Analysis of Urban Heat Island Effect in SPA Area of Los Angeles City Using GIS

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Course Name:
Geographic Information Systems for Public Policy, Planning & Development，

Spring 2024，PPD 631

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Date:

December 12, 2024

Abstract

The urban areas Heat Island effect (UHI) is the phenomenon in which temperatures in metropolitan areas are greater than in adjacent rural areas. It is mostly driven by human activity, construction development, and vegetation loss (Anderson & Taylor, 2024). Los Angeles City is organized into eight Service Planning Areas (SPAs), each with distinct land use, socioeconomic features, and geography. However, there have been relatively few research on how these variables influence the spatial distribution and intensity of the heat island effect. The purpose of this study is to investigate the geographical disparities in the urban heat island effect in eight SPA regions in Los Angeles city and determine the primary driving variables of UHI patterns in each area, with an emphasis on population density, building density, and green space coverage. The geographic information system (GIS) is an effective tool for analyzing this topic since it can depict spatial distribution, multi-source data integration, spatial overlay analysis, spatial statistics, and modeling (Lee et al., 2023).Using GIS techniques, this study displayed the surface temperature distribution of each SPA area, revealing disparities in the intensity of the heat island impact among regions. The findings of this study are critical for developing targeted urban planning and environmental strategies to mitigate the impact of UHI and promote equitable adaption measures in various neighborhoods throughout Los Angeles City.

1. Introduction

The Urban Heat Island effect (UHI) is a typical environmental concern for developed areas like Los Angeles city. It refers to the fact that urban temperatures are much greater than those in adjacent rural and natural areas (Oke et al., 2019). This effect is especially noticeable in Los Angeles city due to its high population density, dense built environment, and relative lack of green space coverage. The primary drivers of the UHI impact include high traffic flows, heat storage qualities of building materials, and insufficient urban greening (Stone & Rodgers, 2020). For cities like Los Angeles, the heat island effect not only has an impact on citizens' health and living conditions, but it also considerably boosts energy consumption, particularly during high summer temperatures, increasing the pressures imposed by climate change.

This study aims to use GIS to analyze the spatial differences in urban heat island effects in different SPA areas in Los Angeles City and the reasons for their differences in heat island effects. Specifically, the study focuses on two core issues:

1. What are the differences in the urban heat island effect in different spa areas in Los Angeles City?

2. Which SPA areas (such as SPA 1 to SPA 8) show more significant heat island effect? What could be the reason? Is it related to population density, building density or green space coverage?

To answer the research issues raised above, Geographic Information Systems (GIS) will be used as the primary analytical tool. GIS can successfully combine data from several sources, such as remote sensing, land use information, and demographics, to perform spatial analysis and visualization. The purpose of this study is to show the spatial disparities and driving forces behind the urban heat island effect in different regions by conducting a detailed investigation of the urban heat island impact in eight Los Angeles City SPAs. This study will provide a scientific foundation for local governments and urban planners, particularly in terms of rationally allocating green spaces and optimizing building layouts to reduce high temperature hazards, ultimately boosting community resilience and quality of life in Los Angeles City.

2. Data and Methodology

Data Sources

Vegetation Coverage Data, NDVI

https://data.census.gov/table/ACSST5Y2022.S0101?t=Age%20and%20Sex&g=040XX00US06$1400000&y=2022
https://www.census.gov/geographies/mapping-files/time-series/geo/tiger-geodatabase-file.2023.html#list-tab-1258746043
https://earthexplorer.usgs.gov/

Download the Landsat satellite remote sensing image, use ENVI 5.6 to invert the surface temperature, and calculate the surface temperature of the study area.

The NDVI index is calculated by NIR and R bands, and then the vegetation coverage index is calculated by dichotomy.

Download DEM data and extract it to the study area.

Download the Tract data from the above connection, and then use the connection field to connect the data attributes.

Use partition statistics to count the data into the table. Then MGWR is used, and LST is taken as an independent variable, and others are taken as dependent variables.

3. Processing and mapping of map data

3.1 Data integration and comprehensive mapping

Spatial superposition analysis:

Overlay layers of surface temperature, socioeconomic status, and green cover. Use GIS's spatial overlay function to examine the spatial relationship between various quantities in each SPA region. Create a complete spatial distribution map that depicts the superposition impact of surface temperature, population density, and green coverage in each SPA area to investigate their relationship.

Hot spot analysis:

Use GIS's hotspot analysis tool to discover regions with high UHI. These places may have greater temperatures, poorer socioeconomic situations, or less green cover.
Create a UHI heat map to identify high-risk areas and assist policymakers in developing targeted solutions.

Map layout and output:

The findings of the preceding study are presented on maps, which include surface temperature distribution maps, socioeconomic features maps, green coverage maps, and full analysis maps. Legends, titles, scale bars, and annotations should be included to make the map legible and easy to read, allowing for easier interpretation and presentation of research findings.

Through these GIS processing and mapping procedures, the UHI effect of each SPA region in Los Angeles City can be completely defined, as well as the spatial relationship between socioeconomic features, green coverage, and surface temperature. This method provides trustworthy data support and visualization tools for determining the severity and causes of UHI in various places.

3.2 Steps in GIS software

Import base map: Load the base map of Los Angeles City (administrative boundaries or basemap).

Import SPA area data: Add SPA boundary data to the map and set the colors of different areas (such as red, blue, green, etc.). Add labels for each SPA area (SPA 1 - SPA 8).

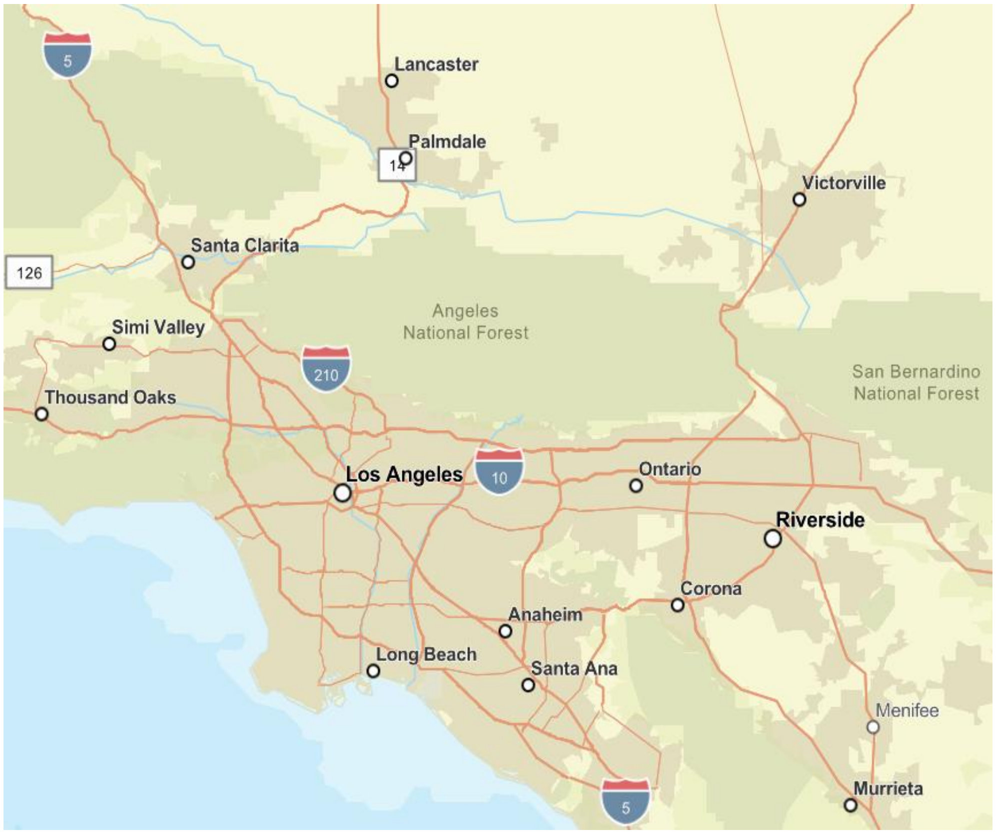
Add weather stations:

Import the longitude and latitude coordinates of the weather stations as point data to the map. Set the color according to the type of weather station (blue, yellow, red).

Set legend and style:

Add a legend to explain the meaning of different colors and symbols. Adjust the style, such as simplifying the design and choosing an appropriate font.

3.2 Map of Los Angeles City



3.3 SPA Data in GIS software

Data import: Import surface temperature data into GIS software, as well as socioeconomic data, such as population density, income level, and spatially join them with Los Angeles City's SPA area vector data, to ensure that each SPA area has relevant socioeconomic information.

Reasons for SPA regional division:

Red (SPA 1): represents the Antelope Valley, which covers the remote northern region and may emphasize its geographical uniqueness and resource needs.

Blue (SPA 2): San Fernando Valley, which is densely populated and is identified as a comprehensive service area.

Green (SPA 3): San Gabriel Valley, which is greener and may be related to natural resources and residents' living characteristics.

Yellow (SPA 4): Downtown Los Angeles (Metro), a dense service demand area.

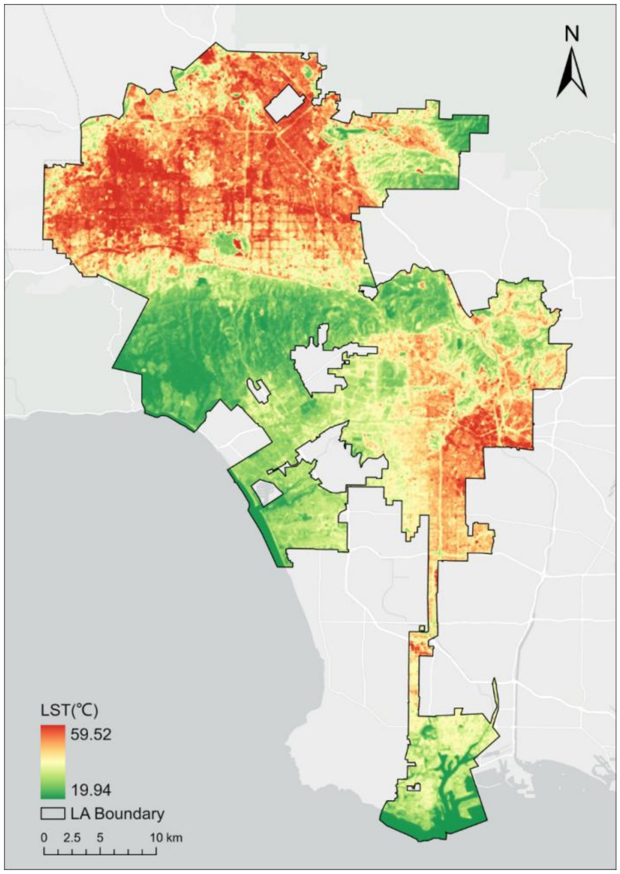
Orange (SPA 5): West LA, a high-income community, emphasizing unique service needs.

Light blue (SPA 6): South LA, which is generally a community with high resource and service needs.

Pink (SPA 7): East LA, characterized by cultural diversity and dense needs.

Brown (SPA 8): South Bay, a coastal community that combines residential and industrial needs.

3.3 SPA Area of Los Angeles City



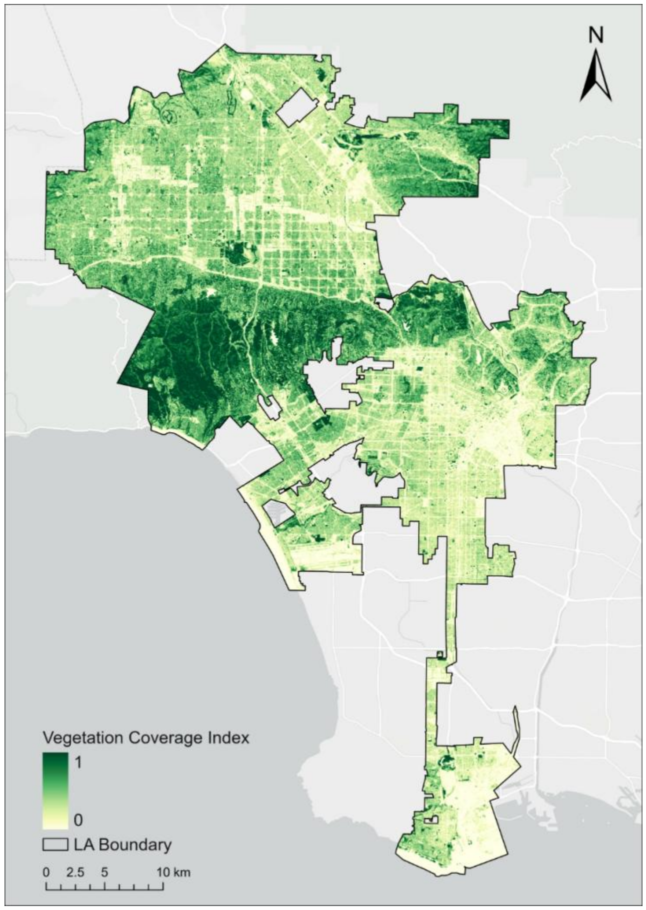
3.4 Weather Data in GIS software

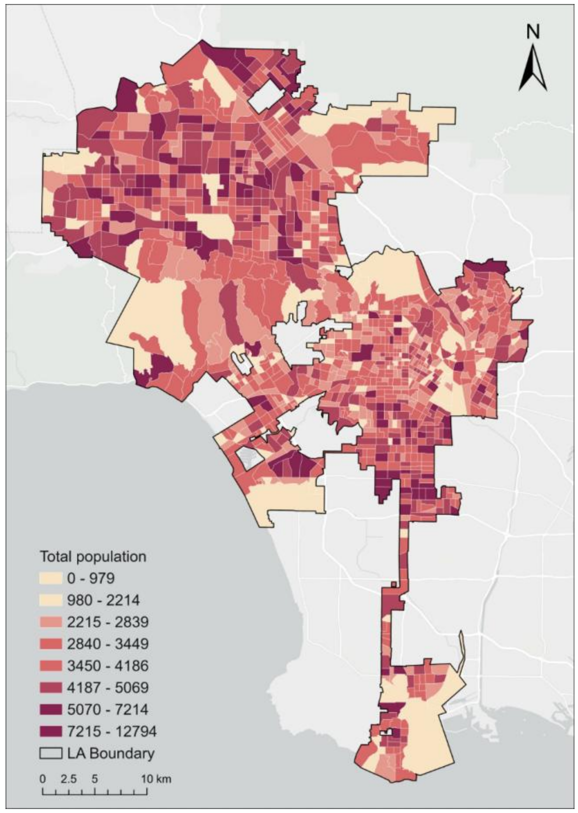
Blue weather spot signifies Precipitation monitoring focuses on capturing regional rainfall and precipitation patterns. Blue is frequently connected with water or humidity and may indicate precipitation places. SPA 1 monitors precipitation in arid regions to determine water resource conditions. SPA 2 and SPA 5 track changes in humidity and rainfall in a marine climate.

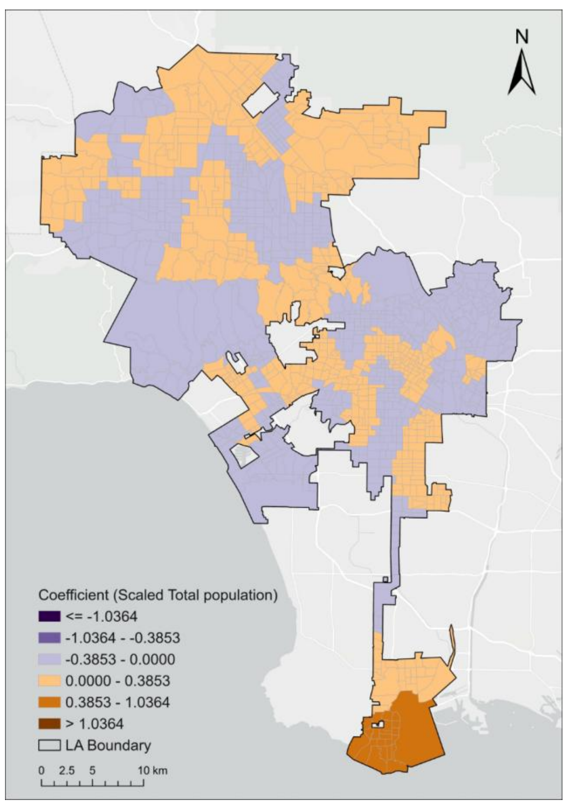
Yellow weather dots reflect temperature monitoring, specifically data collecting relating to high temperatures and the heat island effect. Yellow color frequently linked with heat or sunlight and can be used to represent temperature data. SPA 4 (Downtown Los Angeles) and SPA 6 (South Los Angeles) the urban heat island effect is strong, and high temperatures must be closely managed. SPA 7 with hot summers and a possibility of excessive heat.

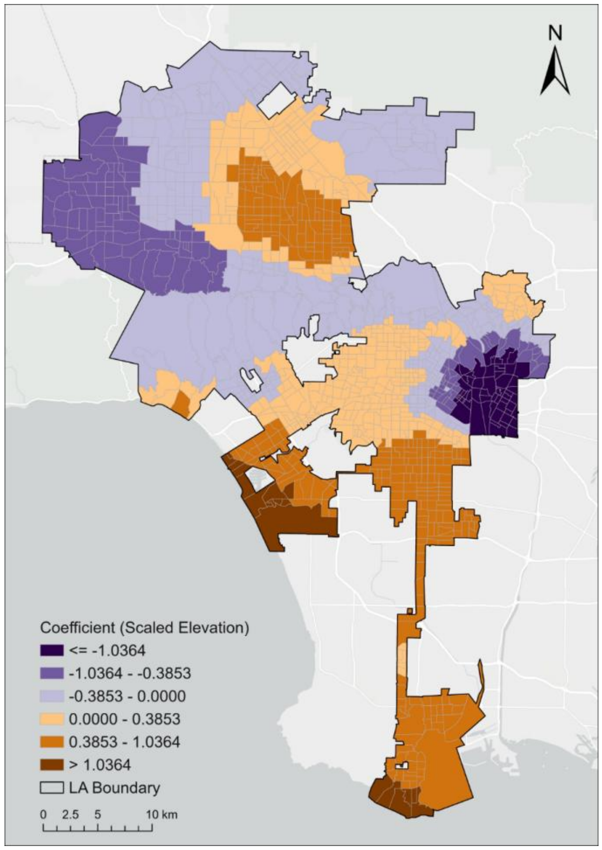
Red weather areas indicate extreme weather monitoring, which includes unusual or dangerous weather events such as storms, droughts, and thunderstorms. Red indicates warning or high risk and can be used to record extreme weather data. SPA 1 (Antilope Valley) need to be monitored for extreme weather. SPA 3 (San Gabriel Valley) extreme weather conditions such as thunderstorms or cold air may occur.

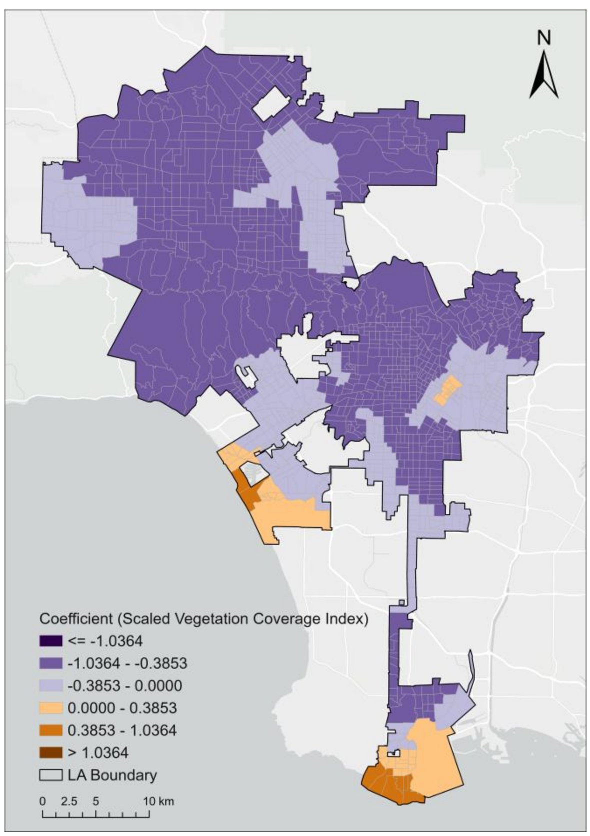
3.4 Urban Heat Island Effect in SPA Area of Los Angeles City

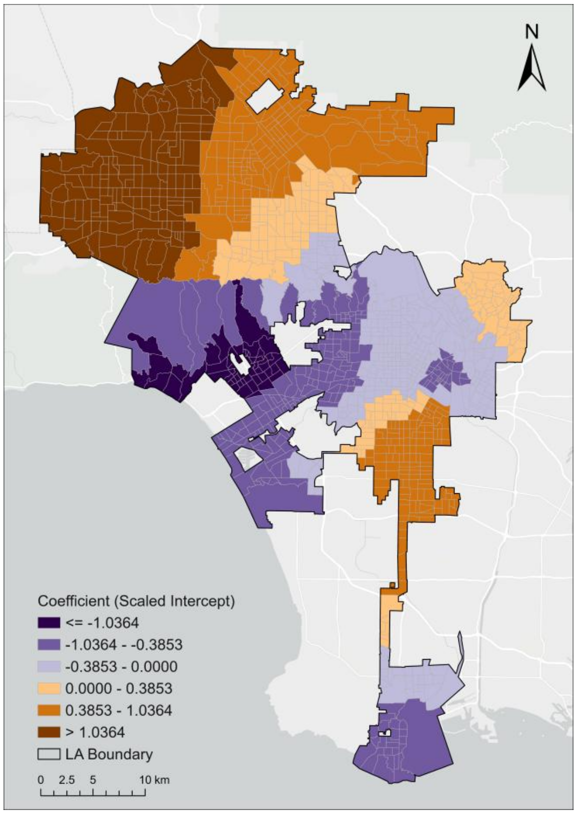


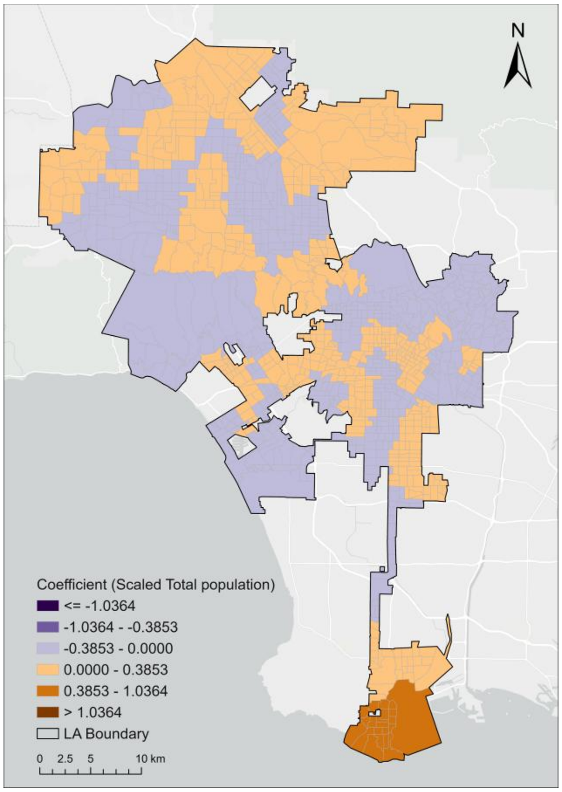

N
Total population
0 - 979
980 - 2214
2215 - 2839
2840 - 3449
3450 - 4186
4187 - 5069
5070 - 7214
7215 - 12794
LA Boundary
0 2.5 5 10 km


N
Coefficient (Scaled Total population)
<= -1.0364
-1.0364 - -0.3853
-0.3853 - 0.0000
0.0000 - 0.3853
0.3853 - 1.0364
> 1.0364
LA Boundary
0 2.5 5 10 km


N
Coefficient (Scaled Elevation)
<= -1.0364
-1.0364 - -0.3853
-0.3853 - 0.0000
0.0000 - 0.3853
0.3853 - 1.0364
> 1.0364
LA Boundary
0 2.5 5 10 km


N
Coefficient (Scaled Vegetation Coverage Index)
<= -1.0364
-1.0364 - -0.3853
-0.3853 - 0.0000
0.0000 - 0.3853
0.3853 - 1.0364
> 1.0364
LA Boundary
0 2.5 5 10 km





4. Results and Analysis

4.1 Analysis of differences in urban heat island effects in different SPA areas in Los Angeles City

The urban heat island effect in Los Angeles City varies greatly based on the urbanization level, geographical location, and green space coverage of the SPA area. The heat island effect is most pronounced in SPA 4 (Downtown Los Angeles) and SPA 6 (South Los Angeles), owing to extremely high population density and building density in these areas, as well as low green space coverage, resulting in an imbalance between urban heat absorption and heat dissipation. The former is the central commercial district, with high-rise buildings, while the latter is a crowded residential and industrial neighborhood. In contrast, SPA 1 (Antilope Valley) and SPA 8 (South Bay) have a weak heat island impact.

The metropolitan Heat Island (UHI) effect describes the phenomena in which metropolitan regions are much hotter than surrounding rural areas. Its severity is affected by numerous things. Population density is important because bigger concentrations of people result in more frequent activities and higher heat outputs. Similarly, building density helps because densely packed structures absorb and retain heat more effectively due to the thermal characteristics of building materials. In contrast, green space coverage functions as a natural cooling mechanism; places with less vegetation have weaker cooling effects, worsening the UHI impact. Finally, geographic location determines UHI intensity, with inland locations being more vulnerable to heat islands than coastal regions, which benefit from moderating oceanic forces. These factors all influence the spatial and intensity patterns of UHIs in metropolitan environments.

4.1 Summary Statistics for Coefficients Estimates

Explanatory Variables	Mean	Standard Deviation	Minimum	Median	Maximum
Intercept (Scaled)	0.1984	0.7909	-1.6783	0.046	2.0513
Total population (Scaled)	0.0153	0.1199	-0.2605	-0.0044	0.917
Vegetation Coverage Index (Scaled)	-0.393	0.1859	-0.6583	-0.4366	0.5396
Elevation (Scaled)	0.0704	0.5515	-1.8167	0.1003	1.3963

Model Diagnostics

Statistic	GWR	MGWR
R-Squared	0.9585	0.9623
Adjusted R-Squared	0.9384	0.9494
AICc	375.8144	274.3456
Sigma-Squared	0.0616	0.0506
Sigma-Squared MLE	0.0415	0.0377
Effective Degrees of Freedom	749.9891	829.9476

Summary of Explanatory Variables and Neighborhoods

Explanatory Variables	Neighbors (% of Features)a	Significance (% of Features)b
Intercept (Scaled)	30 (2.70)	528 (47.44)
Total population (Scaled)	30 (2.70)	33 (2.96)
Vegetation Coverage Index (Scaled)	31 (2.79)	881 (79.16)
Elevation (Scaled)	31 (2.79)	241 (21.65)

Optimal Bandwidths Search History

Iterations	Intercept (Scaled)	Total population (Scaled)	Vegetation Coverage Index (Scaled)	Elevation (Scaled)	AICc
0	33	33	33	33	375.8144
1	30	421	30	30	1434.5188
2	30	110	30	30	578.0498
3	30	30	30	30	427.1125
4	30	30	31	30	377.9467
5	30	30	31	30	348.6673
6	30	30	31	30	325.2648
7	30	30	31	30	307.6533
8	30	30	31	31	296.1002

9	30	30	31	31	287.4552
10	30	30	31	31	282.135
11	30	30	31	31	278.6311
12	30	30	31	31	276.1794
13	30	30	31	31	274.3456

Bandwidth Statistics Summary

Explanatory Variables	Optimal Number of Neighbors	Effective Number of Parameters	Adjusted Value of Alpha	Adjusted Critical Value of Pseudo-t Statistics
Intercept (Scaled)	30	58.98	0.0008	3.3489
Total population (Scaled)	30	90.67	0.0006	3.4679
Vegetation Coverage Index (Scaled)	31	74	0.0007	3.4122
Elevation (Scaled)	31	59.41	0.0008	3.351

4.2 SPA Areas with Significant UHI Effect and Reasons

SPA regions with severe heat island effects include SPA 4 (Downtown Los Angeles) and SPA 6 (South Los Angeles). SPA 4 has the greatest heat island effect, owing to its exceptionally high population density (more than 7,000 people per square mile), densely packed structures, and less than 20% green space coverage. SPA 6 also has a greater heat island impact due to dense residential and industrial zones. There are regular activities, and green space coverage is less than 30%. SPA 1 (Antilope Valley) and SPA 8 (South Bay) have a rather weak heat island impact. SPA 1 has a low urbanization level, a green space coverage rate of more than 80%, and a large natural area, whereas SPA 8 is adjacent to the ocean, influenced by sea breeze and humid climate, and has a high green space coverage rate (50%-70%). In general, the heat island effect is associated with higher population and construction density and lower green space coverage.

Areas with a dense population and structures are more likely to retain heat, whereas areas with more green space have considerable natural cooling benefits.

Influencing Factors

Population Density:
- Higher density leads to more human activity and anthropogenic heat.
- Example: SPA 4 and SPA 6 have high population densities, contributing to strong UHI.

Building Density:
- Dense buildings retain heat and reduce cooling efficiency.
- Example: SPA 4 has many high-rise buildings, intensifying UHI.

Green Space Coverage:
- Vegetation helps cool areas through evapotranspiration, reducing UHI.
- Example: SPA 1 and SPA 3 have higher green space coverage, leading to weaker UHI.

5. Discussion and Recommendations

Discussion

The urban heat island effect (UHI) in Los Angeles City exhibits clear spatial distribution characteristics. SPA 4 has the largest heat island impact due to its high building density and scarcity of green space, whereas SPA 2 has a substantially smaller heat island effect due to its considerable vegetation coverage, emphasizing the importance of greening in urban cooling. Similarly, economic and societal factors influence UHI. Areas with high population density and lower socioeconomic conditions typically experience larger heat island impacts, suggesting an imbalance in urban planning and climate adaptation resources. Environmental studies have found a negative correlation between green space coverage and heat island intensity, stressing the importance of vegetation in reducing urban high temperatures. These issues can be addressed by the following strategies: First, increase the cooling effect by increasing urban greening, such as promoting rooftop gardens and street greening in SPA 4 and other high-risk areas, as well as protecting and expanding existing green spaces in areas such as SPA 2. Second, in terms of land use optimization, reduce impervious surfaces, prioritize green infrastructure, and promote the use of sustainable building materials and designs to reduce heat retention. Finally, conducting public awareness campaigns through community engagement and education to educate individuals about building-level cooling measures (such as reflective roof materials and backyard greening) and collaborating with local governments to strengthen the resilience of disadvantaged communities to heat.

6. Limitations and Conclusion

This study has significant limitations in terms of data and scope. As can be seen from the figure, the LST is obviously higher in the northern and eastern regions, which proves that these regions have higher heat island effect. Other graphs also show that the distribution should be regular, so the next step is to analyze the results of MGWR.

Judging from the correlation coefficient, the population coefficient is concentrated in the southern region as a whole, which proves that the population here has a great influence on its results. In terms of vegetation coverage, most areas show obvious negative correlation, which shows that vegetation coverage and surface temperature have a reducing effect. Topographically, there is also a clear image relationship, with the south and north being positive and the other parts being negative.

From the perspective of Scaled Intercept, the Adjusted R-Squared reached 0.9384 for the overall results of the model, which indicated that the selection of factors had a strong correlation with the results. On the whole, the results are in line with expectations, especially the vegetation has a strong influence on the surface temperature. However, the results of population are not in line with expectations, which may be due to the time and scale of data.

In the future, I think we can optimize from the scale of population, divide more reasonable evaluation units and try more suitable models.

7. Reference

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