Exploring Spatial Patterns of Urban Heat Islands in Zagreb

16.4.2025.
CORP, Graz

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Introduction

- This study focuses on the City of Zagreb’s urban area defined by General Urban Plan, **analyzing how built-up intensity and planned land use affect land surface temperature** (LST).

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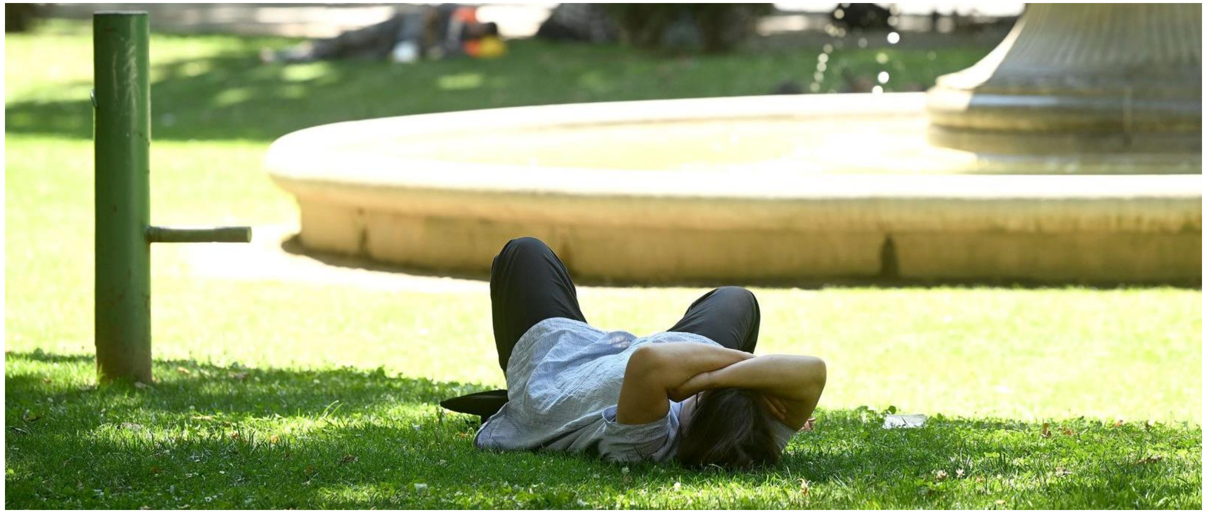
What are Urban Heat Islands?

- Urban heat islands are built-up areas with higher temperatures than surrounding regions.
- Structures like buildings, roads, and other infrastructure absorb and re-emit the sun’s heat more than natural landscapes such as forests and water bodies.
- Urban zones, especially city cores with dense construction and limited greenery, become “islands” of elevated temperatures compared to nearby areas.



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Some examples from Europe

- **Bochum, Germany**:
  - More green = lower LST (Schmidt & Lawrence, 2022).
- **Andalusia, Spain**:
  - Green planning essential for thermal balance (Hidalgo García & Díaz, 2023).
- **Naples & Florence:**
  - UHI formed on bare/built-up land; vegetated areas remained cooler (Guha et al., 2018).
- **Dubrovnik, Croatia:**
  - Long-term trend of increased summer temperatures (Boras et al., 2022).
- **Italy:**
  - Inland cities worse than coastal due to less water/green cooling (Morabito et al., 2020).

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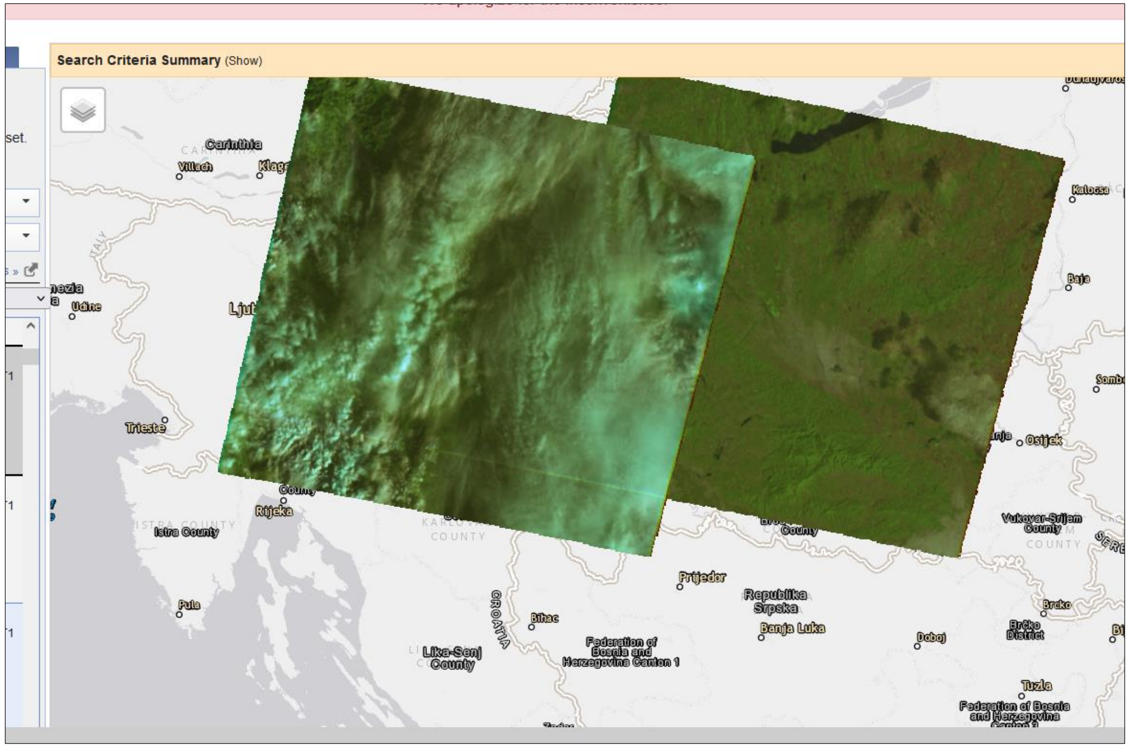
Remote Sensing & GIS in UHI Research

- Satellite data (e.g. Landsat, Sentinel) and indices (NDVI) are key tools for mapping LST and UHI intensity.
- Integration of spatial regression, clustering (k-means), and spatial autocorrelation identifies UHI hotspots and drivers (Erdem et al., 2021).
- GIS supports spatial planning, enabling targeted UHI mitigation strategies through mapping, zoning, and land-use optimization (Hidalgo García & Díaz, 2023).



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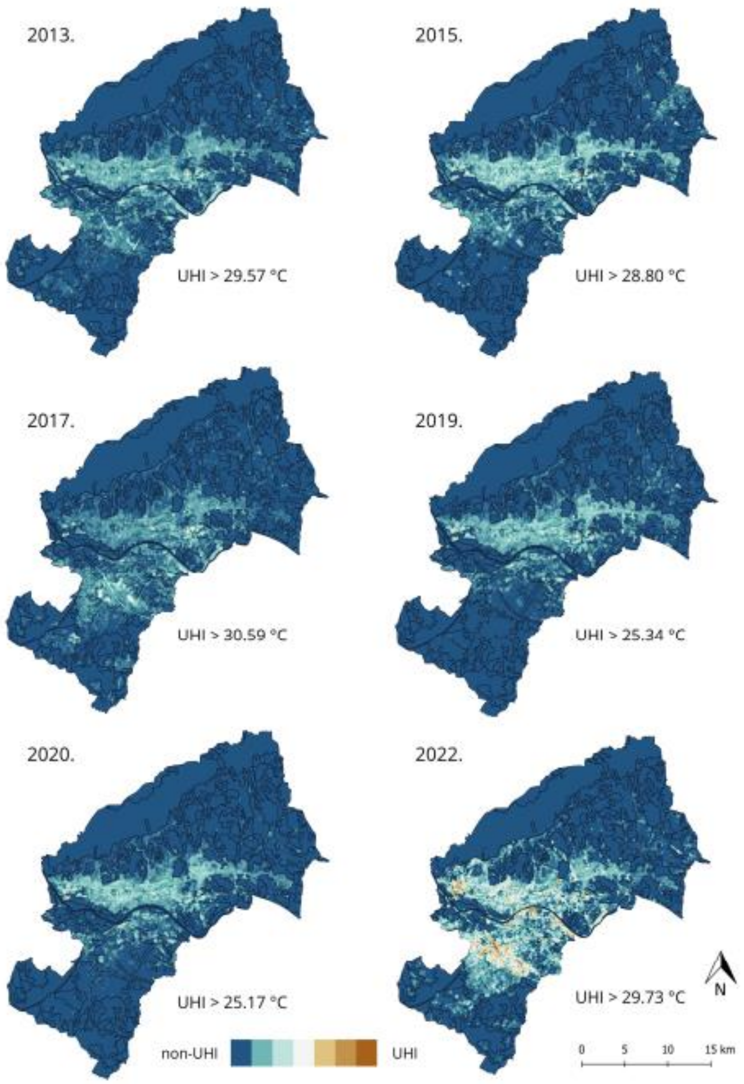
UHI in Zagreb – Previous findings

- Landsat 8 (2013–2022): built-up areas = higher LST; vegetated zones = lower temps (Seletković et al., 2023).
- NDVI and LST show strong negative correlation (Krtalić et al., 2020).
- City center & industrial zones = UHI hotspots; parks = cooling (Krsnik, 2024).
- Commercial/transport zones retain heat due to impervious surfaces (Krtalić et al., 2020).
- Remote sensing flags industrial areas as hotspots (Krsnik, 2024).
- Green areas reduce temps by up to 2°C (Seletković et al., 2023).



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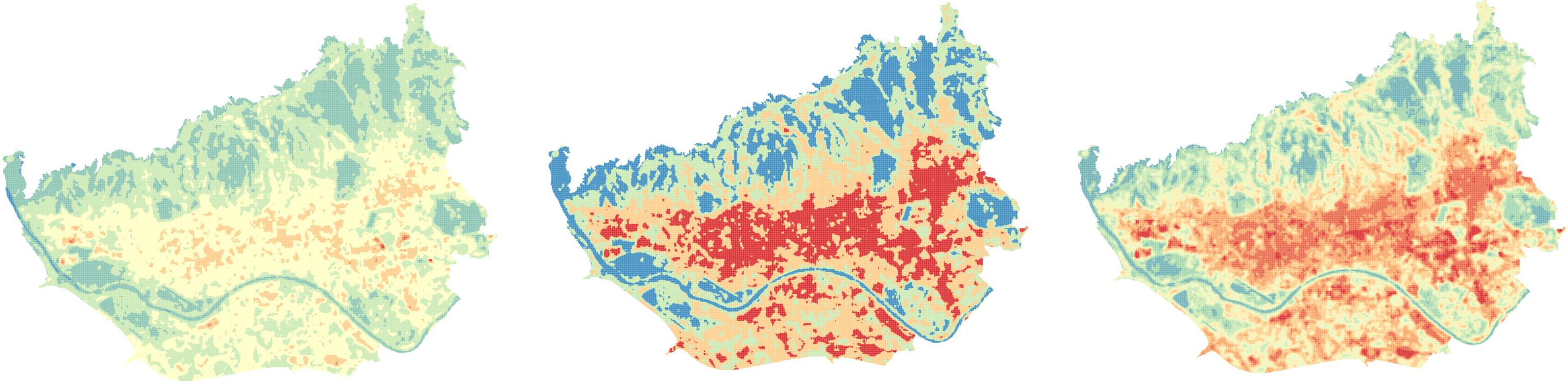
Visual representation

- Visual interpretation is useful for initial understanding but is subject to various interpretations and does not provide quantitative insights.
- Scientifically based decisions require the integration of visualizations with anvanced analyses such as spatial correlations, regressions, and zonal statistics for accurate identification of UHI.



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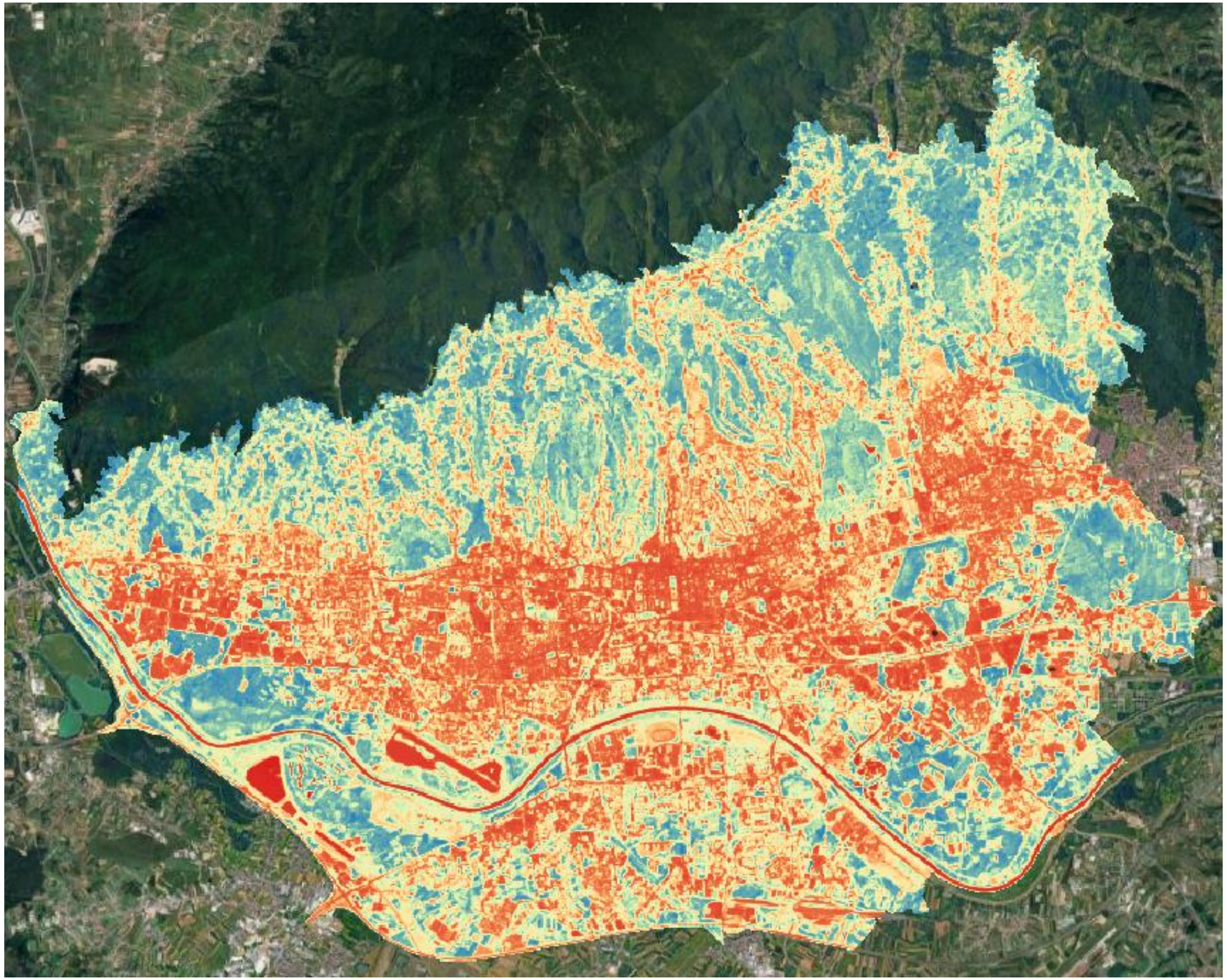
Methodological introduction

- Research area is focused on spatially explicit analysis of UHI intensity in **Zagreb's General Urban Plan (GUP)**



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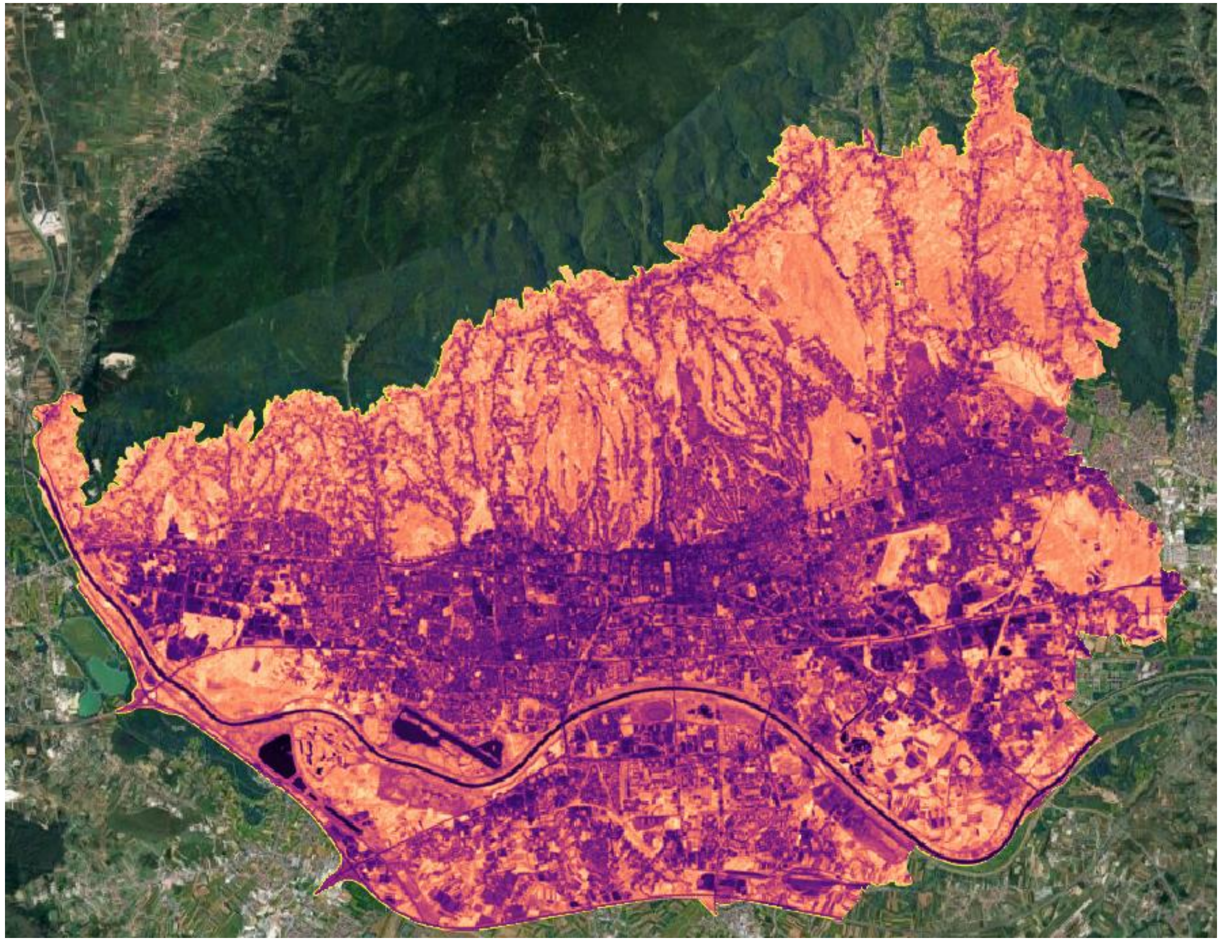
Key facts

- Main goal is to establish statistical correlations between LST, land-use categories, and built-up intensity to evaluate spatial planning impacts on temperature distribution
- **Key innovation is development of a composite UHI index based on:**
  - **LST > daily mean (heat anomaly)**
  - **NDVI < 0.2 (low vegetation)**



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Landsat 9 – Key Features for UHI Analysis

- What is Landsat?
  - Joint NASA & USGS satellite program (since 1972)
  - Captures Earth's surface changes (urbanization, vegetation)
  - Landsat 9 launched in 2021; continues high-resolution Earth observation
- Spectral Bands Used:
  - B4 (Red Band, 30m): Reflectance of red light, used for NDVI
  - B5 (NIR Band, 30m): Reflectance of healthy vegetation, key for NDVI
  - B10: Measures thermal radiation → LST
- Spatial Resolution:
  - B4 & B5: 30m (each pixel = 30×30m area)
  - B10: 100m native, resampled to 30m for analysis alignment

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Research Contribution

Introduces Exploratory Spatial Data Analysis (ESDA) to move from descriptive to causal analysis.

→

Combines satellite data (through LST, NDVI) with urban planning data for a more precise spatial understanding of UHI.

→

Quantifies how zoning types influence local temperature variations

→

Confirms role of vegetation and built-up intensity in UHI patterns

→

Enables evidence-based spatial planning for climate adaptation in dense urban zones

Software Environment

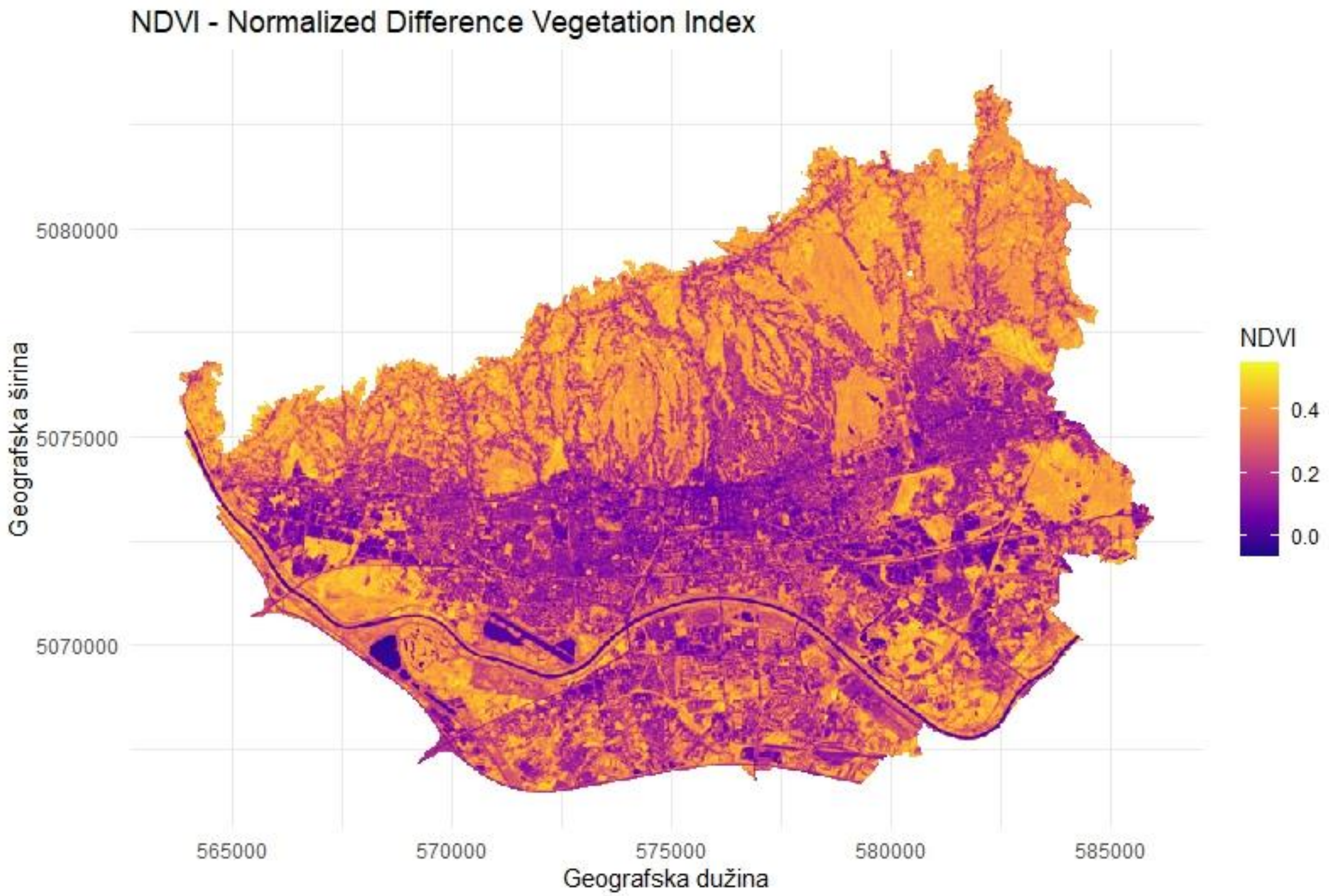
- The analysis was conducted using the R programming language and the QGIS and RStudio applications, with Landsat satellite data and local spatial data used to assess urban heat islands.

QGIS

RStudio®

Workflow

- Data import
- LST calculation
- NDVI calculation
- Statistical analysis
- Reclassification and data export



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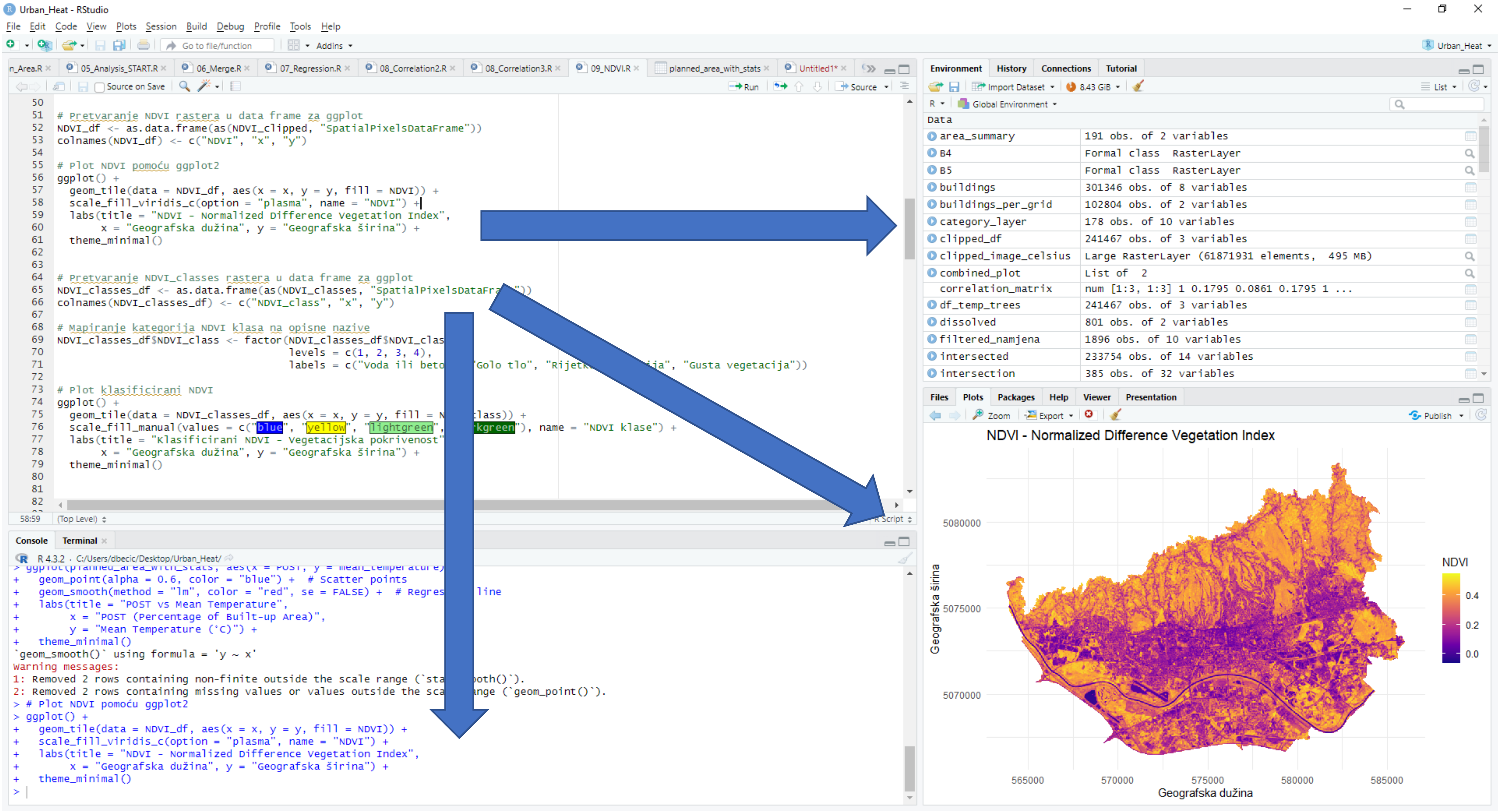
Workflow



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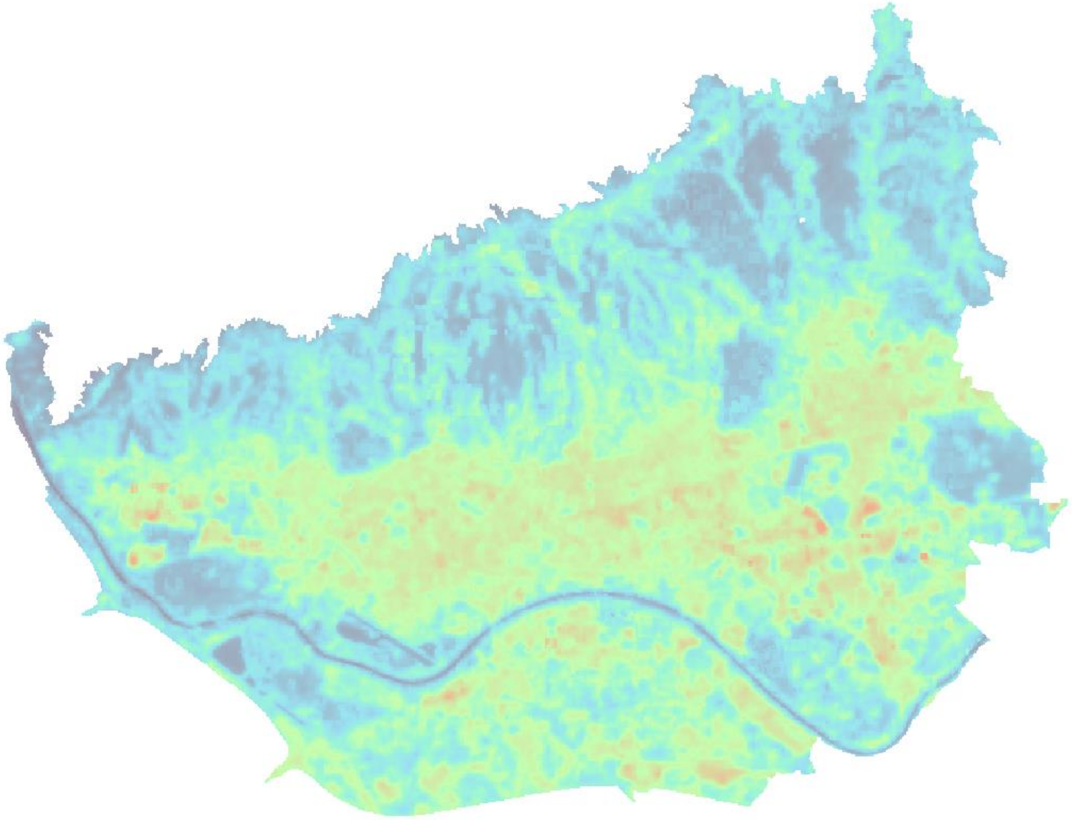
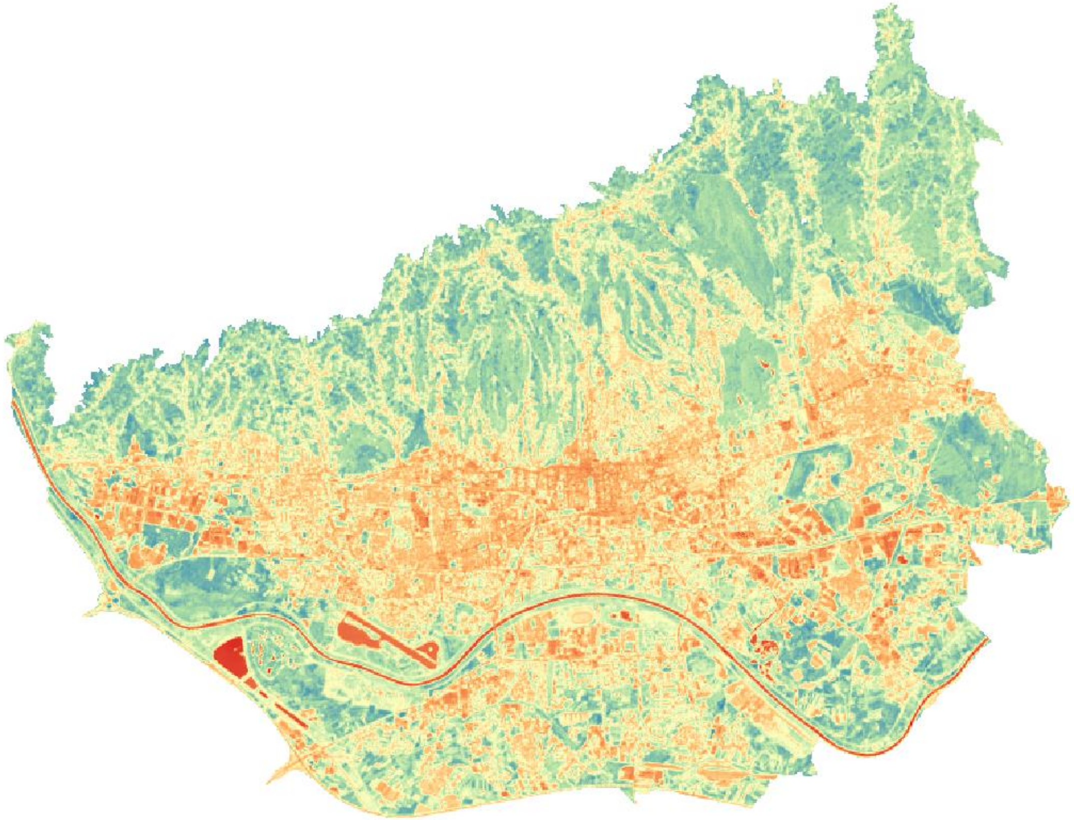
Satellite Imagery Data

LST: Land Surface Temperature



NDVI: Landsat Normalized Difference Vegetation Index



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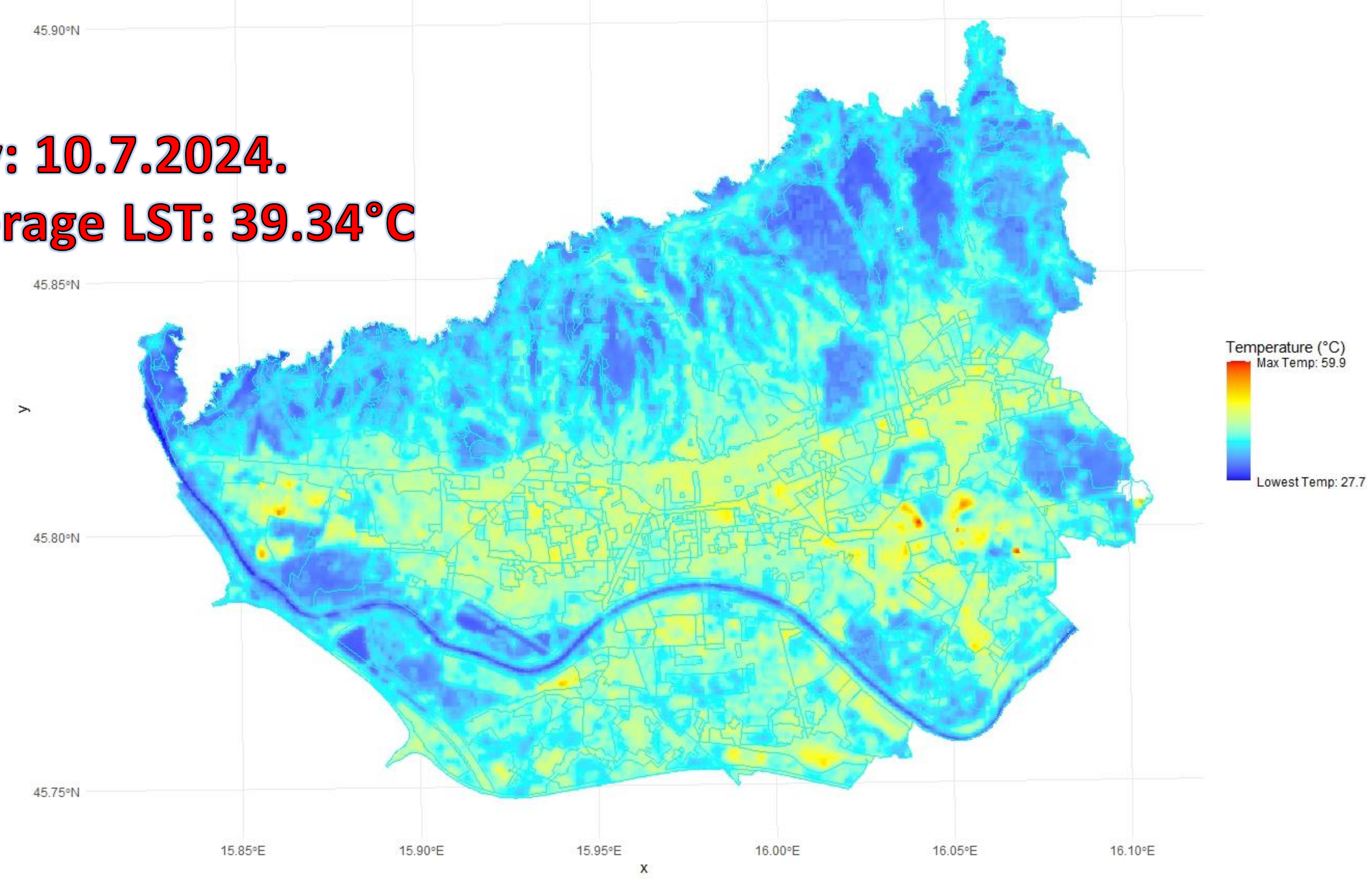
Main insight



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Three-Stage Analytical Framework

1. Correlation & Regression Analysis
   - Examines relationships between LST and urban features (e.g. built-up intensity, planned green zones).
   - Regression quantifies impact of land-use types and built-up density on LST.
2. UHI Index Construction
   - UHI zones = LST > daily mean + NDVI < 0.2
3. Local Indicators of Spatial Autocorrelation (LISA)
   - LISA detects local hot/cold spots (high/low temperature zones)
   - Reveals areas where urban form drives heat accumulation.

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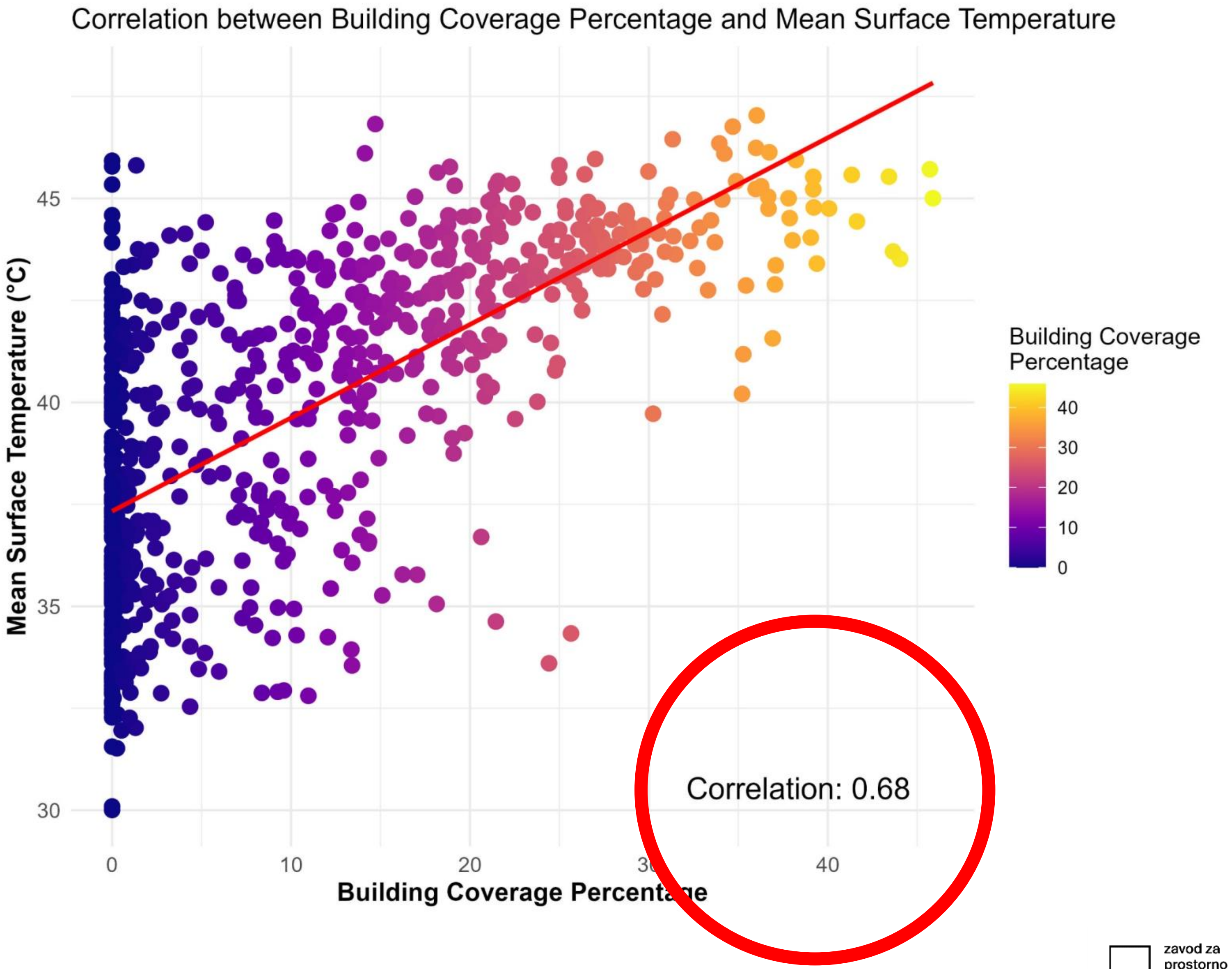
Correlation

- Correlation is a statistical measure showing the strength and direction of the relationship between two variables
- Moderately strong positive correlation (0.68) between built-up intensity and mean LST
- Confirms that higher built-up intensity significantly increases surface temperatures



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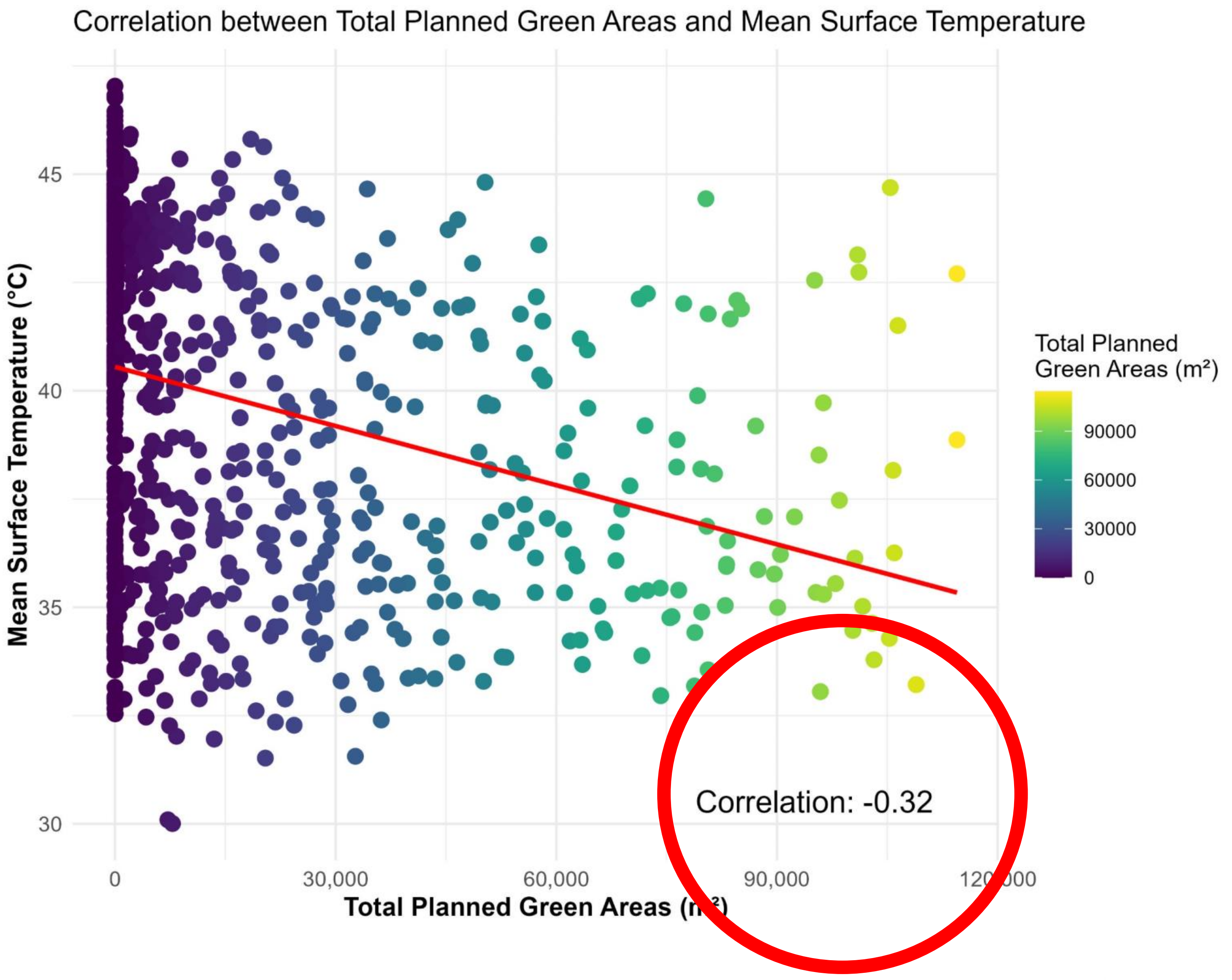
Correlation

- Moderate negative correlation (-0.32) between planned green spaces and mean LST
- Confirms that vegetation has a cooling effect on surface temperatures
- Areas with more green space show lower temperatures, reducing UHI intensity



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Linear Regression Analysis

- Linear regression is used to examine how different land-use categories influence land surface temperature (LST).
- The model shows that park-forests (Z2) and protective green areas (Z) have the strongest negative effect on temperature, meaning they significantly reduce LST.
- Coefficients:
  - Z2_Area = -3.11×10^{-6}
  - Z_Area = -3.29×10^{-6}
- The regression model is statistically significant ($F = 7.25$, $p < 0.001$), confirming a meaningful relationship.

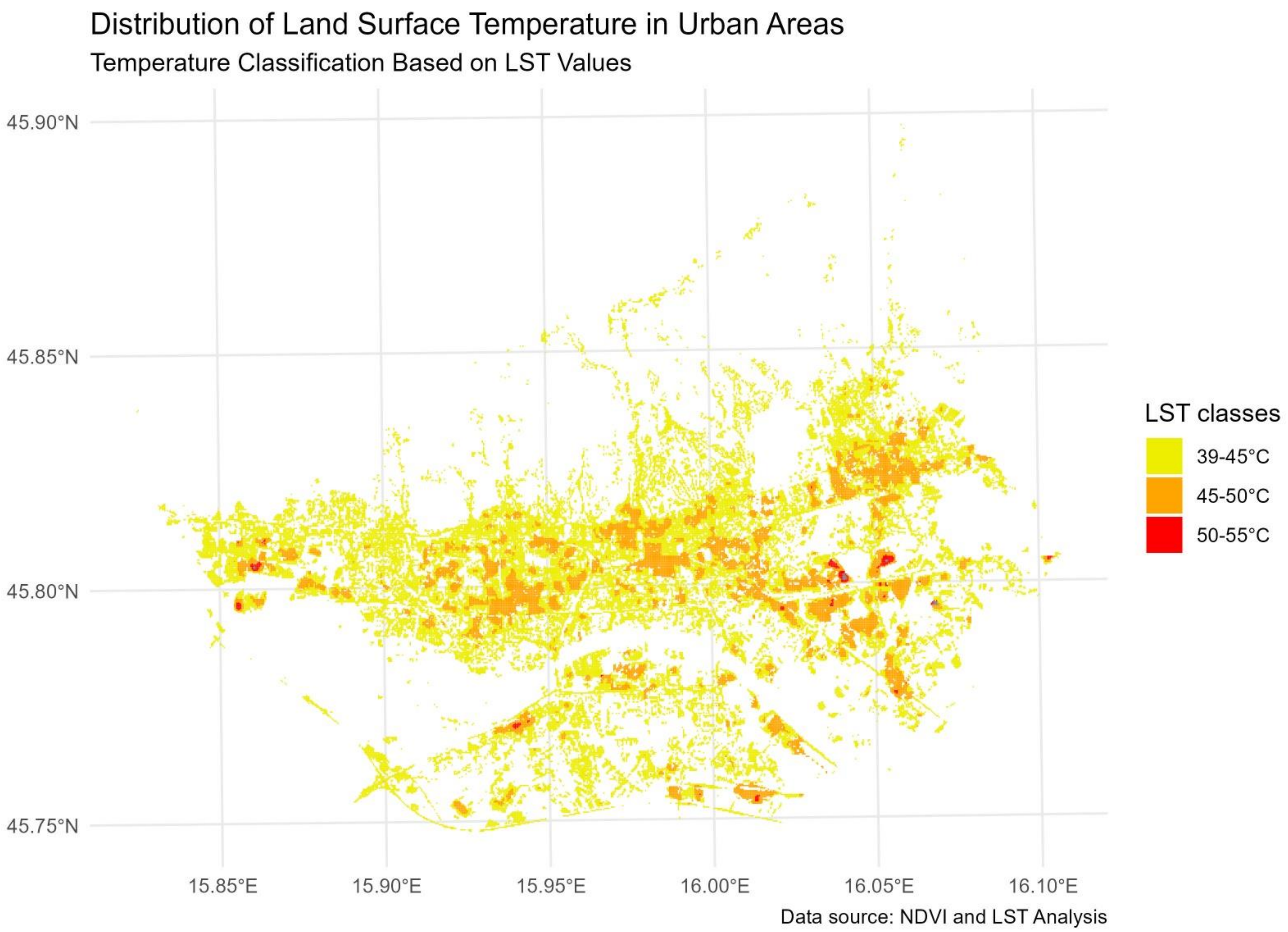
Linear Regression Summary

term	estimate	std.error	statistic	p.value
(Intercept)	39.542	0.131	301.159	0.000
Z1_Area	0.000	0.000	0.429	0.668
Z4_Area	0.000	0.000	2.558	0.011
Z2_Area	0.000	0.000	-3.831	0.000
Z3_Area	0.000	0.000	-0.194	0.846
R2_Area	0.000	0.000	-0.806	0.421
R1_Area	0.000	0.000	2.688	0.007
V1_Area	0.000	0.000	-1.112	0.266
V2_Area	0.000	0.000	0.760	0.448
Z_Area	0.000	0.000	-4.045	0.000
V3_Area	0.000	0.000	-2.546	0.011

Composite Urban Heat Island (UHI) Index

- The second stage of the analysis involves creating a composite UHI index by integrating:
  - Land Surface Temperature (LST)
  - Normalized Difference Vegetation Index (NDVI)
- Thresholds applied:
  - LST > 39°C – highlights zones with significant surface heat, based on the daily average from satellite imagery.
  - NDVI < 0.2 – identifies areas with low vegetation cover.
- This dual-filtering method allows more accurate identification of heat-prone zones by distinguishing:
  - Areas with high temperatures due to built-up intensity
  - From those where lack of vegetation is the dominant factor.

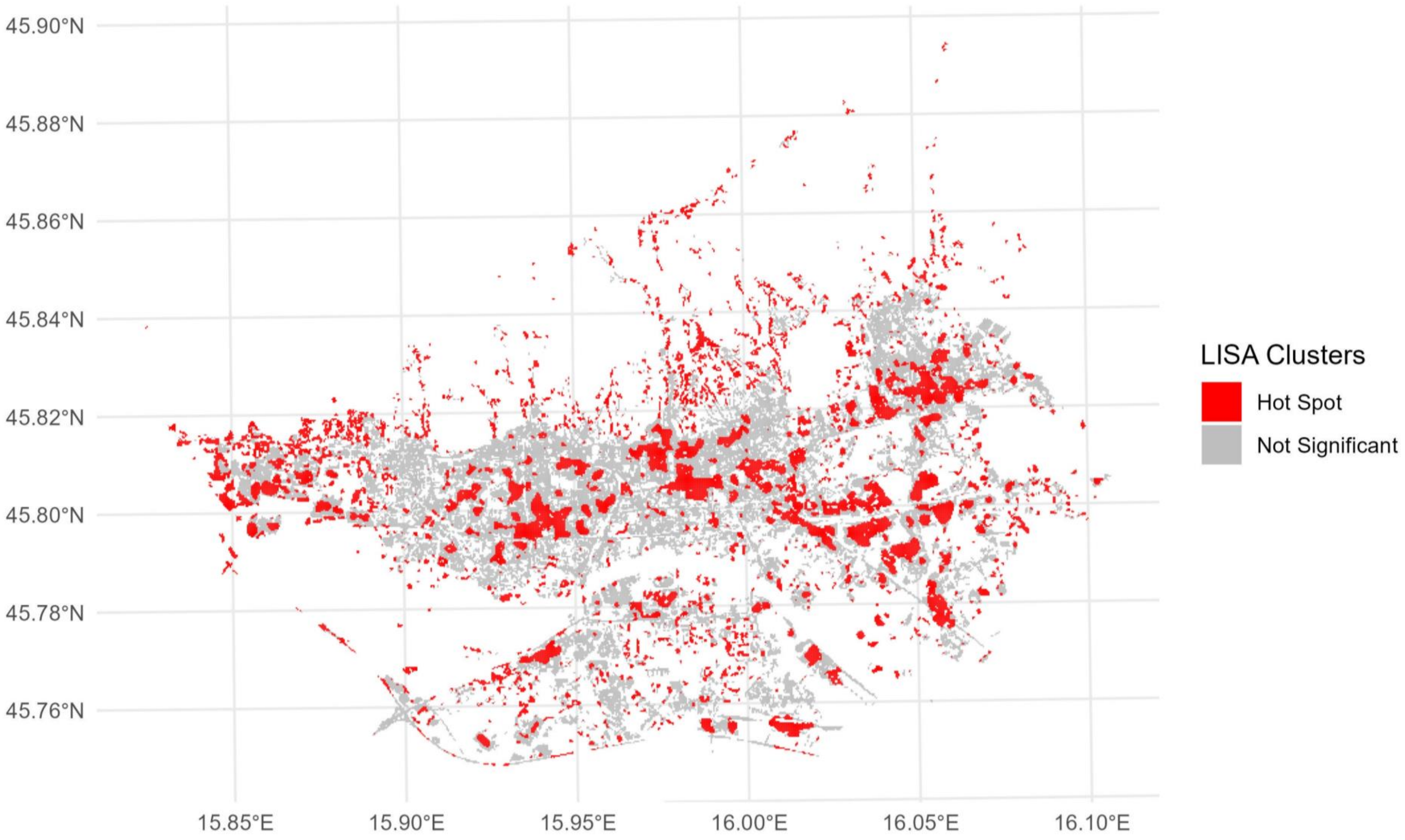
Composite Urban Heat Island (UHI) Index



Spatial Autocorrelation and Hotspot Detection

- Third stage of the analysis uses Local Moran’s I (LISA) to examine spatial clustering of high land surface temperature (LST) values.
- Local spatial analysis (LISA):
  - Identifies statistically significant hotspots – areas where high LST zones are surrounded by other high-temperature areas.
- Implications:
  - Enables precise spatial targeting for climate adaptation.
  - Spatial autocorrelation tools provide evidence-based support for urban planning by highlighting critical UHI zones requiring intervention.

Spatial Autocorrelation and Hotspot Detection



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Conclusions

- This study integrates correlation, regression, and spatial autocorrelation to assess UHI dynamics in Zagreb.
- Built-up intensity is a major contributor to increased land surface temperatures (LST), while planned green zones (Z, Z2) significantly reduce local heat.
- Moran’s I (0.920, $p < 0.001$) and LISA identify spatially clustered UHI hotspots in dense, impervious urban areas.
- Use of Landsat-9 imagery (July 10, 2024) ensures high-resolution analysis of extreme temperature conditions.
- Findings confirm spatial dependency of UHI formation, validating the influence of zoning and land use patterns.

Implications

- While not focused on proposing mitigation strategies, the study identifies priority zones for climate adaptation planning.
- Results highlight the importance of:
  - Green infrastructure expansion
  - Preservation of planned green areas (Z1–Z4)
  - Evidence-based zoning adjustments
- Future work should:
  - Use multi-temporal analysis for long-term monitoring.
  - Integrate additional climate factors (e.g., wind, humidity, anthropogenic heat).

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Thank you!

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