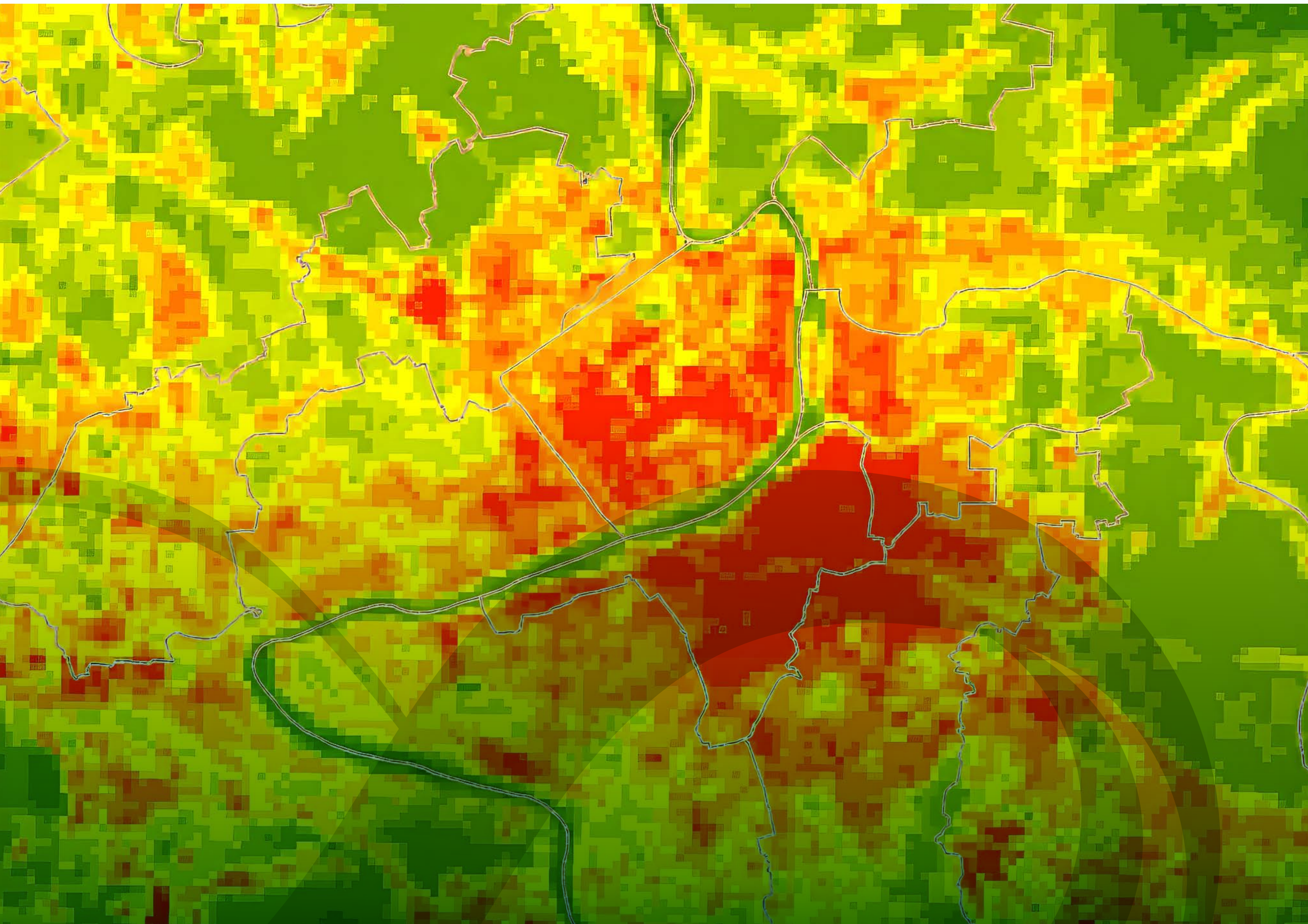
IMPACTS OF GREEN SPACE DECLINE ON URBAN HEAT

in Hue City, Viet Nam



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Content

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Abbreviations

Entropy	A metric used to quantify texture complexity in remote sensing imagery
LST	Land Surface Temperature
MAE	Ministry of Agriculture and Environment
NDBI	Normalized Difference Built-up Index
NDVI	Normalized Difference Vegetation Index
RANGE	Surface temperature variation
SR	Surface Reflectance
STD	Standard Deviation
UI	Urban Index

List of Tables and Figures

1. Summary

Hue City is an urban area that is frequently affected by extreme weather events and natural disasters. Among these hazards, extreme heat has become increasingly severe due to the impacts of climate change. In addition to extreme climatic factors, rapid urban development characterized by the expansion of impervious concrete surfaces and the decline of green spaces and water bodies has further intensified heat-related risks. This situation increases pressure on public health, energy consumption, and the resilience of urban infrastructure. As Hue moves toward the goal of green urban development and climate change adaptation, quantitatively assessing the relationship between the loss of green spaces and urban thermal variations has become particularly urgent.

This report aims to analyze and assess the impact of green space loss on summer temperatures in Hue City during the period 2014–2024. The study is based on satellite imagery data (Landsat and Sentinel) and meteorological data. The findings provide scientific evidence to support green space planning, identify areas vulnerable to extreme heat, and propose solutions to mitigate the impacts of extreme heat in the future.

This study utilizes a time series of Landsat 8 and Landsat 9 imagery acquired during the summer months (April–July) over the period 2014–2024 to calculate Land Surface Temperature (LST). Cloud contamination was removed using the QA band to eliminate pixels affected by clouds, cloud shadows, or haze. LST was derived from the thermal infrared band, with surface emissivity corrected based on the Normalized Difference Vegetation Index (NDVI). The results were then normalized to ΔLST, representing the deviation from the citywide summer mean for each respective year. To enhance reliability, the calculated LST values were calibrated using in-situ observations from the Hue meteorological station by comparing and adjusting the mean bias between satellite-derived LST and observed air temperature at corresponding times.

The results were analyzed across three primary spatial categories (urban core, peri-urban, and rural areas) based on the updated administrative boundaries of Hue City in 2025. A comparative assessment was also conducted between two groups "green loss" and "non green loss"[1] to quantify the role of vegetation cover. In addition, temporal variability indicators, including standard

1 In this study, "green loss" is defined as areas that transitioned from vegetated cover to non-vegetated cover during the 2014–2024 period, based on change detection analysis of binary-classified vegetation cover derived from the NDVI index

deviation (Std) and temperature range (Range), were applied to evaluate the stability or fluctuation of thermal conditions over time.

The study covers the entire administrative boundary of Hue City under the 2025 delineation. Particular emphasis was placed on representative case-study areas: Thuận Hóa Ward (representing a highly concrete-dominated urban core), Quảng Điền Commune (a rural area maintaining substantial vegetation cover), and An Cựu Ward (including former An Cựu, An Đông, and An Tây), a peri-urban zone experiencing rapid urbanization over the past decade.

Findings

- Over the past decade, Hue City has experienced rapid urbanization accompanied by a significant decline in green space. Between 2014 and 2024 alone, green space area in the 12 central wards[2] decreased by approximately 20%.
- Summer temperatures in the urban core are consistently 4-8°C higher than the citywide mean. Peri-urban areas record temperatures 1-4°C above the mean, while rural areas are generally equal to or below the city mean.
- A comparison between Thuận Hóa and Quảng Điền shows that the urban core maintains persistently high average summer temperatures (36–39°C), whereas rural areas exhibit lower baseline temperatures (29–33°C) but greater inter-annual fluctuations. This reflects the thermal regulation role of vegetation cover and water bodies.
- In the case of An Cựu, an area undergoing rapid urbanization, a clear transition is observed from a relatively "cool" state comparable to rural conditions (2014–2016) to a more stable "high-heat" state with temperatures ranging from 33–35°C since 2020. This shift highlights the thermal impact of impervious surface expansion and concrete expansion.
- A comparison between the "green loss" and "non green loss" groups shows that areas experiencing vegetation loss tend to maintain prolonged high temperatures with lower variability (lower Std and Range), while areas without green loss display lower mean temperatures but higher variability (higher Std and Range). This further confirms the moderating role of mixed surface structures incorporating vegetation and water bodies.

2 New wards effective from July 1, 2025

These quantitative results demonstrate the impact of the Urban Heat Island (UHI) effect in the central urban area as well as in rapidly urbanizing peri-urban zones through spatial and long-term trend analyses. The study also contributes to filling gaps in observed temperature data in Hue. However, several limitations should be noted.

Gaps

- First, LST represents surface temperature rather than air temperature; therefore, the results primarily reflect relative trends and spatial differences rather than absolute thermal conditions experienced by residents.
- Second, Landsat imagery has a relatively long revisit cycle and is affected by cloud cover. In some years, limited usable imagery required seasonal averaging to mitigate data gaps.
- Third, due to the absence of meteorological stations within the dense urban core, LST calibration relied solely on the Hue meteorological station (located outside the urban core), which may not fully capture localized urban heat hotspots.

2. Background


Hue City, 2023 © Thanh Ngo, ISET

In recent years, global climate change has increased both the frequency and intensity of extreme heatwaves, particularly in urban areas. Cities in Central Vietnam are among the most severely affected regions. In Hue City, especially in the inner wards and peri-urban areas, urbanization has accelerated markedly over the past decade, characterized by high population density in the city center and rapid expansion of new built-up areas in surrounding zones. The highest temperature ever recorded in Hue reached 42.2°C on April 27, 2024, marking a local record. Earlier, the historic heatwave of 2019 caused extremely high temperatures across Central Vietnam, with Hue reaching 40.6°C and Ha Tinh recording 43.4°C, the national record at that time. In 2023, a new national record of 44.1°C was set at the Hoi Xuan station (Thanh Hoa). This sequence of records reflects a clear upward trend in extreme temperatures across the region, indicating a rapidly warming climate. During such heatwaves, significant temperature differences are observed between densely built urban cores and rural areas or zones with abundant vegetation and water bodies. This situation underscores the urgent need to examine the role of green spaces and urban structure in regulating thermal conditions and mitigating risks associated with extreme heat events.

The application of remote sensing data in Urban Heat Island (UHI) research has been widely adopted globally and in Vietnam. Satellite imagery such as Landsat, ASTER, and MODIS enables the calculation of Land Surface Temperature (LST) and the analysis of its relationship with land cover, thereby identifying the formation and intensity of UHI within urban spaces (Voogt & Oke, 2003; Weng & Yang, 2004; Yuan & Bauer, 2007).

In Vietnam, numerous studies have demonstrated the impact of land-use change and green space reduction on urban thermal dynamics. In Hanoi, land-use transformation and declining green areas have intensified temperature differences between urban cores and surrounding zones (Nguyen et al., 2018; Nguyen, 2020; Trinh et al., 2022; Nguyen Thi Thuy Hanh & Quach Thi Chuc, 2022). In Ho Chi Minh City, Landsat-based monitoring of new urban developments has shown that built-up areas exhibit significantly higher surface temperatures compared to vegetated and water-covered areas (Tran & Ha, 2010; Tran et al., 2011; Tran Thi Van et al., 2017; Pham et al., 2024).

In Hue, rapid urbanization over the past decade has involved the implementation of numerous urban development projects. Between 2014 and 2024, green space within the 12 central wards declined from 26,149 hectares to 20,539 hectares (a reduction of approximately 5,610 hectares). However, quantitative research examining the relationship between green space change, land use, and surface temperature remains limited. In this context, the present study was conducted to quantitatively analyze the relationship between green loss and urban thermal variation in Hue during the 2014–2024 period. By utilizing a Landsat satellite image time series, combined with calibration methods and temperature variability indices, the study provides scientific evidence of the role of green spaces in regulating urban thermal conditions. These findings contribute to green space planning, climate-adaptive infrastructure development, and risk management strategies for extreme heat events.

3. Methodology

3.1. Methodology

To assess the impact of green loss on urban thermal characteristics in Hue City, the study applies a three-step methodological framework.

Steps

1. Data collection and preprocessing (satellite imagery and meteorological observations
2. Calculation of key indicators (Land Surface Temperature – LST, NDVI, and green space area) and classification of study areas into analytical groups
3. Statistical analysis based on representative spatial subsets (urban core – peri-urban – rural; green loss and non green loss; selected representative wards).

The main analytical dimensions include:

1. Green space loss across Hue City (40 wards) and the 12 central wards during the 2014-2024 period
2. Assessment of the impact of green space on heat conditions, including:
    - 2.1. **Urban and sub-urban temperature differences**: Analysis of Land Surface Temperature (LST) derived from Landsat imagery in urban core and sub-urban areas, with LST calibrated against in-situ air temperature measurements.
    - 2.2. **Green loss areas:** Relative comparison of temperatures between areas experiencing green loss and non-green loss areas within the same year and time period.
    - 2.3. **Non-Green loss areas**: Evaluation of temperature variability between areas characterized by mixed green cover and impervious surfaces and areas experiencing significant vegetation loss.

3.2. Data sources

To assess the relationship between green loss and urban thermal variation, the study integrates in-situ meteorological observations and satellite imagery. This combined approach ensures reliability through ground-based measurements while enabling full spatial coverage of the urban area through Landsat and Sentinel images.

(1) In-situ Meteorological Data

- **Source:** Hue Meteorological Station.
- **Data type:** Monthly mean air temperature (April–July) for the period 2014–2024.
- **Purpose:** Reference and calibration of satellite-derived Land Surface Temperature (LST).

(2) Landsat 8/9 - Collection 2, Level-2

- **Source:** U.S. Geological Survey (USGS), downloaded from Earth Explore[3]
- **Features**
    - **Data type:** Collection 2, Level-2 (Surface Reflectance & Surface Temperature), jointly processed by NASA and USGS with standardized radiometric and atmospheric corrections.
    - **Sensors:**Operational Land Imager (OLI – optical) and Thermal Infrared Sensor (TIRS – thermal).
    - **Bands used:** SR (Surface Reflectance): Red (B4), NIR (B5) for NDVI calculation. Thermal: ST_B10 (LST band) for surface temperature estimation.
    - **QA PIXEL:** Cloud and cloud-shadow masking.
    - **Spatial resolution:** Optical bands: 30 m. Thermal band: 100 m (resampled from original 30 m product).
    - **Temporal resolution:** 16-day revisit cycle.
- **Time coverage:** Summer months (April-July), 2014–2024.
- **Purpose:** (i) NDVI calculation and green space classification (2014-2018); (ii) LST calculation and summer temperature time-series analysis (2014-2024).

3 https://earthexplorer.usgs.gov

(3) Sentinel-2 - Level-2A

- **Source:** European Space Agency – ESA.
- **Data type:** Sentinel-2 Level-2A (Surface Reflectance).
- **Features:**
  - **Spatial resolution:** 10 m (Red, NIR).
  - **Temporal resolution:** 5 days.
  - **Time coverage:** 2019–2024.
- **Purpose:** NDVI calculation and green area classification.

(4) Additional Data

- **Google Earth imagery:** High-resolution images (DigitalGlobe) were used to validate and adjust NDVI thresholds for green area classification.
- **Administrative boundaries:** Ward-level shapefile of Hue City (2025 boundary), obtained from the Vietnam Department of Survey, Mapping and Geographic Information.

! Data Limitations

- Landsat's 16-day revisit cycle and frequent cloud cover during summer resulted in limited usable imagery in some years; seasonal averaging was applied to reduce uncertainty.
- The Hue meteorological station does not directly represent microclimatic conditions within the dense urban core.
- Green space classification based on NDVI may be affected by soil moisture and shadow effects; this was mitigated through cross-validation with high-resolution Google Earth imagery.

3.3. Calculation

After defining the scope and analytical framework, the study implemented the following computational steps:

Steps

1. Processing and correcting land surface temperature data derived from remote sensing imagery,
2. Calculating the NDVI vegetation index to determine green coverage,
3. Calculating indicators (ΔLST, standard deviation, and thermal amplitude); and analyzing the results by spatial groups and zones.

TABLE 1. Data used in this study

Data	Source	Time	Resolution	Use
Mean monthly temperature in summer	MAE	2014-2024		LST adjustment
Landsat 8/9 C2 L2	U.S. Geological Survey (USGS)	2014-2024	30 m (optical), 100 m (thermal)	NDVI calculation in 2014-2018; LST calculation in 2014-2024
Sentinel-2 L2A	European Space Agency (ESA)	2019-2024	10 m	NDVI calculation in 2019-2024
Google Earth image	DigitalGlobe	2014-2024	0.5 m	Adjust NDVI threshold

3.3.1. Land Surface Temperature (LST)

LST definition

Land Surface Temperature (LST) represents the thermal radiation emitted from the Earth's surface, directly reflecting the interaction between surface materials (vegetation, bare soil, concrete, asphalt, water bodies) and solar radiation. LST reflects the instantaneous thermal state of the surface and exhibits strong variability depending on land cover types. Therefore, LST is widely used in Urban Heat Island (UHI) studies and in assessing land-use impacts, particularly urbanization.

LST Calculation

LST was derived from Brightness Temperature (BT) obtained from the thermal infrared band of Landsat imagery.

1. Converting Digital Number (DN) values from Landsat images into Top of Atmosphere (TOA) radiance.

2. Calculating Brightness Temperature (BT) from the TIRS thermal band.

3. Correcting surface emissivity (ε) based on NDVI using the NDVI threshold method:

   - NDVI < 0.2 → bare soil / impervious surfaces (ε ~ 0.97).
   - NDVI > 0.5 → vegetation (ε ~ 0.99).
   - 0.2 ≤ NDVI ≤ 0.5 → mixed pixels; ε calculated proportionally to vegetation fraction.

4. LST for each pixel is calculated using

$$LST = \frac{BT}{1+((\lambda . BT)/\rho).\ln(\varepsilon)} - 273.15 \qquad \textit{Formula (1)}$$

Where: **BT:** *Brightness Temperature (Kelvin)*

λ = *Central wavelength of TIRS Band 10*

ρ = *Physical constant related to Planck's constant*

ε: *Surface Emissivity*

Cloud Masking, Image Selection, and LST Computation

- Landsat 8 Collection 2, Level-2 imagery was used. Cloud and cloud-shadow masking were performed using the QA_PIXEL quality assessment band. Bitmasks corresponding to cloud, cloud shadow, and haze were applied to remove atmospherically contaminated pixels, ensuring only high-confidence thermal pixels were retained.

- LST was calculated using Equation (1) for each scene. Brightness Temperature (BT) was derived from the ST_B10 thermal band. The single-channel algorithm with surface emissivity correction was applied.

- All images acquired between April 1 and July 31 of each year were collected and processed. For each year, the images were composited using the median method to generate a representative summer LST map. This approach effectively reduces residual cloud contamination and outliers while reflecting stable summer surface temperature characteristics.

- The selected Landsat scenes were acquired during the daytime overpass of Landsat 8 (approximately 10:00–11:00 local time), ensuring temporal consistency in interannual LST comparison.

LST Normalization Using Meteorological Station Data

- Normalization procedure:

  (i) Calculate the mean LST for the entire study area from Landsat images during April–July of each year;

  (ii) Compare this mean value with the corresponding observed mean air temperature at the Hue meteorological station;

  (iii) Derive a multiplicative normalization factor by dividing the observed temperature by the mean Landsat-derived LST;

  (iv) Apply this factor to annual LST map to generate a normalized LST map.

This normalization approach was intended to reduce year-to-year atmospheric and acquisition-related variability while preserving the spatial distribution and relative thermal contrasts of the original Landsat-derived LST patterns. The procedure was not intended to directly convert LST into air temperature, but rather to improve interannual comparability of thermal conditions across the study period.

3.3.2. NDVI Calculation and Green Area Identification

NDVI (Normalized Difference Vegetation index)

NDVI was calculated from the Red and Near-Infrared (NIR) bands using:

$$NDVI = \frac{NIR - Red}{NIR + Red}$$

Spectral bands used:

- Sentinel-2 (2019-2024): NIR (Band 8), Red (Band 4)
- Landsat 8 (2014-2018): NIR (Band 5), Red (Band 4).

NDVI Adjustment (NDVI_adj)

To reduce noise in urban environments, NDVI_adj was generated by combining the original NDVI with additional filtering conditions:

- Pixels with NDVI > 0.3 were initially selected as vegetation areas
- An entropy-based filter was applied to retain pixels with low entropy values (< 0.5), which are more consistent with homogeneous vegetation surfaces and less associated with complex urban textures
- Apply Urban Index (UI_NDBI): select pixels with low UI_NDBI values associated with vegetation-like surfaces, thereby improving separation between vegetated areas and impervious urban surfaces with similar spectral responses.
- Entropy was calculated using a 3×3 moving window. UI_NDBI was derived from a combination of NDBI and NDVI. A raster logic model using the "AND–NOT" rule was applied to generate the final vegetation mask.

These additional filtering steps were introduced because NDVI alone may overestimate vegetation in dense urban environments due to spectral confusion caused by shadows, mixed pixels, sparse shrubs, and reflective impervious materials.

Definition

GREEN LOSS

Areas that transitioned from vegetated to non-vegetated status during 2014-2024, based on binary classification of NDVI-derived vegetation layers.

NON GREEN LOSS

Areas that did not experience vegetation decline during 2014–2024, including areas that maintained or increased green coverage.

This classification enables direct comparison of thermal characteristics between different land-use states.

NDVI Threshold Determination

- Thresholds between 0.2 and 0.4 were tested using 50 validation points across 10 different wards. The threshold of 0.3 yielded the highest agreement with ground conditions.
- The entropy threshold (< 0.5) was determined empirically through iterative comparison with high-resolution reference imagery and urban land-cover characteristics.
- NDVI results were validated against 5 m resolution Planet imagery provided free of charge for tropical regions under a program supported by the Norwegian government and High-resolution Google images.

3.2.3. ΔLST, Std and Range

ΔLST (Land Surface Temperature Difference)

- ΔLST represents the difference between the mean LST of each ward and the mean LST of the entire city in the same year.
- This indicator enables the identification of wards with temperatures above the citywide mean (hot spots) or below the citywide mean (cool spots).

$$\Delta LST\ (ward) = LST(ward) - LST\ (city)$$

Standard Deviation (Std)

- The standard deviation (Std) reflects the interannual variability of LST, calculated for each ward or group of wards.
- A low Std indicates stable thermal conditions, a high Std indicates wide temperature fluctuations from year to year.

$$Std = \sqrt{\frac{\sum_{i=1}^{n}(x_i - \bar{x})^2}{n}}$$

where: *x_i: Summer LST value for each year*

$\bar{x}$: Mean value of the LST

n: Number of years

Biên độ (Range)

- **Biên độ (Range):** hiệu số giữa LST max và LST min trong giai đoạn, cho thấy độ dao động cực trị của nền nhiệt.

$$Range = Max\ (LST\ summer) - Min\ (LST\ summer)$$

3.3.4. Representative Ward Pairs and Group-Based Analysis

Representative Ward Pairs Analysis

To clarify detailed differences in thermal dynamics among the urban core, rapidly urbanizing areas, and rural areas that maintain substantial green space, the study selected representative ward/commune pairs for comparative analysis:

- **Thuận Hóa - Quảng Điền:** Thuan Hoa represents the urban core, characterized by high building density and homogeneous concrete coverage. In contrast, Quang Dien represents a rural area with extensive green space and water surfaces. This paired comparison clearly illustrates the contrast between an "urban heat hotspot" and a "natural climate-regulating area".
- **An Cựu - Quảng Điền:** An Cuu is a typical peri-urban area undergoing rapid urbanization. Comparison with Quang Dien enables observation of the outward expansion of the Urban Heat Island (UHI) effect from the city center toward peri-urban zones.
- For these analysis, the 2014–2024 time series was analyzed to track annual summer mean LST, thereby identifying long-term thermal stability or variability across different spatial contexts.

Group-Based Analysis:

Analysis was conducted for spatial and land use groups to quantify overall differences:

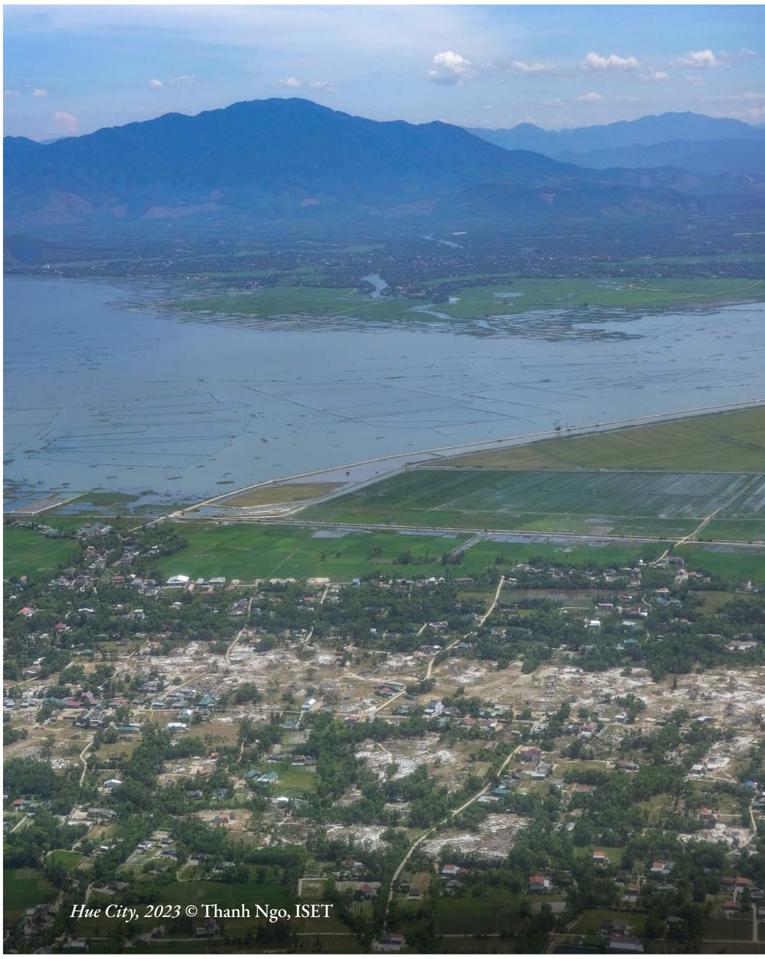
- **By spatial location:** urban core, peri-urban, and rural groups. The mean ΔLST of each group was compared to the citywide mean.
- **By green space status:** Green loss and Non-green loss. The mean summer LST values of these groups were directly compared to determine temperature difference in areas experiencing vegetation loss.

This approach provides both detailed insights (representative wards) and a broader overview (spatial and land-use status groups), aligning with the objective of assessing the impact of green space loss on urban thermal characteristics.

3.3.5. Limitations

Several limitations were identified during the study:

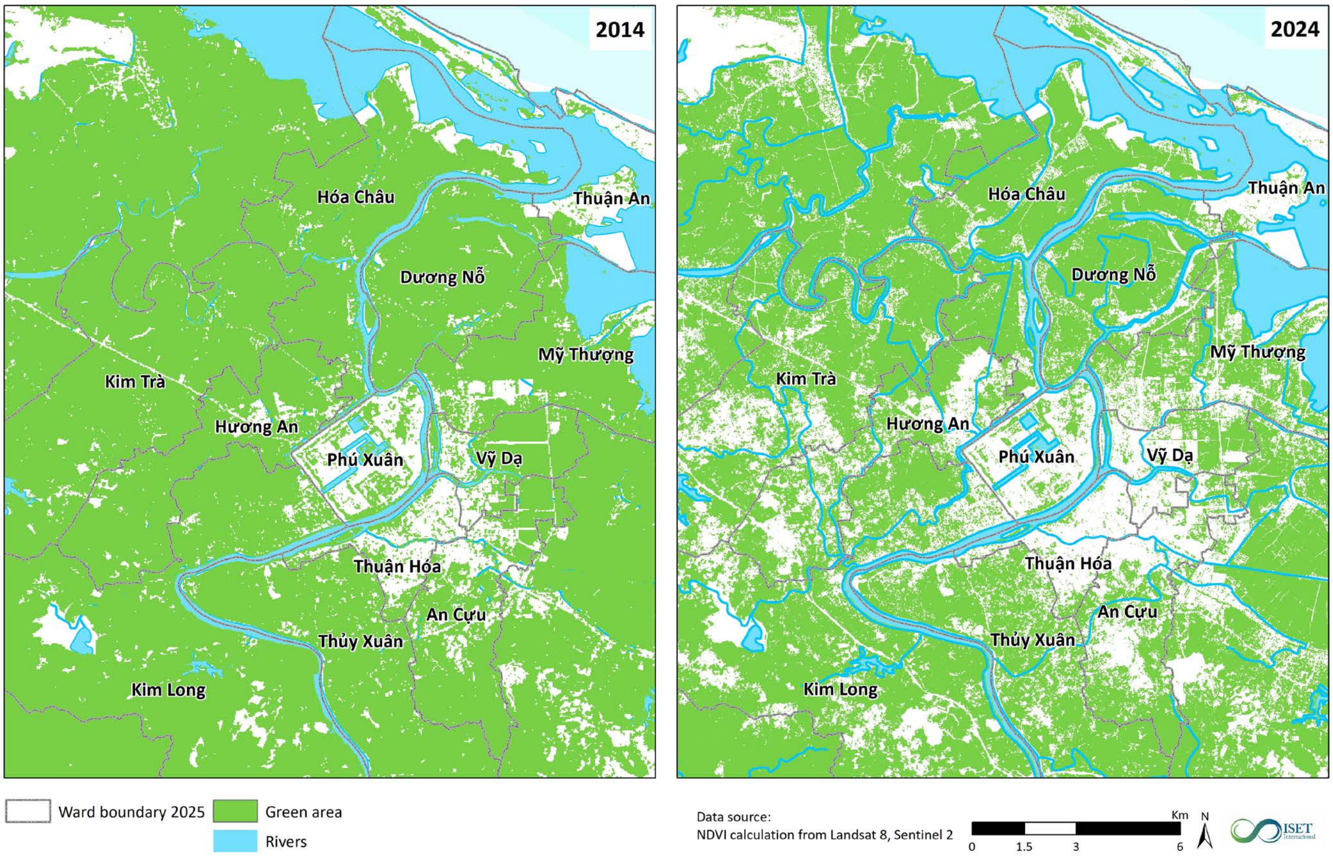
- LST reflects surface temperature (soil, concrete, rooftops, etc.) and cannot fully substitute for air temperature measured at the same time. Therefore, the results only indirectly represent urban thermal conditions.
- The 30 m spatial resolution of Landsat imagery is insufficient to capture fine-scale urban microclimates (e.g., narrow streets, small parks, small water bodies). Localized variations may be smoothed.
- Number and quality of images vary by year. Years with high cloud cover or fewer available scenes may introduce bias, although median compositing was applied to reduce the noise.
- Vegetation classification based on NDVI is influenced by soil moisture, shading, and thin clouds, potentially causing misclassification despite validation using high-resolution imagery.
- Lack of detailed ward-level meteorological data prevents separate calibration for urban core, peri-urban, and rural areas.



Hue City, 2023 © Thanh Ngo, ISET

4. Results

FIGURE 1. Green space distribution in Hue City in 2014 and 2024



4.1. Green Space Decline in Hue City during 2014–2024

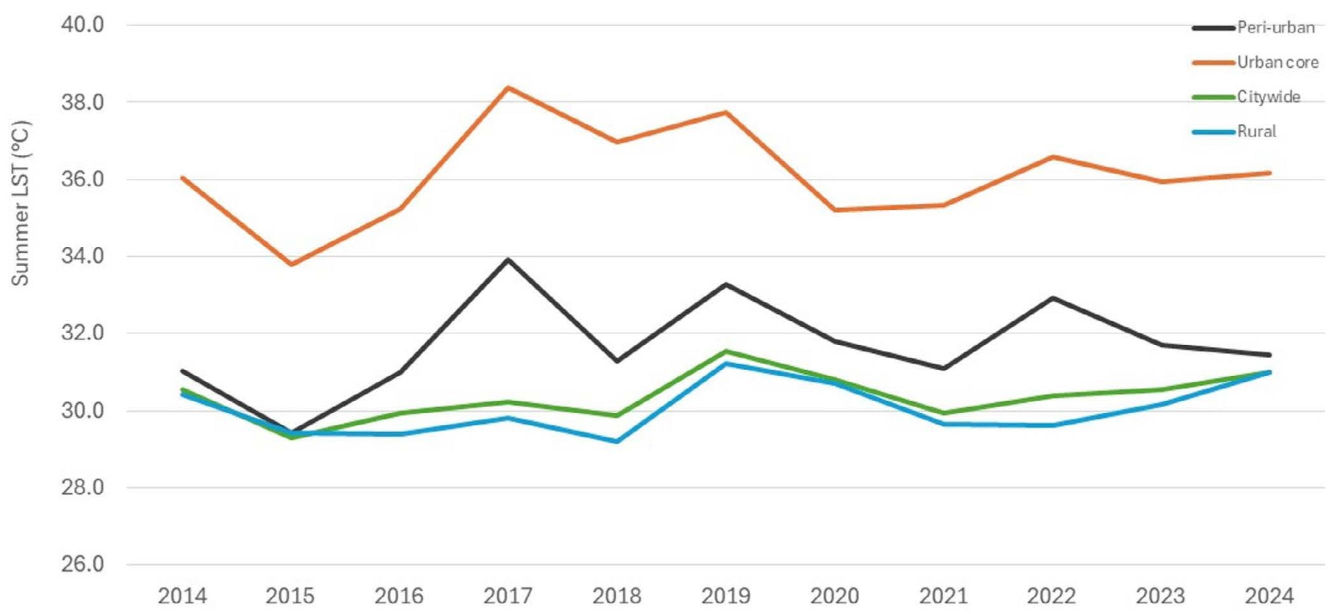
During the period 2014-2024, Hue City experienced rapid urbanization, accompanied by a substantial reduction in vegetated areas, ponds, and agricultural land. Based on the 2025 ward boundaries, within the 12 central wards of the city (An Cuu, Duong No, Hoa Chau, Huong An, Kim Long, Kim Tra, My Thuong, Phu Xuan, Thuan An, Thuan Hoa, Thuy Xuan, and Vy Da), total green space decreased from 26,149 ha in 2014 to 20,539 ha in 2024.

Analysis of green space distribution maps for 2014 and 2024 (Figure 1) reveals that urban expansion was strongly concentrated in the central and peri-central areas of Hue City. Large areas of vegetation, agricultural fields, and ponds were converted into built-up land, particularly in Huong An, Hoa Chau, An Cuu, and Vy Da. These areas originally exhibited high vegetation density in 2014; however, by 2024, extensive built-up zones (represented as white areas) had increasingly fragmented and replaced the former green patches.

4.2. Urban–Suburban–Rural Temperature Differences

To examine differences in land surface temperature (LST) across urban zones, Figure 2 illustrates the annual trends of mean summer surface temperature (April–July) during 2014–2024, comparing inner-city, peri-urban, and rural areas relative to the citywide mean for Hue City.

FIGURE 2. Summer land surface temperatures in inner-city, peri-urban, and rural areas compared with the citywide mean in Hue City during 2014–2024



Inner-city areas (orange line)

Inner-city zones consistently recorded the highest surface temperatures throughout the 2014–2024 period, typically 4–8°C higher than the citywide mean (green line). This pattern reflects the cumulative effects of high building density, extensive concrete and asphalt surfaces, and the lack of green space in the urban core (e.g., Phu Xuan and Thuan Hoa wards).

Peri-urban areas (dark line)

Peri-urban zones exhibited intermediate temperature levels, generally 1–4°C above the citywide mean. However, this trend was less stable than that observed in the inner city and showed greater interannual variability. This variability can be attributed to the heterogeneous land cover in peri-urban areas, where vegetation, rivers, and water bodies remain interspersed with expanding built-up areas (e.g., An Cuu, Duong No, Hoa Chau, Huong An, Kim Long, My Thuong, Thanh Thuy, Thuy Xuan, and Vy Da).

Rural areas (light blue line)

Rural areas generally exhibited surface temperatures equal to or lower than the citywide mean, with many years showing temperatures up to 1°C lower. This contrast highlights the strong regulating effect of vegetation and green space, which helps maintain more stable and cooler thermal conditions.

The differences in mean land surface temperature among urban core, peri-urban, and rural areas are also illustrated in Figure 3. This map was generated based on the calculated land surface temperature difference (ΔLST) at each pixel relative to the mean summer land surface temperature of Hue City in 2021.

The ΔLST value was calculated as:

$$\Delta LST_{pixel} = LST_{pixel} - LST_{mean\_city}$$

where:

LST_{pixel}: summer land surface temperature of each Landsat pixel after calibration.

LST_{mean_city}: mean summer LST over the entire administrative area of Hue City.

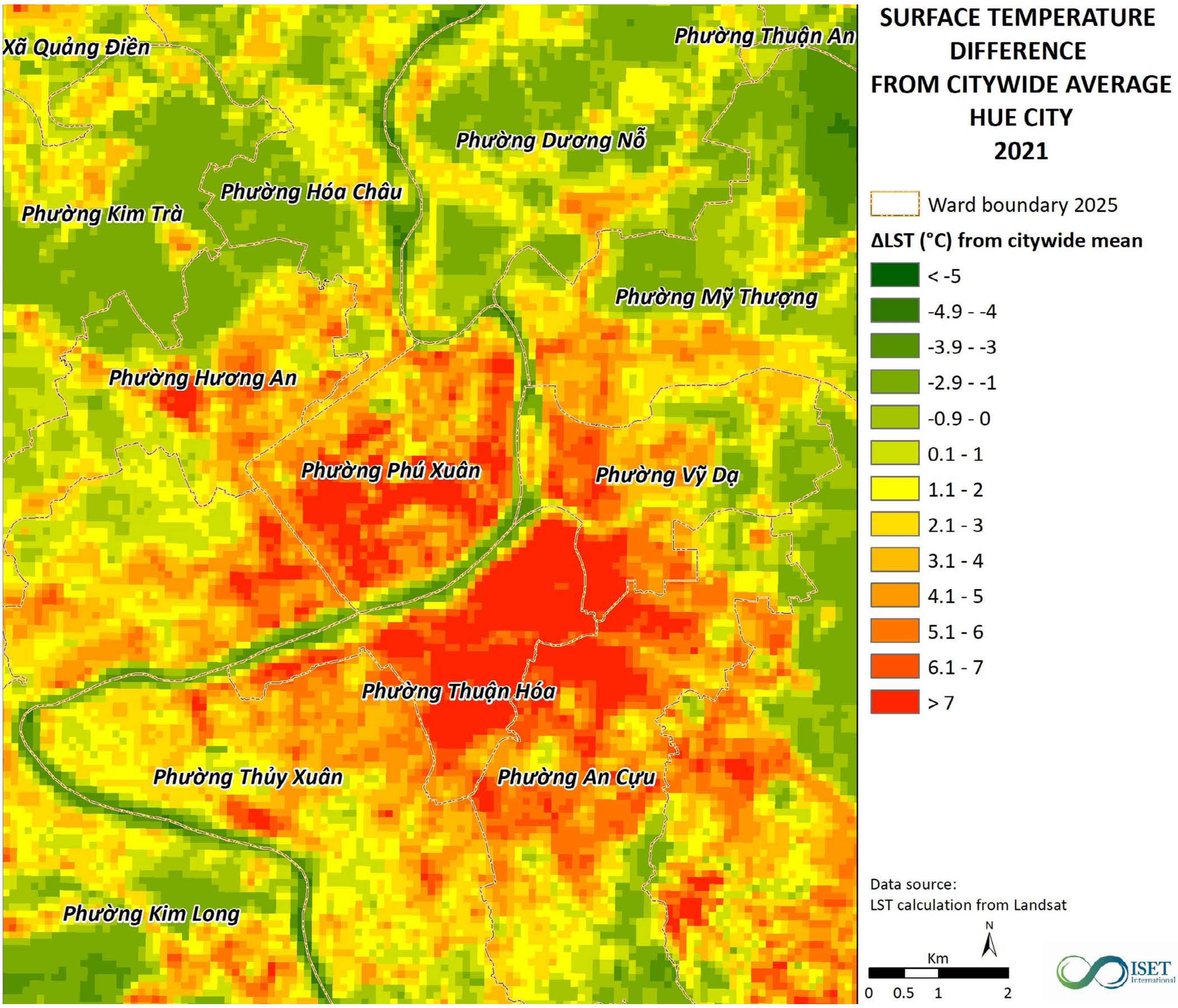
The map shows:

Red/orange areas: Zones warmer than the city mean (positive ΔLST), with the highest values **(> +7°C)** concentrated in Thuan Hoa, Phu Xuan, and parts of An Cuu and Vy Da.

Yellow areas: Zones near or slightly above the city mean **(0–3°C)**, forming transitional belts around high-ΔLST cores.

Green areas: Zones cooler than the city mean (negative ΔLST), ranging from **−0.9°C to below −5°C**, mainly in peripheral areas and scattered patches within the city.C.

FIGURE 3. Spatial distribution of ΔLST in Hue city in summer of 2021

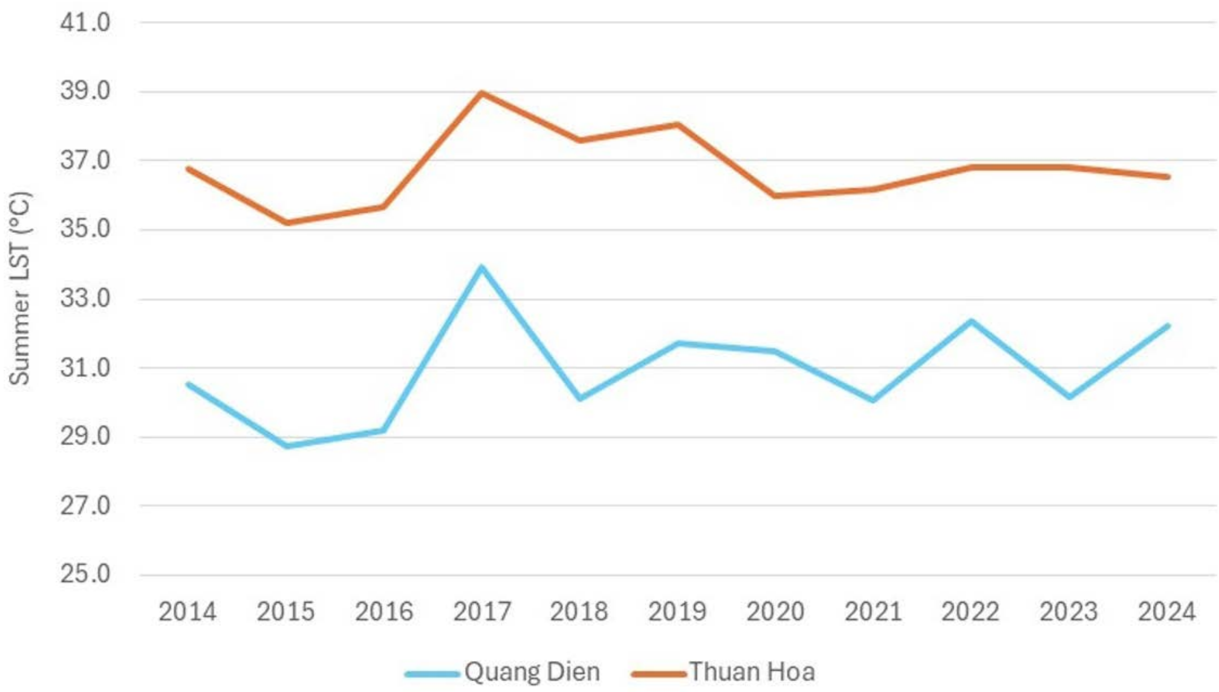


Urban–Rural Temperature Difference

To further specify this overall pattern, the study selected two representative wards between the urban core and rural areas to clearly illustrate differences in thermal regime and the role of green space.

Thuan Hoa Ward was selected to represent the inner-city area, characterized by high population density and extensive impervious surfaces, while Quang Dien Commune represents a rural area that still maintains large proportions of green space and open water. Figure 4 compares summer land surface temperature (LST in April–July) between Thuan Hoa Ward and Quang Dien Commune. The results clearly demonstrate the thermal regulation function of vegetation and the heat stress associated with urbanization.

FIGURE 4. Mean summer land surface temperature of Thuan Hoa Ward and Quang Dien Commune



Quảng Điền (blue line)

- Mean summer temperatures were markedly lower, ranging from 29–33°C .
- Interannual variability was greater than in Thuan Hoa, reflecting dependence on yearly meteorological conditions (rainfall, radiation, wind) as well as diverse surface structures (paddy fields, gardens, ponds, and water bodies).
- This pattern indicates that rural landscapes with extensive vegetation and water surfaces function effectively as a "microclimate buffer," moderating temperature extremes.

Thuận Hóa (orange line)

- Mean summer LST consistently ranged from 36–39°C, remaining stable throughout the entire study period .
- Despite minor interannual fluctuations, Thuan Hoa exhibits a persistently elevated and stable thermal baseline, reflecting an urban environment with limited self-regulation capacity.

The 5-8°C temperature gap between Thuan Hoa and Quang Dien clearly demonstrates the adverse effects of green space loss, which increase mean temperature levels.

Peri-Urban–Rural Temperature Difference

The urban heat island effect is not confined to the historic urban core but shows a clear tendency to expand toward peri-urban areas. To assess the outward spread of urbanization, the study further analyzed An Cuu Ward (new administrative unit, including former An Cuu, An Dong, and An Tay) the fastest urbanizing peri-urban area over the past decade compared with Quang Dien.

An Cuu Ward represents the primary urban expansion zone of Hue City, hosting numerous residential developments, new urban areas, and major infrastructure projects. This makes it particularly suitable for examining temperature changes associated with progressive impervious surface expansion. Figure 5 presents mean summer LST (April–July) for An Cuu and Quang Dien during 2014–2024, highlighting the impact of recent urbanization on local thermal conditions .

- **2014–2016:** In An Cựu, Mean summer temperatures remained around 33°C, indicating a transitional landscape where rural characteristics and green space were still present. While Quảng Điền has a lower thermal background (29–33°C) with flexible interannual variation, supported by dominant green space and water surfaces.
- **2017–2022:** LST increased markedly to 34–37°C, with a peak of nearly 37°C in 2019. This period coincides with record heat years across central Vietnam (2017, 2019) and the rapid development of large-scale urban projects in An Dong and An Tay, which significantly reduced green space.
- **Post-2022:** LST remained elevated (33–35°C), reflecting a persistent high-temperature state driven by continued urban development (e.g., AEON Hue, An Cuu Galleria).
- Over the study period, An Cuu Ward consistently exhibited higher summer LST than Quang Dien Commune, with a persistent difference of 2–4 °C. The stability of this gap indicates systematic land-use and urbanization contrasts rather than short-term variability.

Urban–Peri-Urban Temperature Difference

To more precisely quantify the summer temperature gap between the urban core and peri-urban areas on an annual basis, the study compared the land surface temperature differences of urban core and peri-urban wards relative to the citywide mean summer LST for each year. The results presented in Figure 6 show that the urban core consistently exhibits higher temperatures than the citywide mean and is significantly warmer than peri-urban areas:

FIGURE 5. Annual Mean Summer Land Surface Temperature (April–July) of An Cuu Ward and Quang Dien Commune (2014–2024)

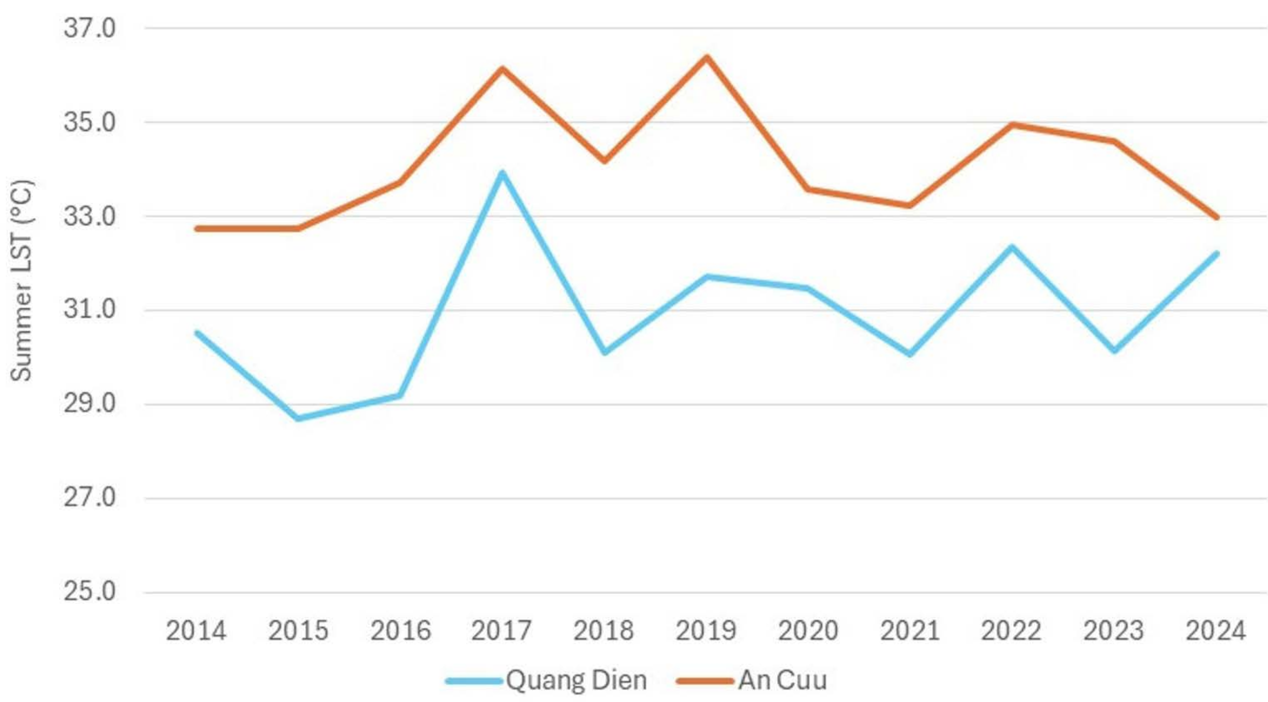
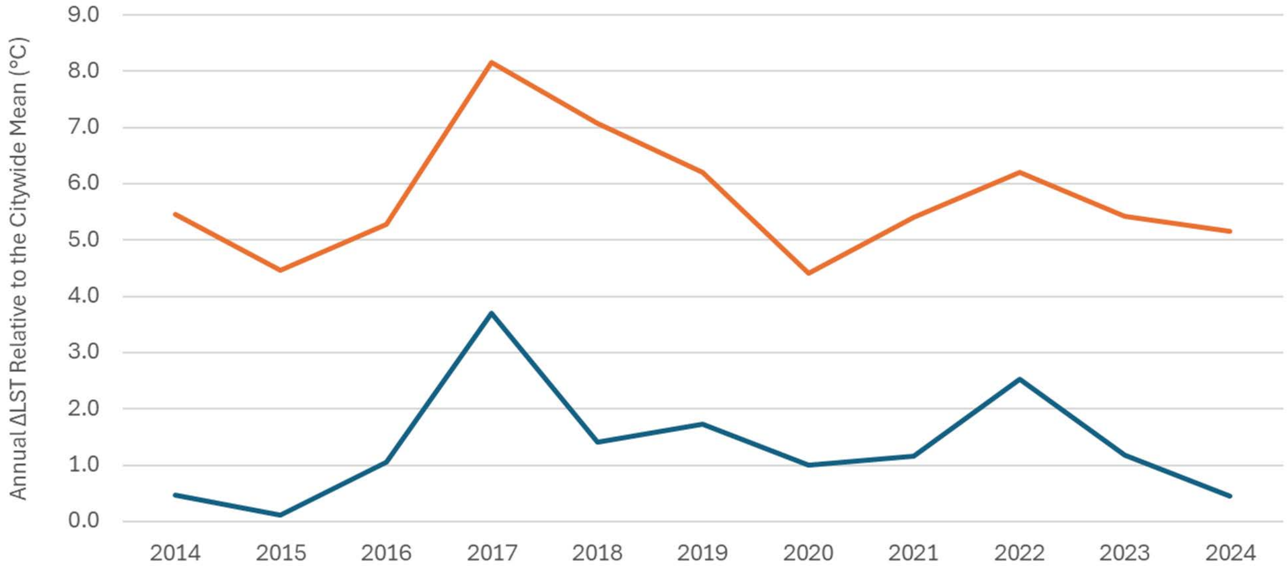


FIGURE 6. Urban core and peri-urban land surface temperature differences relative to the citywide mean summer temperature of Hue City, 2014–2024



Orange line (Urban core)

Represents the mean LST difference of the two central core wards (Phu Xuan and Thuan Hoa) relative to the citywide mean summer LST (April–July) of the same year. As shown in Figure 6, the urban core is consistently warmer than the city mean by approximately 4.5-8 °C and warmer than peri-urban areas by about 3.5-5 °C.

Blue line (Peri-urban)

Represents the mean LST difference of nine peri-urban wards (An Cuu, Duong No, Hoa Chau, Huong An, Kim Long, My Thuong, Thanh Thuy, Thuy Xuan, and Vy Da) relative to the citywide mean LST in the same year. The values are positive in most years (approximately 1-4 °C above the city mean) but remain clearly lower than those of the urban core (orange line).

Overall, the temperature differences among urban core, peri-urban, and rural areas in Hue indicate that the Urban Heat Island (UHI) effect has consistently persisted in the city center over multiple years and is progressively expanding toward rapidly urbanizing peri-urban zones. In contrast, rural areas continue to play a crucial role in moderating the underlying thermal regime. These findings reaffirm that green space is a key factor in mitigating thermal stress and safeguarding public health in the context of ongoing urbanization and climate change.

Hue City, 2023 © Thanh Ngo, ISET

4.3. Localized Impact of Green Space Loss on Land Surface Temperature

To further examine the localized impact of green space loss, a direct comparison of land surface temperature was conducted between areas experiencing green loss and areas without green loss within the same ward and during the same summer of a given year. This approach minimizes the influence of interannual climatic variability.

The land surface temperature difference between green-loss and non-green-loss areas was calculated as follows:

$$\Delta \text{ (Delta)} = LST(\text{green loss}) - LST(\text{non-green loss})$$

Where:

Δ (Delta) *represents the land surface temperature difference*

LST(green loss) *is the mean land surface temperature of areas that experienced vegetation loss*

LST(non-green loss) *is the mean land surface temperature of areas without vegetation loss*

Figures 7 and 8 present mean summer LST and temperature differences between green-loss and non-green-loss areas across 12

FIGURE 7. Mean summer LST and temperature differences between green-loss and non-green-loss areas 2014-2024

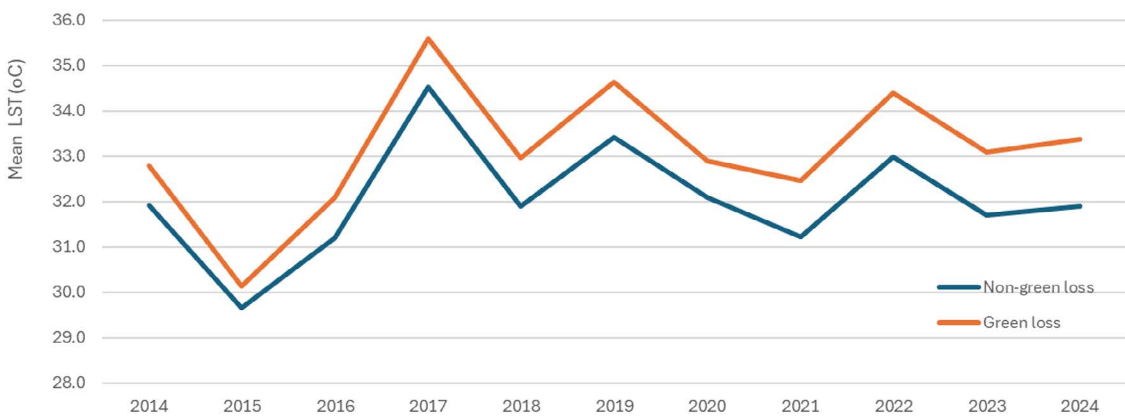
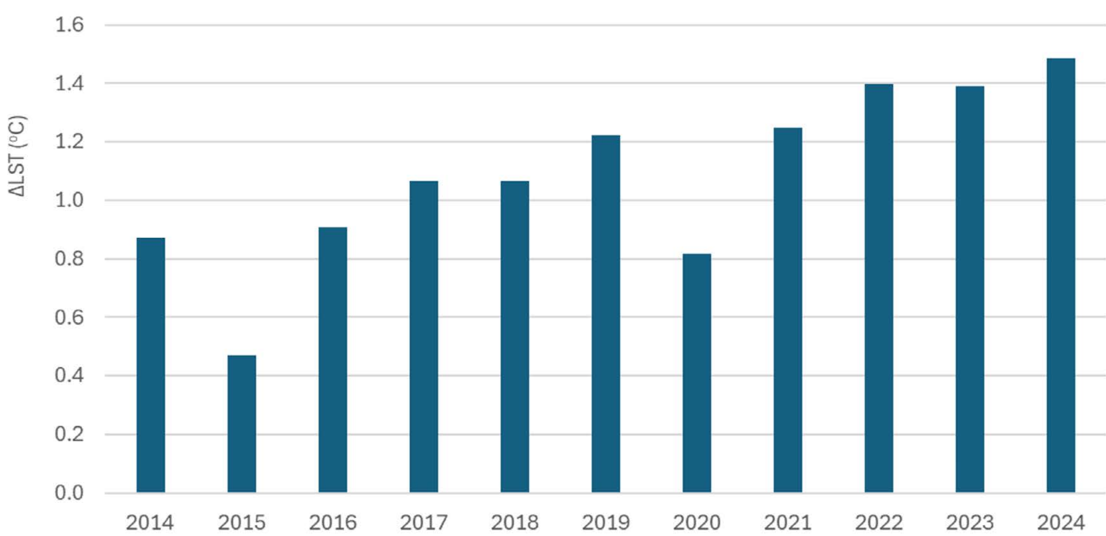


FIGURE 8. Temperature differences between green-loss and non-green-loss 2014-2024



inner-city and peri-urban wards, including An Cựu, Dương Nỗ, Hóa Châu, Hương An, Kim Long, Kim Trà, Mỹ Thượng, Phú Xuân, Thuận An, Thuận Hóa, Thủy Xuân, Vỹ Dạ in period of 2014-2024.

The results indicate that throughout the entire study period, land surface temperature in green-loss areas (ranging from approximately 30.1 °C to 35.7 °C) was consistently higher than in non-green-loss areas (ranging from approximately 29.5 °C to 34.5 °C). Moreover, the temperature difference between these two categories showed an increasing trend after 2020 and remained elevated toward the end of the study period. The highest difference was recorded in 2024 (1.49°C), suggesting that the impact of green space loss on surface temperature increase has become increasingly significant.

> In summary, comparisons conducted within the same summer season and within the same administrative units indicate that areas experiencing green space loss consistently exhibit higher land surface temperatures than areas that maintain vegetation cover. By controlling for the same year of observation, this approach minimizes the influence of interannual climatic variability, thereby clearly confirming the localized and direct impact of green space loss on increasing urban thermal conditions. However, this difference is not only reflected in mean temperature levels but also in the persistence and variability of thermal conditions over time, which are examined in greater detail in the following section.

An Dong ward, Hue City, 2025 © Thanh Ngo, ISET

4.4. Role of Maintained Green Cover in Temperature Variability

In addition to differences in mean temperature, another important characteristic of the urban thermal environment is the degree of stability or variability of thermal conditions over time. This section examines differences in temperature variability regimes between green-loss and non-green-loss areas in order to clarify the role of green space in microclimate regulation and in mitigating prolonged heat stress.

To evaluate these aspects, the study compares two variability indicators-standard deviation (Std) and thermal range (Range) between green-loss and non-green-loss groups. Low Std and Range values combined with high baseline temperatures indicate persistently hot and relatively uniform conditions, characteristic of highly impervious urban surfaces. In contrast, higher Std and Range values occurring under lower overall temperature levels reflect greater thermal dispersion, typically associated with more heterogeneous surface structures (intermixed vegetation, water bodies, and built surfaces), which enhance thermal regulation.

The analysis covers 12 urban core and peri-urban wards: An Cuu, Duong No, Hoa Chau, Huong An, Kim Long, Kim Tra, My Thuong, Phu Xuan, Thuan An, Thuan Hoa, Thuy Xuan, and Vy Da.

Temperatures were compared between two groups:

Non-green-loss areas
Areas without recorded vegetation decline, typically characterized by a mixture of green spaces and built surfaces.

Green-loss areas
Areas where vegetation cover has declined and built surfaces have become more homogeneous.

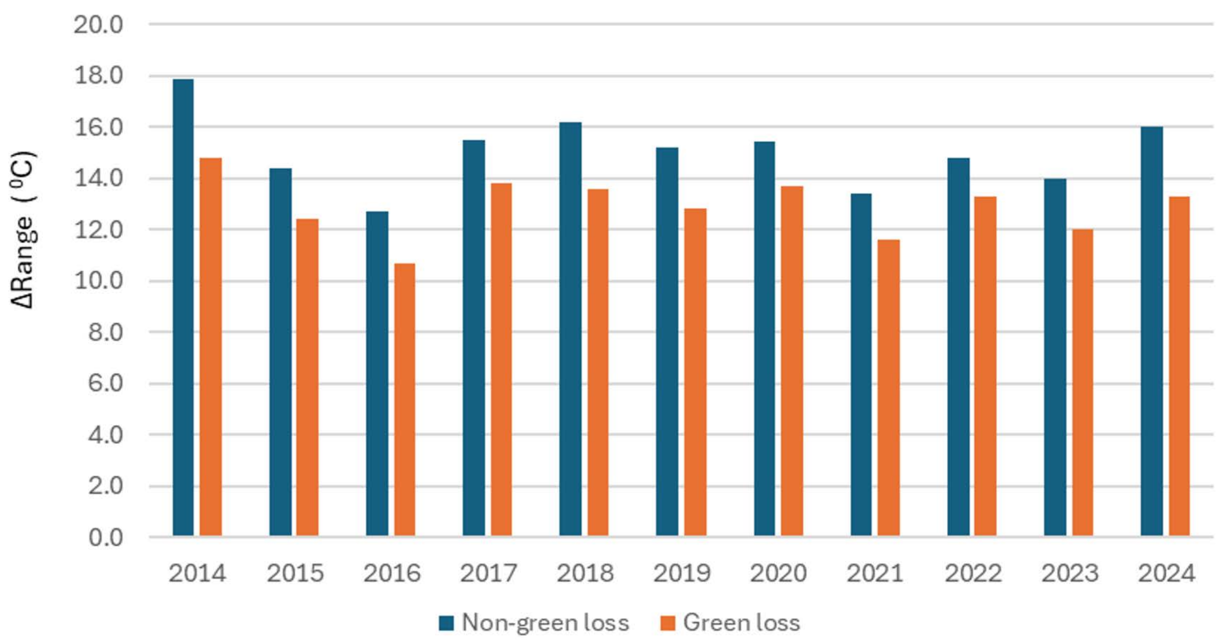
Comparison of Thermal Range

Figure 9 presents the thermal range (Range), defined as the difference between the maximum and minimum mean summer surface temperature within the same year across the 12 wards (Range= Max (LST summer) – Min (LST summer)). A larger range indicates a greater difference between the highest and lowest surface temperatures within the same year for either the green-loss or non-green-loss group.

As shown in Figure 9, the thermal range of the non-green-loss group is consistently higher than that of the green-loss group throughout the 2014–2024 period. The difference in range between the two groups varies approximately from 1.5 to 3.0 °C, indicating a stable and recurring pattern rather than isolated year-specific anomalies.

This suggests that, within the same year, temperature contrasts between the hottest and coolest locations are more pronounced

FIGURE 9. Annual summer thermal range during the period 2014–2024



in non-green-loss areas. This pattern is associated with greater surface heterogeneity and the coexistence of vegetation, water bodies, and built surfaces, which enhance thermal dispersion and microclimate regulation.

In contrast, the narrower thermal range observed in green-loss areas indicates more persistent and spatially uniform high temperatures. This pattern is characteristic of highly urbanized environments where extensive impervious surfaces and limited green or water areas reduce the capacity for effective microclimate regulation.

Comparison of Standard Deviation

The standard deviation (Std) reflects the degree of dispersion of land surface temperature values among areas within the same group around the group mean in a given year. A higher Std indicates greater variability around the mean. The standard deviation was calculated as follows:

$$\text{Std} = \sqrt{\frac{\sum_{i=1}^{n}(x_i - \bar{x})^2}{n}}$$

trong đó:

xi: is the mean summer land surface temperature (LST) of area i within either the green-loss or non-green-loss group.

x¯ is the mean land surface temperature of all areas within the same group in the same year.

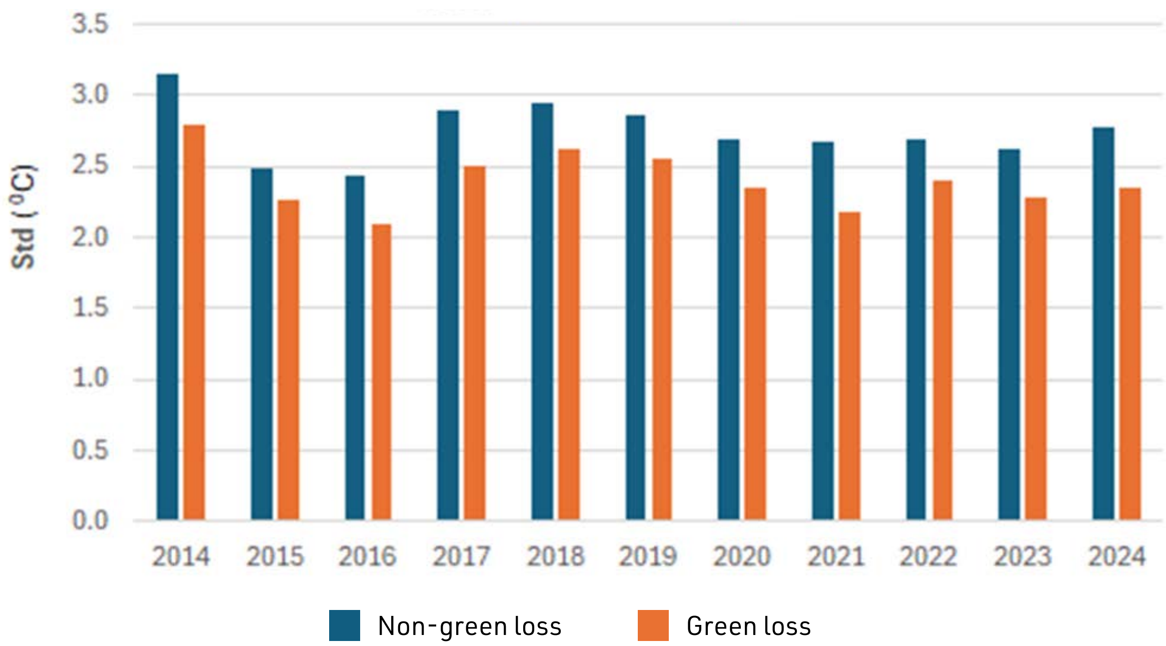
n is the number of areas in the green-loss or non-green-loss group

The results are presented in Figure 10. For all years during the 2014–2024 period, the non-green-loss group consistently exhibited higher summer Std values than the green-loss group. Specifically, the Std of the non-green-loss group ranged from 2.4 °C to 3.2 °C, whereas the green-loss group varied between 2.1 °C and 2.9 °C.

According to the results presented in Section 4.3, the mean land surface temperature of green-loss areas and highly urbanized urban-core zones consistently exceeds that of non-green-loss and rural areas across all years. When combined with the lower thermal range and standard deviation observed in green-loss areas, these findings indicate that zones experiencing significant green space decline where impervious surfaces dominate, maintain persistently high surface temperatures and exhibit limited climate-regulating capacity. Such environments are characterized by prolonged and more intense heat exposure, posing elevated health risks to residents.

In contrast, the non-green-loss group shows higher standard deviation and thermal range values, reflecting greater temperature variability but under lower overall thermal conditions. This pattern is associated with the moderating effects of vegetation and water bodies, which enhance thermal regulation and reduce heat stress on local communities.

FIGURE 10. Standard Deviation of land surface temperature values (2014–2024)



5. Conclusions and Recommendations

Conclusions

The analysis of mean summer land surface temperature (April–July) during the 2014–2024 period reveals a clear impact of green space loss on urban thermal characteristics in Hue City, as follows:

1

Significant decline in green space

Green coverage in Hue City decreased substantially between 2014 and 2024, particularly in central and peri-urban wards experiencing rapid urbanization. This decline has altered the urban surface structure.

2

Expansion of the UHI effect toward peri-urban areas

The case of An Cuu Ward demonstrates a rapid transition from relatively moderate temperatures to persistently high thermal conditions after 2020. This pattern indicates that urban expansion have contributed to the outward spread of thermal hotspots beyond the historical urban core.

3

Persistent and stable Urban Heat Island (UHI) effect

Urban core areas (e.g., Phu Xuan, Thuan Hoa) and peri-urban zones consistently exhibited higher temperatures than the citywide mean by approximately 4-8 °C and 1-4 °C, respectively, while rural areas maintained lower or near-mean temperatures. These differences clearly reflect the influence of urbanization and surface structure on thermal conditions.

4

Higher temperatures in green-loss areas

Within-year comparisons show that green-loss areas consistently recorded higher surface temperatures than non-green-loss areas. The temperature difference became more pronounced after 2020, reaching approximately 1.5 °C in 2024. This confirms that green space decline is a key driver of increasing urban thermal levels, with the trend becoming increasingly stable and evident over time.

5

Adverse effects of green space loss on thermal regimes

Analysis of thermal range and standard deviation indicates that green-loss areas exhibit lower variability but consistently high and spatially uniform temperatures, characteristic of prolonged heat exposure and limited microclimate regulation capacity. In contrast, non-green-loss areas show higher thermal variability under lower overall temperature levels, reflecting the moderating effects of vegetation and water bodies in dispersing and regulating heat.

Rural area in Hue City, 2025
© Tho Nguyen, ISET

Although this study focuses on land surface temperature rather than air temperature, the consistent time-series analysis and controlled within-year comparisons provide a reliable basis for identifying urban thermal trends in Hue City. The findings confirm that protecting and expanding green space is essential not only for reducing mean temperatures but also for maintaining microclimate balance and mitigating urban heat risks amid ongoing urbanization and climate change.

Recommendations

Based on the findings regarding green space decline and urban thermal dynamics in Hue City, the following recommendations are proposed under three pillars: **Planning – Data – People**, aiming to reduce heat risks, enhance climate adaptation, and strengthen urban resilience.

PLANNING

Shaping a Heat-Responsive Urban Structure

1

Prioritize protection of remaining green spaces

Remaining green areas in rapidly urbanizing wards (e.g., Phu Xuan, Thuan Hoa, An Cuu, Vy Da, Huong An) should be designated as critical green zones in land-use planning, with restrictions on conversion to built-up land. This preventive measure is essential to control further increases in urban heat.

2

Systematic integration of green infrastructure

Green infrastructure solutions such as pocket parks, green corridors, street trees, urban ponds, and water bodies should be systematically incorporated into urban plans and new development projects, particularly in fast-growing peri-urban areas. Priority should be given to distributing green spaces as interconnected networks to disperse thermal hotspots rather than concentrating solely on large parks.

3

Use of thermal hotspot maps in planning decisions

Surface temperature and green space loss analyses should be integrated into urban planning review and adjustment processes to identify areas requiring building density control or additional green space allocation.

DATA

Monitoring and Early Warning

1

Establish an urban heat monitoring system

Develop a network of temperature and humidity sensors in key urban and peri-urban locations, linked to the Hue-S digital platform, to support heat early warning, evaluate green infrastructure effectiveness, and inform climate risk management.

2

Periodic monitoring of green space and thermal conditions

Implement regular (annual or biennial) monitoring of green space, water bodies, and surface temperature using remote sensing to track trends, identify emerging thermal hotspots, and support adaptive policy adjustments.

3

Standardization and integration of thermal–green data

Observational and remote sensing datasets should be standardized, integrated, and shared across relevant agencies to establish a unified evidence base for urban climate risk management.

People – Institutions – Community

1

Integration with climate adaptation and disaster risk strategies

Extreme heat adaptation should be incorporated into the city's Climate Change Adaptation Plans and Disaster Risk Management strategies. Thermal hotspot and green-loss analyses should guide the identification of vulnerable areas and prioritization of green infrastructure investments.

2

Public health and community support measures

Implement targeted health support measures in densely built areas with significant green loss and persistent high temperatures. Potential actions include heat early warning systems, public cooling shelters, and expanded tree canopy coverage around schools and healthcare facilities. Priority should be given to vulnerable groups such as the elderly, children, and outdoor workers.

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