0.001235995	0.436839372	0.438075367
Jali	0.272275754	0.044601785	0.063949183	0.448551059	0.384601876
Kacyiru	0.177362508	0.073148401	0.000642598	0.448372364	0.447729766
Kimihurura	0.183692468	0.065029543	0.02749447	0.418891668	0.391397199
Kimironko	0.166103184	0.063608619	0.032010678	0.423922479	0.391911801
Kinyinya	0.205141927	0.06243041	0.031168878	0.409010977	0.377842098
Ndera	0.257014452	0.051065252	0.022096081	0.45202899	0.429932909
Nduba	0.285409427	0.055524263	0.050314348	0.47713241	0.426818062
Remera	0.163672622	0.069196325	0.004553065	0.417600483	0.413047418
Rusororo	0.265063482	0.052503061	0.006867778	0.450896055	0.444028277
Rutunga	0.289765635	0.060745239	-0.068113789	0.474206507	0.542320296
Gatenga	0.214958681	0.066462544	0.027109899	0.397357494	0.370247595
Gikondo	0.151833785	0.061521202	0.031547979	0.383127928	0.351579949
Kagarama	0.216283219	0.064465339	0.060289178	0.428227395	0.367938217

Kanombe	0.200041008	0.063638748	-0.035103362	0.41598019	0.451083552
Kicukiro	0.12392859	0.050488104	0.029776454	0.350320101	0.320543647
Kigarama	0.187363895	0.067220766	0.028551374	0.406922936	0.378371563
Masaka	0.245533378	0.066336872	-0.072183244	0.433000624	0.505183868
Niboye	0.160264235	0.060552269	0.039985165	0.424847245	0.38486208
Nyarugunga	0.20462265	0.07636056	-0.004128114	0.446979314	0.451107428
Gitega	0.111527155	0.043809952	0.025911011	0.285412431	0.25950142
Kanyinya	0.265855991	0.055950255	-0.064369522	0.433139861	0.497509383
Kigali	0.251114495	0.06028252	-0.054068591	0.466350704	0.520419296
Kimisagara	0.158373043	0.081378313	0.034390934	0.374055892	0.339664958
Muhima	0.147477815	0.08379441	-0.108986892	0.457586765	0.566573657
Nyakabanda	0.183492562	0.095538241	0.044142127	0.405371338	0.361229211
Nyamirambo	0.202993707	0.061332399	0.042821068	0.421233594	0.378412526
Nyarugenge	0.169392443	0.071457107	0.02084803	0.373390555	0.352542525
Rwezamenyo	0.099138251	0.033707155	0.026092838	0.235446155	0.209353317
Gahanga	0.211987203	0.081148231	-0.132554173	0.46659863	0.599152803
Mageregere	0.253577423	0.065752721	-0.078177296	0.490322292	0.568499587

Source: RStudio Team (2024). RStudio: Integrated Development Environment for R. Posit Software,PBC

Table S3: Summary statistics of NDVI values for sectors in Kigali City for the year 2021

Sector	Mean	St. dev	Min.	Max.	Range
Bumbogo	0.213136	0.048104	-0.008748	0.432278	0.441027
Gatsata	0.203265	0.067665	0.048863	0.389770	0.340907
Gikomero	0.242868	0.042519	0.007820	0.396692	0.388872
Gisozi	0.160140	0.058723	0.037737	0.398551	0.360814
Jabana	0.228119	0.047198	0.059537	0.393298	0.333760
Jali	0.243660	0.044116	0.065651	0.399006	0.333355
Kacyiru	0.170751	0.067883	0.014528	0.415640	0.401112
Kimihurura	0.178458	0.056490	0.045632	0.387924	0.342292
Kimironko	0.149676	0.055018	0.044034	0.349763	0.305729
Kinyinya	0.188605	0.054510	0.037036	0.378983	0.341948

Ndera	0.200936	0.043008	0.030298	0.394392	0.364093
Nduba	0.232722	0.049463	0.032879	0.421520	0.388641
Remera	0.153496	0.058584	0.020400	0.409555	0.389155
Rusororo	0.202909	0.046124	0.041662	0.417407	0.375745
Rutunga	0.241049	0.049642	-0.016848	0.423935	0.440783
Gatenga	0.180765	0.058860	0.043457	0.371366	0.327909
Gikondo	0.152722	0.052386	0.050098	0.341321	0.291222
Kagarama	0.170024	0.052292	0.058044	0.349281	0.291237
Kanombe	0.187457	0.059388	-0.030281	0.390641	0.420922
Kicukiro	0.121945	0.046577	0.039058	0.343668	0.304611
Kigarama	0.163498	0.059122	0.035394	0.378188	0.342795
Masaka	0.212093	0.057298	-0.052371	0.451507	0.503878
Niboye	0.142639	0.048077	0.048731	0.346020	0.297288
Nyarugunga	0.168721	0.067177	-0.007216	0.416865	0.424080
Gitega	0.108987	0.036995	0.030910	0.257155	0.226245
Kanyinya	0.253404	0.054154	-0.018862	0.429666	0.448528
Kigali	0.238770	0.060930	-0.046439	0.421052	0.467490
Kimisagara	0.149183	0.068886	0.045589	0.342230	0.296641
Muhima	0.142179	0.067895	-0.067292	0.452572	0.519864
Nyakabanda	0.172057	0.084336	0.044883	0.370778	0.325896
Nyamirambo	0.185391	0.056668	0.044100	0.391887	0.347787
Nyarugenge	0.158067	0.063534	0.033645	0.384154	0.350509
Rwezamenyo	0.096782	0.029346	0.036687	0.201128	0.164441
Gahanga	0.210738	0.068794	-0.021445	0.433583	0.455028
Mageregere	0.244776	0.059380	-0.050701	0.427202	0.477904

Source: RStudio Team (2024). RStudio: Integrated Development Environment for R. Posit Software,PBC

Table S4: Summary statistics of NDVI values for sectors in Kigali City for the year 2024

Sector	Mean	St. dev	Min.	Max.	Range
Bumbogo	0.2148	0.0515	0.0225	0.4357	0.4132
Gatsata	0.1990	0.0710	0.0550	0.4030	0.3480
Gikomero	0.2240	0.0422	0.0132	0.4213	0.4081
Gisozi	0.1481	0.0615	0.0362	0.3870	0.3508
Jabana	0.2185	0.0518	0.0161	0.4161	0.3999
Jali	0.2440	0.0454	0.0642	0.4211	0.3569
Kacyiru	0.1663	0.0654	0.0193	0.3875	0.3682
Kimihurura	0.1801	0.0577	0.0196	0.4003	0.3807
Kimironko	0.1478	0.0586	0.0426	0.3747	0.3321
Kinyinya	0.1731	0.0554	0.0321	0.3743	0.3423
Ndera	0.2060	0.0473	0.0152	0.4183	0.4031
Nduba	0.2343	0.0584	0.0281	0.4535	0.4254
Remera	0.1575	0.0642	0.0231	0.4562	0.4331
Rusororo	0.2123	0.0506	0.0325	0.4035	0.3710
Rutunga	0.2328	0.0517	0.0146	0.4266	0.4120
Gatenga	0.1722	0.0568	0.0336	0.3761	0.3425
Gikondo	0.1529	0.0561	0.0474	0.3578	0.3105
Kagarama	0.1748	0.0588	0.0582	0.3933	0.3351
Kanombe	0.1725	0.0526	0.0308	0.4158	0.3850
Kicukiro	0.1195	0.0498	0.0458	0.4040	0.3581
Kigarama	0.1587	0.0598	0.0244	0.3631	0.3387
Masaka	0.2093	0.0584	-0.0665	0.4399	0.5064
Niboye	0.1424	0.0490	0.0296	0.3340	0.3044
Nyarugunga	0.1658	0.0658	-0.0052	0.4060	0.4112
Gitega	0.1012	0.0319	0.0302	0.2069	0.1767
Kanyinya	0.2448	0.0549	-0.0255	0.4320	0.4576
Kigali	0.2284	0.0616	-0.0150	0.4002	0.4152
Kimisagara	0.1449	0.0722	0.0374	0.3719	0.3345
Muhima	0.1451	0.0756	0.0405	0.4211	0.3807

Nyakabanda	0.1651	0.0838	0.0378	0.3536	0.3159
Nyamirambo	0.1782	0.0577	0.0421	0.3873	0.3452
Nyarugenge	0.1616	0.0664	0.0332	0.3544	0.3212
Rwezamenyo	0.0926	0.0294	0.0344	0.1859	0.1515
Gahanga	0.1946	0.0599	-0.0422	0.4435	0.4857
Mageregere	0.2381	0.0587	-0.0154	0.4450	0.4604

Source: RStudio Team (2024). RStudio: Integrated Development Environment for R. Posit Software,PBC

Table S5: Summary statistics of LST values for sectors in Kigali City for the year 2015

Sector	Mean	St. dev	Min.	Max.	Range
Bumbogo	31.2166	2.3322	23.5085	39.3527	15.8442
Gatsata	31.9534	1.7794	26.0087	37.9205	11.9118
Gikomero	31.8032	2.6621	23.5085	39.5219	16.0134
Gisozi	31.1253	1.6969	26.3232	36.4064	10.0832
Jabana	31.9207	3.0435	23.7101	38.7768	15.0666
Jali	28.8029	3.3372	19.3453	40.1764	20.8311
Kacyiru	34.4877	1.8671	26.6838	40.1679	13.4841
Kimihurura	34.2782	1.5743	27.6887	38.6093	10.9206
Kimironko	34.0043	1.8746	27.4494	38.4315	10.9821
Kinyinya	32.1496	1.9330	27.1897	37.5941	10.4045
Ndera	31.9532	1.8475	24.3766	39.5526	15.1760
Nduba	32.2224	2.7079	24.3083	41.6120	17.3037
Remera	33.9915	1.9797	27.0051	39.8193	12.8142
Rusororo	31.8181	2.3295	23.2965	40.5387	17.2422
Rutunga	30.5317	2.9679	22.7736	38.7289	15.9553
Gatenga	34.4899	2.3668	24.4792	40.5165	16.0373
Gikondo	36.9400	2.1351	30.6624	41.9589	11.2966
Kagarama	33.9895	2.0308	28.0749	39.1288	11.0539
Kanombe	31.9037	3.0975	24.9013	37.3788	12.4775
Kicukiro	36.8399	1.3005	31.1853	39.5971	8.4117
Kigarama	34.3957	2.7213	25.4294	41.2924	15.8630

Masaka	32.3280	2.6515	24.6535	39.3014	14.6479
Niboye	35.2070	1.6004	28.6577	39.3732	10.7155
Nyarugunga	33.9638	2.2524	25.4243	40.4841	15.0598
Gitega	34.1669	1.3812	31.2879	37.8265	6.5387
Kanyinya	28.9609	2.2487	22.7633	35.5365	12.7731
Kigali	29.5588	1.7077	24.4416	37.4266	12.9851
Kimisagara	34.3315	1.6499	29.3054	38.4828	9.1774
Muhima	35.5194	2.6132	26.5522	38.5067	11.9545
Nyakabanda	34.3137	3.5330	26.5300	39.5151	12.9851
Nyamirambo	34.7640	1.8669	28.5535	40.5610	12.0075
Nyarugenge	35.0980	1.4882	29.1926	39.2450	10.0524
Rwezamenyo	38.2899	0.5778	36.0082	39.8569	3.8487
Gahanga	32.0513	2.6787	24.8893	39.1015	14.2121
Mageregere	31.3086	2.4341	24.1100	39.4706	15.3606

Source: RStudio Team (2024). RStudio: Integrated Development Environment for R. Posit Software,PBC

Table S6: Summary statistics of LST values for sectors in Kigali City for the year 2018

Sector	Mean	St. dev	Min.	Max.	Range
Bumbogo	30.91533	2.074995	24.23992	41.59833	17.35841
Gatsata	32.22942	1.997342	24.72015	37.44202	12.72187
Gikomero	29.81759	2.230397	23.19059	37.7223	14.53171
Gisozi	32.3302	1.97734	25.98824	36.86267	10.87443
Jabana	29.69759	2.205566	22.36001	36.28844	13.92843
Jali	29.53723	2.645068	21.20472	38.27773	17.07301
Kacyiru	33.97781	1.858866	26.7026	38.45547	11.75286
Kimihurura	33.39735	1.646079	26.16256	37.78724	11.62469
Kimironko	34.15962	2.046053	27.26145	38.44692	11.18547
Kinyinya	32.05672	1.76177	25.70454	37.43519	11.73064
Ndera	31.06408	1.852888	23.83318	38.38369	14.55051
Nduba	29.40415	2.060103	22.86929	36.96521	14.09591
Remera	33.91931	2.118255	26.49923	40.84808	14.34885

Rusororo	31.13454	2.169783	23.37003	39.12369	15.75365
Rutunga	30.21404	2.762969	22.82657	38.60586	15.77929
Gatenga	32.70112	2.438559	24.34075	39.24503	14.90428
Gikondo	35.4922	2.203788	27.5742	39.14761	11.57342
Kagarama	32.89653	2.449024	24.73382	37.68983	12.956
Kanombe	31.24616	3.095172	24.79706	38.81607	14.01901
Kicukiro	35.65349	1.433873	30.73416	38.66738	7.933224
Kigarama	32.38775	2.635209	24.59027	38.89981	14.30954
Masaka	31.01604	2.065683	24.87054	38.0453	13.17476
Niboye	35.16892	1.436437	29.37891	39.66715	10.28824
Nyarugunga	33.31604	2.355131	25.28754	38.84683	13.55929
Gitega	33.58286	1.187073	30.68802	36.21495	5.526938
Kanyinya	29.17451	2.654503	22.78897	37.68983	14.90086
Kigali	29.98211	2.118066	22.71719	36.71398	13.99679
Kimisagara	34.24543	2.087696	26.74362	38.09486	11.35124
Muhima	34.86435	2.641351	25.49092	38.50503	13.01411
Nyakabanda	32.86821	3.886244	24.29632	38.68276	14.38645
Nyamirambo	32.64739	1.982278	26.88376	38.76821	11.88446
Nyarugenge	33.61315	1.439028	28.30566	37.48304	9.177384
Rwezamenyo	36.69503	0.594281	34.92807	38.41103	3.482962
Gahanga	30.94766	2.63133	22.96158	36.85412	13.89254
Mageregere	30.70662	1.865922	24.05022	36.8678	12.81758

Source: RStudio Team (2024). RStudio: Integrated Development Environment for R. Posit Software,PBC

Table S7: Summary statistics of LST values for sectors in Kigali City for the year 2021

Sector	Mean	St. dev	Min.	Max.	Range
Bumbogo	33.58	2.85	25.17	45.06	19.89
Gatsata	33.92	2.36	25.56	40.20	14.64
Gikomero	35.39	2.64	25.86	43.70	17.84
Gisozi	33.88	2.11	27.09	38.94	11.84

Jabana	32.29	2.29	25.72	39.16	13.44
Jali	31.37	3.14	22.31	43.86	21.54
Kacyiru	34.50	2.02	27.77	39.58	11.81
Kimihurura	33.49	1.64	26.69	37.83	11.14
Kimironko	34.90	2.12	28.24	40.57	12.33
Kinyinya	32.74	1.70	26.88	38.03	11.15
Ndera	33.22	1.98	27.93	44.98	17.05
Nduba	31.58	2.33	25.31	39.79	14.48
Remera	34.71	2.09	26.16	41.00	14.84
Rusororo	33.99	2.27	26.63	46.21	19.59
Rutunga	33.90	3.07	25.17	42.68	17.51
Gatenga	34.41	2.25	25.75	41.28	15.53
Gikondo	35.52	2.14	28.46	39.35	10.89
Kagarama	34.12	2.42	26.58	38.96	12.38
Kanombe	32.13	3.71	24.03	39.93	15.90
Kicukiro	35.96	1.65	29.17	39.91	10.74
Kigarama	34.10	2.71	25.59	42.21	16.63
Masaka	33.69	2.69	25.43	41.42	15.99
Niboye	35.40	1.51	28.97	40.25	11.27
Nyarugunga	35.31	2.82	26.65	40.83	14.19
Gitega	35.22	1.23	32.56	38.46	5.90
Kanyinya	30.73	2.83	24.03	39.22	15.18
Kigali	31.24	2.35	23.54	38.44	14.90
Kimisagara	36.17	2.37	28.67	39.89	11.22
Muhima	36.20	2.48	26.40	39.57	13.17

Source: RStudio Team (2024). RStudio: Integrated Development Environment for R. Posit Software,PBC

Table S8: Summary statistics of LST values for sectors in Kigali City for the year 2024

Sector	Mean	St. dev	Min.	Max.	Range
Bumbogo	32.0262	2.1836	22.9513	40.0790	17.1277
Gatsata	31.4359	2.1626	22.2677	37.0660	14.7983
Gikomero	31.5856	2.5512	22.2985	40.0346	17.7361
Gisozi	32.2408	2.3535	24.7355	36.5704	11.8349
Jabana	31.1853	2.1679	24.3766	36.7960	12.4194
Jali	29.1051	2.4230	18.9317	37.5446	18.6128
Kacyiru	33.1434	1.7935	25.5217	37.5599	12.0383
Kimihurura	32.4318	1.2997	25.5012	35.7279	10.2267
Kimironko	33.7930	1.9894	27.1863	38.1991	11.0129
Kinyinya	31.9268	1.8496	23.9340	37.2199	13.2858
Ndera	32.2013	1.9881	23.7785	39.8996	16.1211
Nduba	30.6975	2.1308	22.1344	37.3600	15.2256
Remera	33.1016	1.9215	24.9423	38.0145	13.0722
Rusororo	32.2937	2.2104	23.5153	40.8105	17.2952
Rutunga	30.3815	2.6108	22.2404	38.9921	16.7517
Gatenga	33.8116	1.9334	25.2841	39.7919	14.5078
Gikondo	34.3239	2.1253	27.4734	38.2401	10.7668
Kagarama	33.6409	2.4391	25.4089	39.1186	13.7097
Kanombe	32.2390	3.7686	24.1032	38.6793	14.5761
Kicukiro	34.6805	1.4075	28.3347	38.3085	9.9738
Kigarama	33.1468	2.3399	23.6213	40.0534	16.4321
Masaka	32.5874	2.7622	24.6945	39.3356	14.6411
Niboye	34.8328	1.3058	29.7805	39.3698	9.5893
Nyarugunga	34.1962	2.6043	25.0124	38.8605	13.8481
Gitega	33.2094	0.9107	30.9905	35.6647	4.6741
Kanyinya	28.7916	2.2581	20.8116	37.3788	16.5671
Kigali	29.0292	1.7869	20.6373	34.9161	14.2788
Kimisagara	33.5073	2.1097	26.4275	38.3615	11.9340

Muhima	33.6106	2.1269	26.1711	36.8302	10.6591
Nyakabanda	32.4829	3.2925	25.3098	38.1615	12.8518
Nyamirambo	32.5348	2.1653	27.4699	40.1166	12.6467
Nyarugenge	32.9026	1.3916	28.1809	37.7770	9.5961
Rwezamenyo	35.7185	0.6734	34.2188	37.9137	3.6949
Gahanga	32.0420	3.3115	23.1923	40.2721	17.0798
Mageregere	31.0347	2.1525	23.4726	38.0726	14.6001

Source: RStudio Team (2024). RStudio: Integrated Development Environment for R. Posit Software,PBC