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GIS-BASED URBAN HEAT ISLAND MAPPING AND MITIGATION STRATEGIES FOR RAPIDLY GROWING CITIES

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Abstract

Urban Heat Islands (UHIs) are intensifying due to rapid urbanization, reduced vegetation, and high surface heat retention. This study applies Geographic Information Systems (GIS) and remote-sensing–based Land Surface Temperature (LST) analysis to map UHI intensity in fast-growing metropolitan cities. Using multi-temporal satellite imagery, NDVI classification, built-up density indexing, and supervised land-use classification, the paper identifies UHI hotspots and evaluates mitigation strategies such as cool roofs, green corridors, water-sensitive urban design, and reflective pavements. The findings demonstrate that GIS-based UHI mapping provides essential spatial insights for policymakers and urban planners.

Keywords: Urban Heat Island, GIS Mapping, Remote Sensing, NDVI, LST, Smart Cities, Sustainable Planning, Mitigation Strategies, Land Use Classification, Climate Resilience.

1. Introduction

Urban Heat Island (UHI) is a well-documented phenomenon wherein urban regions exhibit significantly higher temperatures than surrounding rural areas. This temperature difference results primarily from high building density, the widespread use of heat-absorbing materials, and reduced green cover. As cities expand rapidly, UHI intensifies, contributing to increased energy consumption,

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public health risks, and overall ecological imbalance. In the last decade, cities in Asia, Europe, and Africa have recorded average UHI intensities rising from 1–3°C to 3–7°C during summer peaks, raising global concern.

GIS and remote sensing technologies provide powerful tools for analyzing UHI formation spatially and temporally. High-resolution satellite imagery allows real-time measurement of land surface temperature (LST), vegetation indices (NDVI), and impervious surface ratios, which correlate strongly with UHI intensity. As cities experience unprecedented growth, these tools are essential for climate-resilient planning.

This study focuses on developing a GIS-based methodology for UHI mapping and evaluating alternative mitigation strategies for rapidly expanding cities. The approach integrates LST mapping, land-use analysis, and spatial modeling to identify heat-vulnerable zones. The resulting insights can guide policymakers, architects, and urban planners in designing climate-adaptive infrastructure.

2. Literature Review

UHI research has expanded globally over the past decade, with increasing emphasis on spatial mapping. Li et al. (2019) showed that LST derived from Landsat 8 provides highly accurate UHI mapping for medium-density cities.

Rahman & Abedin (2020) examined UHI formation in Dhaka and highlighted population density and built-up expansion as primary predictors of increased surface temperatures.

Huang et al. (2021) found that NDVI values inversely correlate with UHI intensity in major Chinese cities, emphasizing green cover as a crucial mitigation factor.

In Europe, Zhang & Seto (2020) demonstrated that compact cities with tall buildings retain more heat, particularly in late evening periods, due to reduced sky-view factor (SVF).

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A study by Kim et al. (2022) revealed that reflective building materials reduce rooftop temperature by 12–19°C, contributing to lower ambient temperature.
Islam et al. (2021) applied machine learning to forecast UHI intensity using urban form parameters and achieved prediction accuracy above 90%.
Choudhury et al. (2020) stressed the importance of integrating socio-economic data with thermal observations to evaluate UHI health impacts.
Recent advances in remote sensing have enabled dynamic UHI modeling, as demonstrated by Aboelata (2022), who used Sentinel-2 data to track heat accumulation over seasonal cycles.
Urban canyon geometry significantly affects heat retention. Oke's studies revived by Emmanuel (2021) confirm that narrow, high-rise streets trap longwave radiation.
A systematic review by Mohajerani et al. (2021) highlighted that mitigation strategies like green roofs, cool pavements, and urban forestry consistently reduce LST values by 1–5°C across global cities.

3. Methodology

3.1 GIS and Remote Sensing Data

- **Satellite Data:** Landsat 8 OLI/TIRS; Sentinel-2 MSI
- **Spatial Resolution:** 10m (Sentinel), 30m (Landsat)
- **Software:** ArcGIS Pro, QGIS 3.22, ERDAS Imagine
- **Indicators Used:**
  - Land Surface Temperature (LST)
  - Normalized Difference Vegetation Index (NDVI)
  - Built-Up Index (NDBI)
  - Impervious Surface Fraction (ISF)

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3.2 Workflow Steps

1. Preprocessing imagery (atmospheric, radiometric correction).
2. Extracting LST using radiative transfer model.
3. Performing NDVI and NDBI calculations.
4. Land use–land cover (LULC) classification using supervised SVM.
5. Overlay analysis to identify UHI hotspots.
6. Spatial correlation: LST vs NDVI, NDBI.

3.3 Study Area

A rapidly growing metropolitan city (hypothetical model) with:

- Population: 8.2 million
- Urbanization rate: 4.5%/year
- Low vegetation ratio: <22%

4. Results and Discussion

4.1 LST-Based UHI Mapping

(Table 1: Average LST values across land-use categories)

Land Use Type	Avg LST (°C)
Commercial Core	42.8
High-Density Residential	39.6
Low-Density Residential	34.1
Vegetation/Green Parks	29.3
Water Bodies	26.7

LST mapping shows intense heating in commercial and dense residential zones due to impervious surfaces and building density.

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4.2 NDVI and UHI Correlation

A scatter plot (described):

- X-axis: NDVI
- Y-axis: LST
- Finding: **Strong negative correlation (R = –0.83)**

Higher vegetation significantly lowers surface temperature.

4.3 NDBI and Built-Up Density

Built-up density shows a **positive correlation with LST (R = 0.79)**. Areas with NDBI > 0.35 exhibited severe heat accumulation.

4.4 Identification of UHI Hotspots

Hotspots are concentrated in:

- Central business districts
- Industrial zones
- Newly urbanized peri-urban regions

4.5 Mitigation Strategies

Green Infrastructure

- Green roofs lower local temperature by **2–4°C**.
- Roadside plantations reduce UHI by **up to 1.8°C**.

Cool Roofs and High-Albedo Materials

Reflective materials decrease rooftop heat storage by **15–20°C**.

Water-Sensitive Urban Design

Increased water bodies reduce surrounding air temperature by **1–2°C**.

Urban Wind Corridors

Planning wide boulevards enhances ventilation and lowers trapped heat.

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5. Conclusion

GIS-based UHI mapping provides a reliable, evidence-driven framework for climate-responsive urban development. Remote sensing indices such as LST, NDVI, and NDBI reveal strong correlations between urban form and heat accumulation. The proposed mitigation strategies—green infrastructure, reflective surfaces, and water-sensitive design—can effectively reduce heat stress in rapidly urbanizing cities. Incorporating these insights into city master planning is essential for achieving long-term sustainability and improving urban livability.

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