

# Identifying and Combatting Micro-Urban Heat Islands in New York City

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## ABSTRACT

In metropolitan areas, significant temperature variations frequently exist between densely built residential zones filled with structures, concrete, and asphalt, and greener neighborhoods with more plant life. These warmer zones are called micro-urban heat islands (MUHIs), and people residing in MUHIs experience a higher incidence of heat-related issues, such as dehydration, heat exhaustion, or even heat stroke. This study mapped the locations of MUHIs in New York City over three clear summer days: June 6, 2023; August 9, 2023; and September 1, 2023. By comparing the surface temperatures of MUHIs to those in parts of a city with more green space, this study demonstrates that MUHIs are more likely to occur where there are high levels of pavement, asphalt, and industrial infrastructure. In contrast, areas in New York City with higher levels of vegetation were less likely to have MUHIs. These results suggest that planting more trees and increasing vegetation in MUHIs in New York City may help to reduce high temperatures.

## Introduction

Climate change has caused increased weather changes worldwide, including higher temperatures in urban areas.<sup>i</sup> In the United States, over 80% of Americans live in cities,<sup>ii</sup> where the built environment contributes to these high temperatures in urban heat islands (UHIs).<sup>iii</sup> UHIs have been shown to have significantly higher temperatures than nearby rural areas.<sup>iv</sup> UHIs primarily result from artificial materials utilized in city construction, which tend to absorb warmth during daylight and gradually emit it at night. The elevated temperatures of urban heat islands are attributed to concrete and asphalt infrastructures such as roads and buildings, the decrease in greenery in metropolitan areas, and the human-induced heat produced by structures, vehicles, and industrial establishments.<sup>v</sup> Urban temperatures fluctuate based on the spatial arrangement of natural surfaces, such as plants, water bodies, and soil, in contrast to nonporous surfaces, such as concrete and asphalt.<sup>vi</sup>

A specific category of urban heat islands, micro-urban heat islands (MUHIs), denotes smaller, distinct regions within metropolitan areas with higher temperatures than their neighboring regions.<sup>vii</sup> By investigating MUHIs in America's largest city<sup>viii</sup>, New York City, it is possible to identify the parts of the city that experience the greatest heat and, consequently, the most significant risks to human and animal well-being.<sup>ix</sup> This analysis will also aid in identifying zones that could benefit from enhanced greenery to mitigate MUHI development.

## Methods

### Study Area

The Area of Interest (AOI) for this MUHI assessment focused on New York City, with the total area used in this classification being the sum of the areas of all land-use types. The city of New York covers an area of approximately 302.6 square miles (783.73 km<sup>2</sup>)<sup>x</sup> and includes a variety of landscapes, ranging from densely populated urban areas to more open natural spaces.

## Data Acquisition from Landsat 8

Temperature readings were acquired through Landsat 8 Collection 2 Level 2 satellite imagery supplied by the United States Geological Survey (USGS). Landsat 8 is equipped with an Operational Land Imager (OLI) sensor and a Thermal Infrared Sensor (TIRS) to assess the visible and thermal infrared electromagnetic radiation bouncing off Earth's surface.<sup>xi</sup> OLI takes images across nine spectral bands, encompassing the visible, near-infrared, and shortwave infrared segments. The TIRS gauges land surface temperature using two thermal infrared spectral bands. The OLI spectral bands 1–7 and 9 possess a spatial resolution of 30 m, signifying that each pixel represents a 30-meter square. Band 8 is a panchromatic band with a spatial resolution of 15 m, which aids in identifying surface temperature discrepancies.<sup>xii</sup> TIRS spectral bands 10 and 11 had a spatial resolution of 100 m, adjusted to 30 m. Landsat 8 catalogs the quantity of reflected light in each spectral band for every 30-meter pixel on a scale of 0 to 255. A numerical figure of 0 indicates no reflected light, and 255 signifies the utmost reflected light.

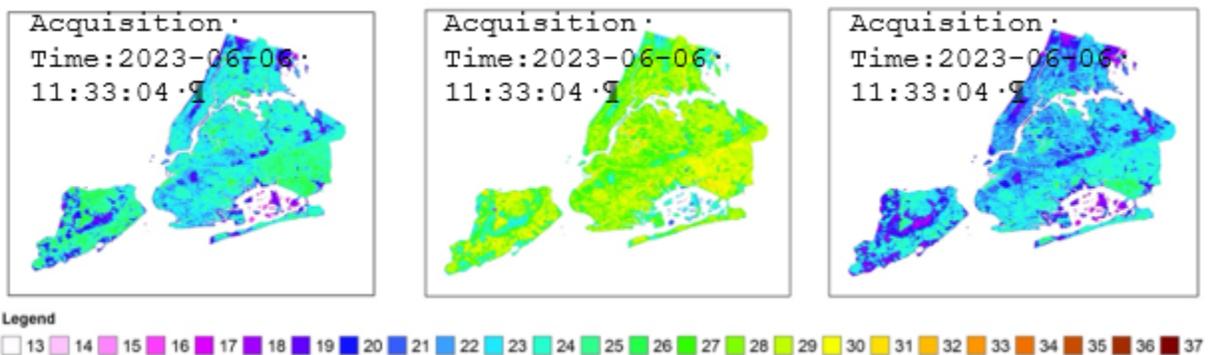
Three images corresponding to warm sunny days without cloud cover were selected – June 6, August 9, and September 1, 2023. We did not use Landsat imagery for July 2023 because of excessive cloud cover, which interfered with our analysis. All images were corrected for terrain, geometric, radiometric, and atmospheric distortions<sup>xiii</sup> and downloaded from the USGS website using the EarthExplorer web-based software tool.<sup>xiv</sup>

## Estimation of Land Surface Temperatures (LSTs)

LSTs enable the detection of regions with temperatures exceeding those of their surrounding environment, such as MUHIs, and were derived using spectral bands 4 and 5 from Landsat 8. These bands facilitated the calculation of the Normalized Difference Vegetation Index (NDVI), a metric that assesses vegetation density by analyzing the reflectance of the visible and near-infrared wavelengths.<sup>xv</sup> NDVI derives the Proportion of Vegetation (PV), which measures the vegetation density within each pixel and subsequently determines Land Surface Emissivity (LSE) based on vegetation proportions. Land Surface Emissivity (LSE) measures how efficiently a surface radiates heat.

Infrared spectral band 10 data were used to calculate the (TOA) reflectance using calibration coefficients. The TOA reflectance was then converted to Brightness Temperature (BT) using Planck's Radiance Function<sup>xvi</sup>, where BT is the temperature derived from infrared energy emitted by the surface.

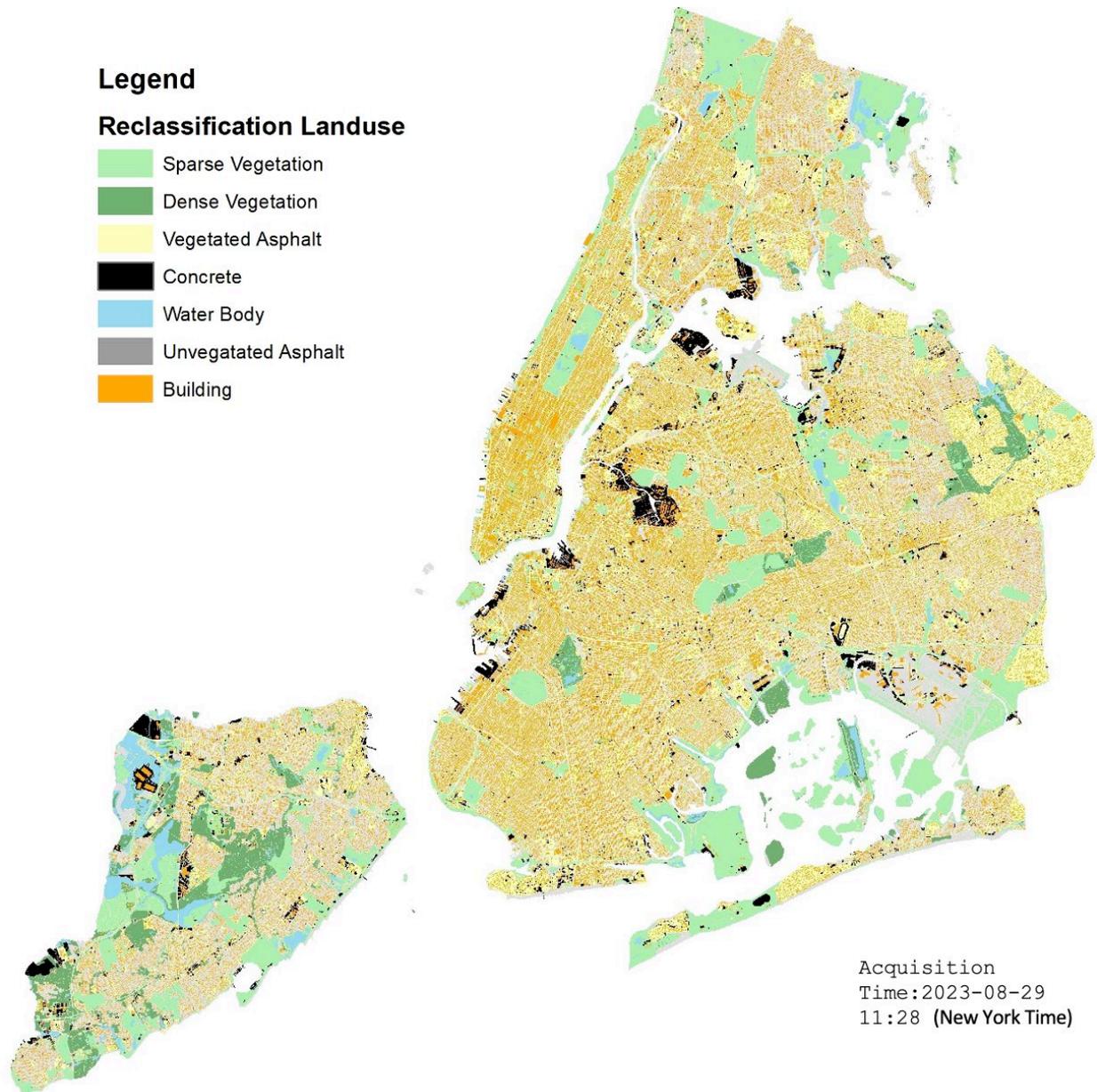
Both LSEs and BTs were used to calculate the LSTs. The LSTs were adjusted by integrating ground-based temperature measurements to ensure the satellite data accurately reflected actual ground temperatures. The adjustment was based on the mean difference between satellite-derived temperatures and ground measurements. GIS mapping software was used to generate the MUHI maps. Figure 1 shows the LSTs for the three images of the study area.



**Figure 1.** Land Surface Temperature (LST) of New York City over Three Days in 2023 – Temperature in Celsius

## Classification of Land Type

The land-use type was classified into the following categories using OpenStreetMap (OSM) data: sparse vegetation, dense vegetation, vegetated asphalt, concrete, water bodies, unvegetated asphalt, and buildings. The use of OSM improved the accuracy of the analysis by allowing for more precise identification of the areas contributing to MUHIs. Figure 2 shows the reclassified land-use type for New York City.



**Figure 2.** Reclassified Land Use

### MUHI Thresholds and Masks

Two temperature thresholds were applied to identify areas in New York City that had experienced MUHIs (Figure 3). The first is the Canopy Threshold, which identifies areas where the surface temperature exceeds the highest temperature, associated with dense vegetation or tree canopies. The highest dense vegetation temperature was determined using NDVI data.<sup>xvii</sup> The second threshold is the top 2%, which identifies areas based on their vegetation coverage level and is often used to find locations with very low vegetation cover. This threshold was determined by statistical analysis of the temperature distribution. Using the defined temperature thresholds, binary masks were created to identify MUHIs.

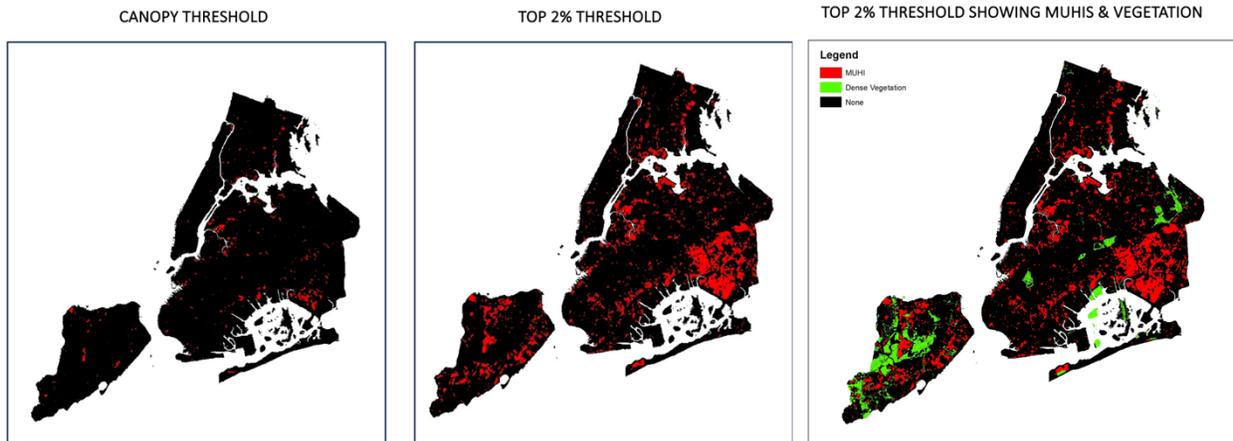


Figure 3. Application of MUHI Thresholds

### Results

Table 1 shows the pixel reclassification of land use types derived from the OSM data for New York City. The reclassified land-use types included sparse vegetation, dense vegetation, vegetated asphalt, concrete, water bodies, unsaturated asphalt, and buildings. The Value column indicates the number of pixels for each land use type, whereas the Pixel Count column provides the total pixel count for each land type class. The Area column indicates the total area for each land type class by converting pixel counts to the total area in square kilometers, knowing that each pixel has a cell size of 5 m × 5 m, and hence, an area of 25 square meters.

Table 1. Land Type Classification

Value	Pixel Count	Land Type	Area (km <sup>2</sup> )
1	7,682,719	Vegetated Asphalt	192.07
2	8,668,158	Unvegetated Asphalt	216.70
3	5,010,902	Sparse Vegetation	125.27
4	1,255,592	Dense Vegetation	31.39

5	746,695	Water Body	18.67
6	853,438	Concrete	21.36
7	6,278,434	Building	156.96
		<b>Total Area</b>	762.40

In Table 2, the August 9, 2023, images were analyzed for both the canopy and the top 2% thresholds because, of the three days under study, August 9 was the hottest 2).<sup>xviii</sup> Canopy threshold analysis revealed areas within the MUHIs that exhibited temperatures equal to or exceeding 31°C, corresponding to approximately 14.96 km<sup>2</sup>. The top 2% threshold analysis revealed areas within the MUHIs that exhibited temperatures equal to or exceeded 30°C, corresponding to approximately 95.88 km<sup>2</sup>. By applying these two thresholds, the hottest areas in New York City can be identified as MUHIs by land type.

The definitions of "canopy threshold" and "top 2% threshold" denote temperature points that indicate areas with intense heat levels. The canopy threshold signifies the temperature detected in the regions with dense greenery. This measure is vital because greenery usually helps reduce surface temperatures; thus, any location exceeding this threshold indicates a potential micro-urban heat island (MUHI). In contrast, the top 2% threshold identifies areas of the city with temperatures ranking among the hottest 2% of all temperatures documented in the study. This helps us determine the exact location of the MUHIs. Although the two thresholds may appear similar, they play distinct roles. A canopy threshold involves comparing temperatures with the cooling impact on plant life, whereas the top 2% threshold pinpoints heat zones.<sup>xix</sup>

**Table 2.** Land Type Classification for August 9, 2023 Data

	<b>Canopy Threshold</b>	<b>Top 2% Threshold</b>
Threshold Temperature	31°C	30°C
Total MUHI Area	14.96 km <sup>2</sup>	95.88 km <sup>2</sup>
	Portion of a Material That Contains a MUHI	Portion of a MUHI That Contains Material
Building	3.35%	16.58%
Concrete	11.35%	35.49%
Dense Vegetation	0.02%	0.24%
Sparse Vegetation	1.09%	2.10%
Unvegetated Asphalt	3.13%	15.61%
Vegetated Asphalt	1.39%	13.36%

Data for August 2023 revealed that buildings, concrete, and asphalt surfaces significantly contributed to the formation of MUHIs in New York. Buildings and concrete surfaces showed a higher percentage in the top 2%

threshold category than in the canopy threshold, indicating that these materials are more prevalent in areas with the highest temperatures. In contrast, dense vegetation showed a minimal contribution to MUHIs, underscoring its effectiveness in mitigating urban heat.

## Discussion

Notable MUHI locations were identified in New York City, where heat intensifies due to the concentration of asphalt and concrete surfaces and the lack of vegetation (Figure 4). Urban locations surrounded by large uninterrupted areas of urban surface cover rather than vegetation are more susceptible to MUHI formation.<sup>xx</sup> The most prominent MUHI locations were John F. Kennedy Airport<sup>xxi</sup> and the National Grid Depot<sup>xxii</sup> in New York, where extensive areas of asphalt and concrete contribute to higher surface temperatures. These materials are critical factors in MUHI formation, making these locations hotspots for urban heat generation. The analysis indicates that MUHIs are concentrated toward the center of these areas, consistent with previous observations that MUHIs tend to be the hottest at the center,<sup>xxiii</sup> where urban heat intensifies owing to the abundance of impervious surfaces. The lack of vegetation at these locations further contributes to heat accumulation, resulting in some of the most extensive MUHIs in New York.

In contrast, areas of the city with more greenery, such as Central Park, had lower temperatures. NVDI data confirmed that increased vegetation was strongly correlated with cooler surface temperatures, emphasizing the role of green spaces in mitigating urban heat (Figure 1). Furthermore, the findings indicate that structures and paved surfaces play a role in high temperatures at the top 2% threshold within cities. This corroborates the notion that built environments are key contributors to MUHIs.

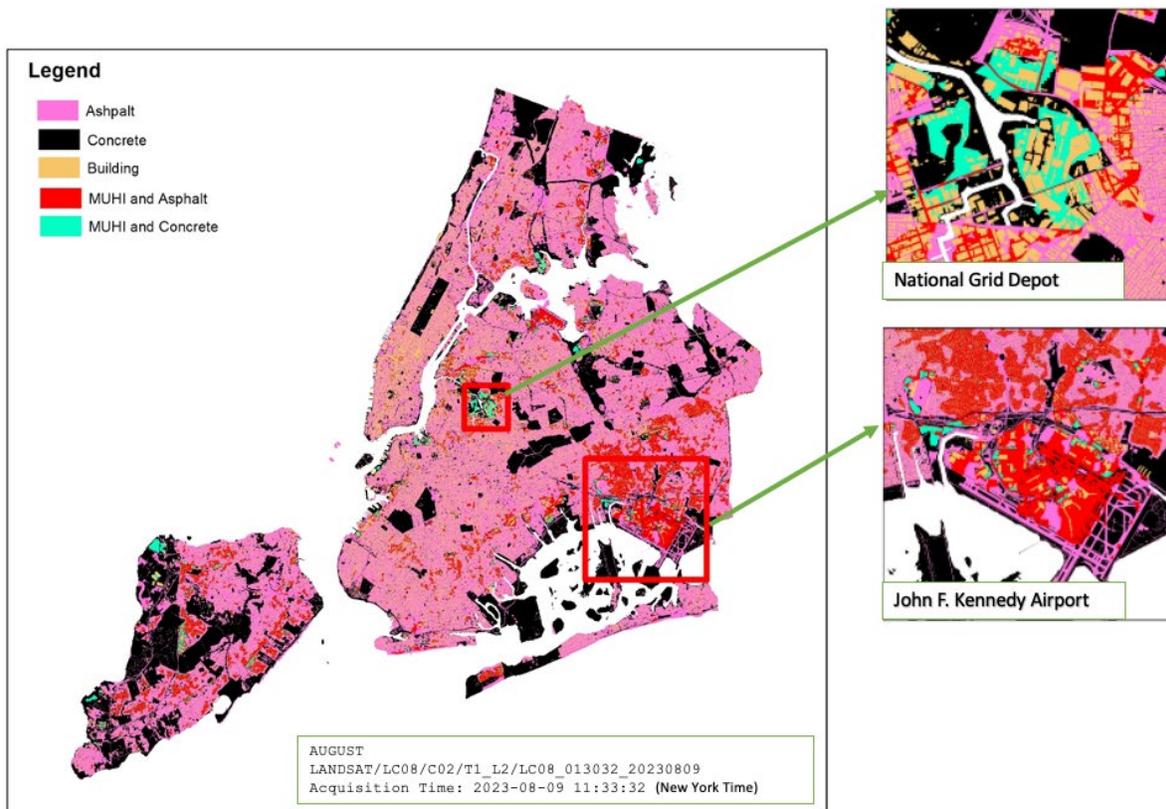


Figure 4. MUHI Overlap with Asphalt and Concrete in New York City

## Conclusion

The analysis of MUHIs in New York City underscores the critical role of urban materials and vegetation in urban heat dynamics. Asphalt and concrete significantly contribute to MUHI formation, whereas dense vegetation mitigates these effects through natural cooling mechanisms. To effectively address the urban heat island effect, urban planning should implement several strategies. First, the number of urban green spaces should be increased. Urban planners should focus on creating more parks, installing green rooftops, and planting street trees to enhance urban cooling by providing shade and promoting evapotranspiration.<sup>xxiv</sup> Second, builders should be encouraged to use materials with higher reflectivity (albedo) in urban construction, such as cool roofs and reflective pavement.<sup>xxv</sup> This will help to reduce heat absorption and lower surface temperatures. Finally, government officials should continuously monitor urban temperatures to track changes over time and assess the effectiveness of various mitigation strategies.<sup>xxvi</sup> By understanding and addressing the factors contributing to MUHIs, cities can improve their living conditions, reduce their energy consumption, and enhance their resilience to climate change.

## Limitations of Study

This study had two empirical and methodological limitations. First, the analysis primarily depended on temperature data from Landsat 8 satellites. However, this method may not accurately reflect the spectrum of temperature fluctuations at ground level in urban settings, such as New York City, because dense urban environments sometimes make measuring temperature variations caused by different building materials or small vegetated areas difficult. The second limitation of this study is that we had to exclude data from July because of cloud cover on days when satellite data were available. This means the research overlooks data that can provide insights into the warmer months.

## Acknowledgments

I would like to thank Mr. Budi Prasetyo for his help in preparing the maps for this study

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