The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences, Volume XLVIII-M-5-2024
ASPRS 2024 Annual Conference at Geo Week, 11–13 February 2024, Denver, Colorado, USA and 21–24 October 2024 (virtual)

Mapping the Spatial Distribution of Urban Heat Island in Scotlandville in the Louisiana State of USA using Satellite Remote Sensing

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Keywords: Normalized Difference Vegetation Index (NDVI), Urban Heat Island (UHI), Remote sensing, Land Surface Temperature (LST), Land cover change

Abstract

Urban Heat Island (UHI) is a phenomenon where urban areas experience higher temperatures than their surrounding rural areas due to human activities and the presence of heat-absorbing materials such as concrete and asphalt. This study aims to map the spatial distribution of UHI in Scotlandville, a neighbourhood in Baton Rouge, Louisiana, using satellite remote sensing approach. Landsat 9 imagery was used to compute the Normalized Difference Vegetation Index (NDVI) and Land Surface Temperature (LST) to extract the urban heat islands and greenspaces within the study area. The results revealed the spatial distribution of UHI across Scotlandville, where 1635 ha of the total area were urban heat islands, representing 64% of the total study area. These findings provide substantial information for urban planning and development policies aimed at mitigating the impact of UHI on local climate and public health. Moreover, this study informs the health and vitality status of the greenspaces and calls for action to plant more trees and properly care for existing ones, as the current state of these greenspaces is insufficient to improve urban resilience and liveability in Scotlandville.

1. Introduction

1.1 Understanding the Urban Heat Island Effect in Scotlandville: Implications for Climate Resilience and Sustainable Urban Planning

Urbanization, as a hallmark of modern development, has brought about various changes to land cover, particularly with the conversion of natural landscapes into built-up environments (Izakovičová et al., 2021). One significant consequence of urbanization is the Urban Heat Island (UHI) effect, a phenomenon where urban areas exhibit higher temperatures compared to surrounding rural regions (Vujovic et al., 2021). This effect is primarily driven by human activities and the proliferation of materials like concrete, asphalt, and metal surfaces, which absorb, retain, and re-radiate heat more intensely than natural landscapes. Urban structures and materials not only increase surface temperatures but also disrupt the natural cooling effects provided by vegetation and water bodies. As urban populations continue to grow globally, addressing the UHI effect has become a critical issue, impacting both urban sustainability and public health (Osei et al., 2023).

Scotlandville, a neighbourhood within Baton Rouge, Louisiana, exemplifies many characteristics associated with UHIs. Baton Rouge's humid subtropical climate intensifies the effects of urban heat, leading to high daytime temperatures and limited night-time cooling (WBRZ, 2024). In Scotlandville, these conditions are compounded by the relatively sparse vegetation and the dense presence of impermeable surfaces. Consequently, Scotlandville faces an increased vulnerability to the impacts of UHI, including heightened energy demands, deteriorated air quality, and exacerbated public health risks, particularly among vulnerable populations such as the elderly and low-income communities (WBRZ, 2024).

Satellite remote sensing has proven to be a valuable tool in studying and mapping UHI, as it offers cost-effective, comprehensive, and temporally consistent data coverage across vast areas (Zargari et al., 2024). Specifically, satellite-based thermal infrared data allow for the estimation of Land Surface Temperature (LST), a critical metric in assessing surface heat variations within urban environments (Osei et al., 2023). Furthermore, the Normalized Difference Vegetation Index (NDVI), derived from multispectral satellite imagery, serves as a proxy for vegetation health and density, enabling the identification of greenspaces within urban landscapes (Gascon et al., 2016). This study employs data from Landsat 9, a satellite mission that provides high-resolution thermal and multispectral data, to map the spatial distribution of UHIs in Scotlandville by calculating LST and NDVI values. Integrating these indices, this study seeks to distinguish urban heat islands from greenspaces, offering insights into the influence of land cover patterns on UHI intensity and distribution.

1.2 Using Satellite Remote sensing for UHI analysis

Urban heat islands (UHIs) are characterized by higher temperatures in urban areas compared to surrounding non-urban regions. Satellite remote sensing, particularly using Landsat data, has proven effective in mapping UHIs by deriving land surface temperatures (LSTs) (Ngie et al., 2014; Alhawiti & Mitsova, 2016). Studies have shown that areas with high-density residential and commercial development, along with impervious surfaces like parking lots, exhibit the highest LSTs using satellite images (Osei et al., 2023; Alhawiti & Mitsova, 2016). Conversely, coastal areas, water bodies, and regions with greater vegetation cover tend to have lower LSTs (Alhawiti & Mitsova, 2016). The integration of remote sensing data with GIS has enabled the creation of detailed UHI maps, which can inform urban planning and mitigation strategies (Quattrochi et al., 2000; Osei et al., 2023). These strategies aim to reduce UHI

effects, potentially improving air quality and creating more comfortable urban environments (Quattrochi et al., 2000).
Based on the application of remote sensing technique which has made UHI studies feasible, the objectives of this study have been defined in twofold: first, to identify the spatial extent of urban heat islands in Scotlandville, and second, to evaluate the status of greenspaces within the study area using satellite remote sensing. The findings are expected to serve as a resource for urban planners, public health officials, and policymakers aiming to mitigate the UHI effect through strategic urban greening, tree planting, and sustainable development practices. Addressing UHI not only improves urban resilience but also promotes environmental justice by enhancing the quality of life for residents, reducing health risks, and fostering more equitable urban landscapes.

2. Research Methodology

2.1 Study Area: Scotlandville, Baton Rouge, Louisiana State, USA

Scotlandville (Figure 1) is a historic neighbourhood located in northern Baton Rouge, Louisiana, within East Baton Rouge Parish. Covering approximately 25 square miles, it is known for being the site of Southern University and A&M College, one of the largest historically Black colleges and universities (HBCUs) in the United States (Scotlandville, 2015). Southern University's 964-acre campus includes extensive greenspaces, which stand in contrast to the densely built urban areas surrounding the campus. The area has a population of around 12,000 people and faces socioeconomic challenges, with 26% of residents living below the poverty line and an unemployment rate of approximately 11%, both above national averages. Scotlandville's population is predominantly African American, with more than 85% of residents identifying as Black or African American (Scotlandville, 2015).
The neighbourhood is bisected by major infrastructure, including U.S. Highway 61 (Scenic Highway) and Interstate 110, which contribute to high traffic volumes and increased impervious surfaces that exacerbate the Urban Heat Island (UHI) effect. Industrial zones and transportation corridors in Scotlandville further compound this effect, with many areas containing heat-retaining surfaces such as asphalt and concrete. The combination of these factors leads to significant temperature differences between Scotlandville and its surrounding rural or less densely built areas.
The local climate is classified as humid subtropical (Köppen classification Cfa), with average summer temperatures frequently exceeding 90°F (32°C), and high humidity levels (Rahmani & Sharifi, 2024). The effects of UHI are particularly pronounced in this type of climate, where limited night-time cooling can impact public health and energy consumption.
Scotlandville's greenspaces are distributed unevenly, with the Southern University campus and surrounding parks serving as some of the primary cooling zones within the area. However, due to urban development pressures, greenspace coverage in the neighbourhood is estimated to be below 25%, insufficient to counteract the urban heat absorbed by impervious surfaces (Rahmani & Sharifi, 2024).

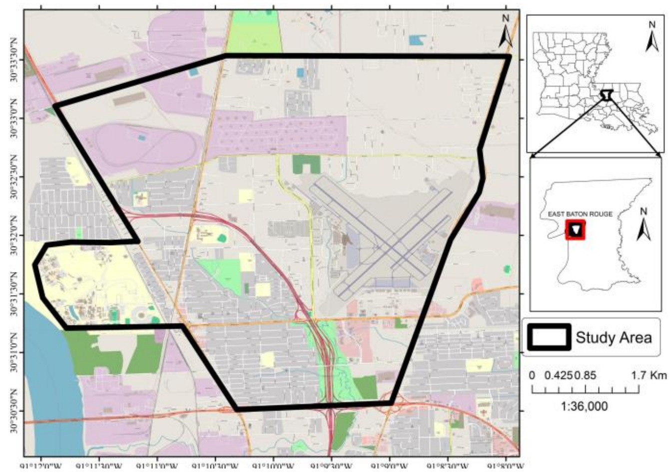

Figure 1. A Map of Scotlandville

2.2 Materials and Data Used

This study used multiple datasets and tools to analyse the Urban Heat Island (UHI) effect in Scotlandville, Baton Rouge, Louisiana. The primary dataset was Landsat 9 Level 2 imagery, sourced from the U.S. Geological Survey (USGS) Earth Explorer platform. Landsat 9 imagery provided high-resolution satellite data critical for deriving Land Surface Temperature (LST) and Normalized Difference Vegetation Index (NDVI), both essential for assessing spatial temperature variations and vegetation cover across Scotlandville. The Level 2 imagery underwent pre-processing for atmospheric correction, which enhanced the accuracy of LST and NDVI calculations and ensured reliable detection of UHI zones. To perform spatial analysis, data processing, and mapping, the study utilized ArcGIS 10.4, developed by ESRI. ArcGIS facilitated data visualization, enabled geospatial analysis, and supported mapping of UHI intensity and greenspaces within the study area. Additionally, its geospatial tools allowed efficient data integration and provided an effective platform for presenting spatial patterns and insights into UHI distribution across Scotlandville. Together, these data and tools provided a comprehensive framework for analysing UHI and identifying priority areas for potential mitigation strategies. The datasets and materials used in this study are elaborated in Table 1 with their sources.

Material/data	Source
Landsat 9 level 2 imagery	USGS Earth explorer
ArcGIS 10.4	ESRI

Table 1. Materials and Data Used

2.3 Data Processing and Analysis

This study employed a systematic data processing approach (Figure 2) to examine the Urban Heat Island (UHI) effect in Scotlandville, Baton Rouge, Louisiana, utilizing Landsat 9 satellite imagery. The analysis involved calculating two key indices: Land Surface Temperature (LST) and Normalized Difference Vegetation Index (NDVI), each providing insights into the thermal and vegetative properties of the urban landscape.

2.3.1 Land Surface Temperature (LST) Calculation

The LST was derived from the thermal infrared (TIR) Band 10 of Landsat 9 Level 2 imagery. This band captures thermal radiation emitted by surface materials, making it suitable for calculating surface temperatures. Initially, the raw thermal data was corrected for atmospheric interference to enhance accuracy. This correction helped account for atmospheric effects such as water vapor and aerosols that can distort the true temperature readings of the Earth's surface.

After pre-processing, LST values were calculated to map temperature variations across Scotlandville. The spatial distribution of LST highlighted areas with elevated surface temperatures, indicative of urban heat islands. Higher LST values were expected in densely developed regions with minimal vegetation, due to the presence of heat-retaining surfaces like concrete, asphalt, and buildings. This LST mapping laid the foundation for identifying and quantifying UHI zones within the study area.

2.3.2 Normalized Difference Vegetation Index (NDVI) Calculation

To assess vegetation cover and health, NDVI was calculated using the red and near-infrared (NIR) bands of Landsat 9. The NDVI is an established index for quantifying vegetation density, with values ranging from -1 to +1. Higher NDVI values indicate healthy, dense vegetation, while lower values correspond to sparse or degraded vegetation (De La Iglesia Martinez & Labib, 2022).

The NDVI formula is as follows:

$$NDVI = NIR – RED / NIR + RED \quad (1)$$

where "NIR" and "RED" represent the near-infrared and red reflectance values, respectively. In this study, NDVI values were calculated for each pixel in the Landsat imagery, enabling the identification of greenspaces across Scotlandville. This was crucial for understanding the distribution of vegetated areas and assessing their potential role in mitigating the UHI effect.

2.3.3 UHI and Greenspace Extraction

With the LST and NDVI values computed, a thresholding method was applied to distinguish UHI zones and greenspaces within the study area. The threshold values for UHI and NDVI were determined based on statistical parameters: mean (μ) and standard deviation (σ) to ensure consistent classification. Specifically, the threshold was set Using equation 2.

$$Threshold = \mu + (0.5\times\sigma) \quad (2)$$

Following the approach from Osei et al. (2023), this threshold formula allowed for the identification of areas with significantly high surface temperatures as UHI zones and regions with substantial vegetation as greenspaces.

UHI Extraction: Pixels with LST values above the threshold were classified as UHI areas, representing urban zones with elevated temperatures due to minimal vegetation cover and high concentrations of impervious surfaces.

Greenspace Extraction: NDVI values above the threshold were used to identify greenspaces, highlighting areas with dense vegetation. These greenspaces were essential in mitigating the UHI effect and improving urban resilience.

2.3.4 Analysis and Interpretation

The spatial patterns of UHI and greenspaces (Figure 3 and Figure 5) were then analysed to understand the distribution of temperature variations and vegetation across Scotlandville. The results indicated that a percentage of the total area of Scotlandville, were classified as UHI zones, while the remaining areas comprised greenspaces and lower-temperature zones. This spatial distribution provided insight into the extent of urban heat in Scotlandville and underscored the importance of vegetation in reducing heat accumulation.

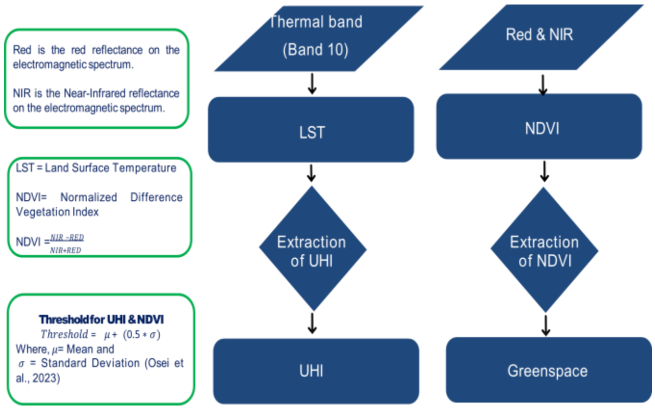

Figure 2. Conceptual framework of the study

3. Results and Discussion

The study reveals that 652 hectares, representing 25% of the total area in Scotlandville, are designated as greenspaces as shown in Figure 3. These greenspaces include parks, open fields, and areas with tree cover that contribute to cooling effects through shading and evapotranspiration. The area was classified as a greenspace if its value is ≥ 0.366 of NDVI, indicating a presence of vegetation cover sufficient to moderate temperatures (Osei et al., 2023). This relatively low percentage of greenspace highlights an imbalance in land use, particularly when contrasted with urbanized zones, which occupy a significant portion of the landscape.

Furthermore, a substantial 1635 hectares of Scotlandville, or 64% of the total area, qualify as Urban Heat Island (UHI) zones, where land surface temperatures consistently reach or exceed 27°C as shown in Figure 5. Temperature measurements across these UHI areas ranged from 20°C to 37°C (68°F to 98.6°F), underscoring the considerable thermal stress within the city. The prevalence of UHI can be attributed to extensive urbanization, which has reduced greenspace coverage and led to increased surface temperatures (Mohajerani et al., 2017; Harmay & Choi, 2023). The data suggest a strong correlation between the density of built-up areas and elevated temperatures, likely due to the use of heat-retaining materials like concrete and asphalt that exacerbate heat absorption and delay heat release (Harmay & Choi, 2023).

Within the UHI zones, temperatures were observed to span from 27°C to 37°C, with the highest readings concentrated in areas with dense infrastructure and minimal vegetation (Figure 3 and Figure 5). Built-up areas exceeding 25% of the total land surface in Scotlandville contribute significantly to the UHI effect. Buildings, roads, and other impervious surfaces absorb solar radiation and retain heat, releasing it slowly and thus keeping temperatures elevated, especially during the night. These areas lack the natural cooling benefits provided by trees and vegetation, such as shading and water transpiration, leading to localized high temperatures and creating uncomfortable conditions for residents (Wang et al., 2024).

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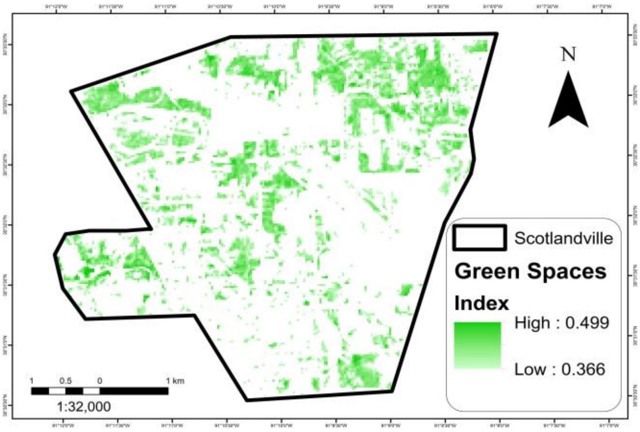

Figure 3. Spatial distribution of Green Spaces in Scotlandville

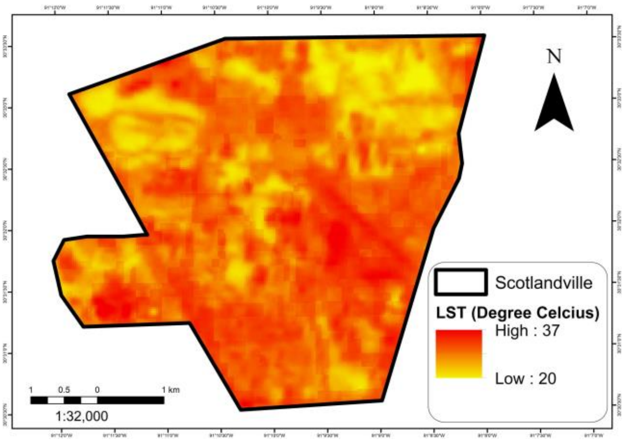

Figure 4. LST in Scotlandville

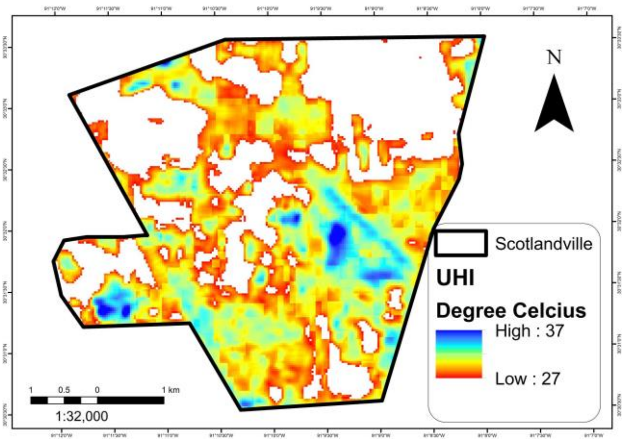

Figure 5. UHI in Scotlandville

3.1 Impact of UHI on Public Health and Urban Liveability

Figure 5 indicates that the UHI effect has considerable implications for public health and urban quality of life. Higher ambient temperatures are linked to increased risks of respiratory and cardiovascular ailments, which can disproportionately affect vulnerable populations, including children, the elderly, and individuals with pre-existing health conditions (Piracha & Chaudhary, 2022). Persistent exposure to high temperatures (Figure 4 and Figure 5), as observed in UHI zones, can increase rates of heat-related illnesses, particularly during warmer seasons. Residents in these areas are likely to experience discomfort and reduced well-being, as well as increased utility costs associated with air conditioning and cooling (Piracha & Chaudhary, 2022).

3.2 Role of Greenspaces in Mitigating UHI

Greenspaces play an essential role in counteracting the UHI effect (Figure 5). Vegetated areas (Figure 3) help moderate temperatures through two main processes: shading, which reduces the amount of solar radiation that reaches the ground, and evapotranspiration, where plants release water vapor that cools the air (Kumar et al., 2024). However, with only 25% of Scotlandville's area designated as greenspace (Figure 3), the capacity of these areas to mitigate heat is limited. The loss of tree cover and reduction in greenspaces have contributed to an intensification of the UHI effect (Figure 5), as urban infrastructure now outpaces green infrastructure. Expanding greenspaces, as well as protecting existing vegetated areas, is essential for enhancing Scotlandville’s resilience to temperature increases (Kumar et al., 2024).

3.3 Need for Sustainable Urban Planning and Policy Interventions

To address the growing impact of UHI, it is critical for Scotlandville to adopt targeted urban planning and policy measures. Expanding and preserving greenspaces (Figure 3) would provide a buffer against rising temperatures (Figure 4) and improve air quality. Measures to increase tree cover, incorporate more green roofs, and use heat-reflective building materials could be instrumental in reducing UHI. Urban planning policies should aim to balance development with environmental sustainability, prioritizing greenspace creation, and maintenance to support the long-term health and comfort of residents (Kruize et al., 2019).
Policy interventions could include incentives for building green roofs, establishing community gardens, and creating shaded walking paths. Encouraging the use of lighter-coloured, reflective materials for road and building surfaces can also help reduce heat retention. Additionally, increasing public awareness about the benefits of greenspaces and sustainable practices can foster community support for these initiatives (Kruize et al., 2019).

4. Conclusion

This study has presented a detailed spatial analysis of Urban Heat Island (UHI) distribution in Scotlandville, Louisiana, utilizing satellite remote sensing to map temperature variations across the area. The findings reveal that UHI zones occupy a substantial 64% of Scotlandville, with temperatures in these areas ranging from 27°C to 37°C (80.6°F to 98.6°F). This high percentage underscores the intensity of urban heat accumulation, driven largely by dense infrastructure, limited vegetation, and heat-retentive surfaces like asphalt and concrete.

Greenspaces, representing only 25% of the total area, are essential in moderating urban temperatures through shading and evapotranspiration. However, the limited presence of these greenspaces restricts their effectiveness, contributing to elevated surface temperatures in urbanized areas. This imbalance between built-up areas and vegetative cover has led to a significant UHI effect, impacting public health, energy demand, and overall urban liveability. Vulnerable groups, such as the elderly and individuals with health conditions, face heightened risks due to prolonged exposure to high temperatures.

https://doi.org/10.5194/isprs-archives-XLVIII-M-5-2024-9-2025

The results underscore an urgent need for urban planning interventions to counteract UHI impacts and foster a more sustainable, resilient environment in Scotlandville. Expanding greenspaces, protecting existing tree cover, and incorporating heat-mitigating infrastructure, such as green roofs and reflective building materials, will be critical. By prioritizing these measures, Scotlandville can reduce the UHI effect, improve air quality, lower energy demands, and enhance the well-being of its residents.

Finally, this study highlights the value of satellite remote sensing in effectively mapping and understanding UHI patterns at a local scale. Future work should continue to leverage geospatial technologies to monitor UHI dynamics over time, informing targeted policies that balance urban growth with ecological sustainability. Through proactive urban planning and the integration of greenspace expansion, Scotlandville can mitigate rising temperatures and promote a healthier, more liveable urban environment for its community.

Acknowledgements

Appreciation to the USDA National Institute of Food and Agriculture (NIFA) McIntire Stennis Forestry Research Program (award number NI22MSCFRXXXG077) for providing financial support through Student Graduate Assistantships. Appreciation to the American Society for Photogrammetry and Remote Sensing (ASPRS) – the Imaging & Geospatial Information Society for providing the student grant award to participate in the Fall 2024 virtual ASPRS International Technical Symposium. The Authors also acknowledge Google earth engine (GEE) and NASA for their open-access data and cloud platform for spatial analysis.

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