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Remote Sensing Technique For Temporal and Spatial Mapping of the LST and Surface Urban Heat Island (SUHI) Development Between 1990–2025 in Plovdiv, Bulgaria

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ABSTRACT

The main objective of this study is to map the temporal and spatial development of land surface temperature (LST) and surface urban heat island (SUHI) within the city of Plovdiv, Bulgaria, for the period between 1990 and 2025. The analysis is based on satellite imagery and remote sensing techniques, using Landsat data processed through Google Earth Engine and geographic information system software. Average summer LST and the normalized difference vegetation index (NDVI) were calculated for selected reference years in order to assess long-term trends in urban heat accumulation and their relationship with land cover characteristics. The results indicate a clear increase in LST over the studied period, with the highest values observed in densely built-up areas, industrial zones, and large open surfaces with limited or no vegetation. In contrast, areas with well-developed green infrastructure, including urban parks and the Maritsa River corridor, exhibit lower surface temperatures and a mitigating effect on urban heat intensity. The analysis also reveals the gradual formation of a surface urban heat island belt surrounding the city core, as well as the emergence of localized micro-scale heat islands in newly urbanized peripheral areas. These patterns reflect the combined effects of urban expansion, land-use change, and regional climate warming. The study confirms the reliability of satellite-based remote sensing for assessing urban thermal environments and highlights its practical relevance for sustainable urban planning, climate adaptation measures, and smart city development.

Keywords: *Remote sensing, Land surface temperature, Surface urban heat island, NDVI, LST, Landsat satellites, Urban climate, Plovdiv, Bulgaria*

INTRODUCTION

Climate change has led to a noticeable increase in the frequency and duration of heat waves across Europe, significantly impacting urban areas. Rapid population growth in cities, coupled with large areas of unvegetated land, makes urban environments particularly susceptible to rising land surface temperatures (LST). Elevated LST poses health risks, especially for vulnerable groups within the urban population, creating a pressing need for innovative urban development practices to mitigate the effects of heat waves. The urban heat island effect, characterized by higher temperatures in urban areas compared to their rural surroundings (Decheng et al., 2018), further compounds these challenges. This phenomenon results from varying land cover types and the presence or absence of vegetation and water bodies within the city.

The connection between urbanization patterns and surface urban heat island (SUHI) has been investigated in numerous scientific studies. Dimitrov et al. (2024) applied thermal photogrammetry using unmanned aerial systems (UAS), combined with geographic information systems (GIS), to analyse surface urban heat island intensity at a local level for the largest housing complex in Bulgaria – the Lyulin district of Sofia. Dimitrov et al. (2024) found a temperature difference of 16.5 °C between locations affected by surface urban heat islands and peripheral non-built or natural land cover types within the urbanized area. In similar research, Dimitrov et al. (2023) used thermal photogrammetry carried out by an unmanned aerial system to determine local climate zones (LCZ) in the city of Burgas, Bulgaria. Sarafova et al. (2025) investigated the urban heat island phenomenon in Bulgaria during the extreme heatwave event of July 2024, using high-resolution ECOSTRESS satellite data from the International Space Station. In their research, Sarafova et al. (2025) mapped and visualized temperature variations across major urban centres in the country. The data cover 26 of the 27 regional capitals, highlighting the pronounced urban heat island effect in densely populated and industrial areas. Spasova et al. (2021; 2024) also investigated the connection between urban heat islands and renewable energy sources in different planning regions of Bulgaria.

Elevated temperatures not only deteriorate the quality of life for residents but also lead to increased energy consumption and higher greenhouse gas emissions. Therefore, mapping areas with elevated LST is a crucial tool for effective urban planning and an integral part of the smart city concept, aimed at enhancing urban sustainability and resilience. Advances in remote sensing in recent decades, together with the large number of available satellite instruments, have significantly improved techniques for mapping surface urban heat islands.

Based on the above, the main goal of this research is to map surface urban heat islands within the city of Plovdiv, Bulgaria, using satellite data, remote sensing techniques, the Google Earth Engine Code Editor, and ArcGIS Pro for result interpretation. Plovdiv is one of Bulgaria's oldest cities, renowned for its rich history and vibrant culture. Situated in the south-central part of the country, it features a unique blend of ancient and modern influences, including well-preserved Roman ruins, such as the Ancient Theatre and Stadium, alongside Ottoman-era buildings and contemporary urban areas. The city is built on seven hills, offering picturesque views and favourable conditions for urban green spaces.

In recent years, the city has experienced significant economic development, and the presence of several industrial zones has attracted both local and foreign investment. As a result of this industrial expansion, Plovdiv has experienced gradual population growth, reflecting positive trends in migration and urbanization. The population of Plovdiv municipality was 329,489 inhabitants in 2024, with a positive net migration of 4,887 people during the same year (www.nsi.bg). This positive migration trend has led to a significant rise in construction activity and rapid urbanization of the city outskirts. The city's rapid growth has resulted in the replacement of natural landscapes with concrete and asphalt surfaces, contributing to the surface urban heat island effect, where built environments absorb and retain heat, leading to higher temperatures compared to surrounding green areas.

Although the city maintains a relatively well-developed green infrastructure, many urban areas lack sufficient vegetation, which reduces the natural cooling effects provided by trees and plants. High building density and the expansion of large industrial infrastructures also lead to increased land surface temperatures, forming distinct surface urban heat islands in certain parts of the city. The geographical characteristics of Plovdiv, including its valley location and surrounding hills, may further influence local climate conditions, limiting air circulation and contributing to heat accumulation during summer periods.

MATERIALS AND METHODS

The area of interest is the city of Plovdiv, Bulgaria (Fig. 2). The city is situated in the south-central part of the country. Plovdiv is the second largest and one of the most significant cities in the Republic of Bulgaria. It is located on both banks of the Maritsa River in the Upper Thracian Plain, at a latitude of 42° 9′ N and a longitude of 24° 45′ E, with its lowest point at 160 meters above sea level. The city covers an area of 101.981 square kilometers, and its population is approximately 338,153 people (www.plovdiv.bg).

Plovdiv is a strategically important industrial, commercial, scientific, cultural, and transportation hub in the Balkans. It is internationally known for the International Fair, whose spring and autumn exhibitions, along with numerous specialized events, make it a center for commerce and business. The city is a key railway junction, and Plovdiv Airport has recently established itself as an alternative to Sofia Airport (www.plovdiv.bg).

Important international highways pass through the city, historically connecting the Orient with Europe, the Baltic Sea with the Mediterranean, and the Black Sea with the Adriatic. Its unique location at an ancient crossroads has contributed to strong cultural and political influences from both Eastern and Western civilizations, while maintaining an exceptional cultural identity. The six granite hills give the city a distinctive and picturesque character and, as protected areas, preserve a significant number of rare plant species. Together with the Maritsa River basin, the green-covered hills create specific climatic conditions – relatively mild winters and hot, humid summers. The favorable climate and geographical position of Plovdiv have supported its continuous development throughout all historical periods.

The city of Plovdiv is located within the transitional continental climate zone of Eastern Central Bulgaria. This region encompasses most of the lowlands along the Maritsa and Tundzha rivers and borders the Continental-Mediterranean climatic region to the southeast (Velev, 2010). ERA5-Land data provide evidence of a warming trend, as historical records for Plovdiv show a clear upward shift. The 40-year average temperature is approximately 12.36 °C, while the average for the most recent 20 years has risen to approximately 13.10 °C and to 13.53 °C for the last 10 years. In addition, significant seasonal shifts are observed: ERA5-Land data for Plovdiv indicate that summer temperatures have increased markedly (by nearly 2 °C) over the last 30 years, whereas winter temperatures have risen more modestly (by about 0.5 °C). ERA5-Land data have a spatial resolution of 9 km, making them highly suitable for identifying regional climate trends compared to standard global climate models. This conclusion is further supported by average annual temperature data for the period 1986–2025, which show a clear positive trend (Fig. 1).

Similar conclusions are reported by Stoyanov et al. (2025), who identified a gradual but consistent increase in mean annual temperature starting around 2005 and accelerating after 2015. As a result, mean annual temperatures reached values between 14.5 and 15 °C during the period 2022–2024, representing a substantial increase compared to the 12–13 °C range observed between 1977 and 2000. Overall, the data indicate a sustained upward trend in mean annual temperatures in Plovdiv for the period 1977–2024 (Stoyanov et al., 2025).

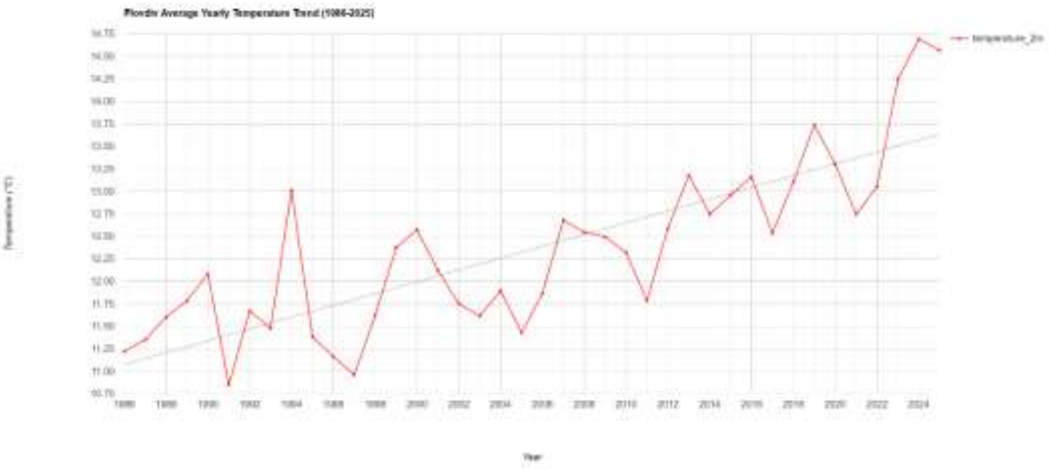


Fig. 1. Monthly temperature trend for Plovdiv (1986–2025), based on ERA5 data with 9 km spatial resolution.

The city has experienced significant economic development in recent years, and the presence of several industrial zones has attracted both local and foreign investment. As a result of the recent boom in industrial activity, Plovdiv has undergone a gradual increase in population, reflecting a positive trend in migration and urbanization. This positive net migration trend has also led to a significant expansion of the construction industry and rapid urbanization of the city outskirts.

Plovdiv’s urban development has changed considerably over time, reflecting its rich historical heritage while accommodating modern needs. The city places strong emphasis on preserving its cultural and historical sites, ensuring that areas such as the Old Town retain their unique architectural style and historical character, which also contributes to the promotion of tourism.

In terms of infrastructure, Plovdiv has seen substantial investments in transportation systems, road networks, and utilities. Improvements in public transport and road infrastructure have increased connectivity both within the city and with nearby regions. In addition, efforts are being made to develop and enhance public spaces, making them more accessible and attractive for residents and visitors. These initiatives include the expansion of parks, pedestrian zones, and recreational areas, thereby improving the overall quality of life.

Plovdiv is also focusing on sustainable urban practices, such as eco-friendly building initiatives and the expansion of green spaces. The city is working to incorporate renewable energy solutions and to promote cycling and walking as alternative modes of transport. Furthermore, Plovdiv is exploring smart city initiatives by integrating digital technologies into urban services in order to enhance efficiency and citizen engagement.

Finally, the growing demand for housing has resulted in increased residential development, with new apartment complexes and mixed-use buildings being constructed to meet the needs of the expanding population.

Due to rapid economic and urban development, Plovdiv, like many urban areas, is highly vulnerable to elevated land surface temperatures (LST). The city’s rapid growth has led to extensive construction, replacing natural landscapes with concrete and asphalt surfaces. This urban expansion contributes to the Surface Urban Heat Island (SUHI) effect, in which built-up environments absorb and retain heat, resulting in higher temperatures compared to surrounding green areas. Although Plovdiv maintains relatively well-developed green infrastructure, many urban zones still lack sufficient vegetation, which reduces the natural cooling effects provided by trees and plants. High building density and the development of large industrial infrastructures further contribute to increased land surface temperatures, forming a clearly distinguishable surface urban heat island in certain parts of the city (Ivanov et al., 2024).

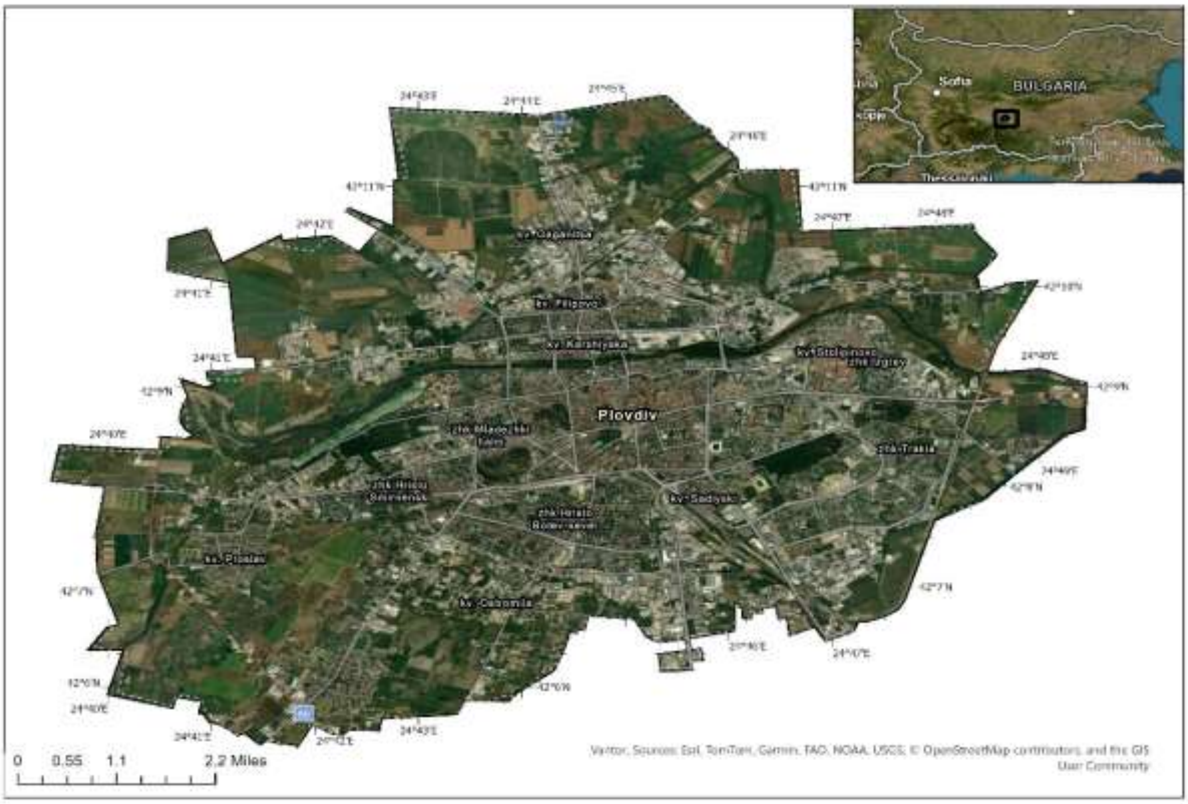


Fig. 2. Seasonal temperature variability for Plovdiv (1986–2025), based on ERA5 data with 9 km spatial resolution.

The geographical characteristics of Plovdiv, including its valley location and surrounding hills, can also influence local climatic conditions by limiting airflow and contributing to heat accumulation during summer periods, as well as temperature inversions in colder months. These inversions are often accompanied by fog formation and elevated concentrations of fine particulate matter. In addition, increasing traffic volumes and frequent traffic congestion contribute to environmental pressures within the city.

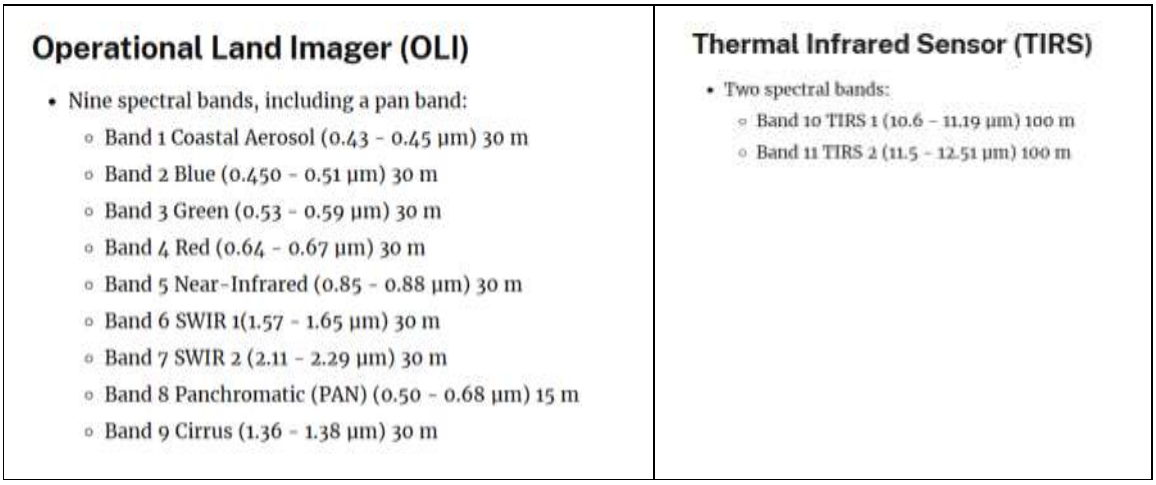
To analyze the temporal dynamics and spatial distribution of land surface temperatures within the city of Plovdiv, a series of satellite images captured during the summer period – from 1 June to 31

August – were used for the years 2025, 2015, 2005, 1995, and 1990. The year 1990 was selected as a reference point because, following the political changes in Bulgaria in 1989, the country underwent a transition to a new economic model, which substantially altered the patterns of urban and economic development in Plovdiv, as well as nationwide.

The satellite images used in this research were acquired by the Landsat 8 and Landsat 5 satellites, operated by NASA. The primary instruments onboard Landsat 8 are the Operational Land Imager (OLI) and the Thermal Infrared Sensor (TIRS). The OLI collects data in the visible, near-infrared, and shortwave infrared portions of the electromagnetic spectrum (VNIR, NIR, and SWIR). The TIRS measures land surface temperature using two thermal bands and employs advanced sensor technology for heat detection.

Landsat 8 imagery provides a spatial resolution of 15 meters for the panchromatic band and 30 meters for multispectral bands, with a swath width of 185 km (115 mi) (www.usgs.gov). The spectral resolution of Landsat 8 imagery is presented in Table 1.

Table 1 – Spectral resolution of Landsat 8 (source www.usgs.gov)



Operational Land Imager (OLI)

- Nine spectral bands, including a pan band:
    - Band 1 Coastal Aerosol (0.43 - 0.45 µm) 30 m
    - Band 2 Blue (0.450 - 0.51 µm) 30 m
    - Band 3 Green (0.53 - 0.59 µm) 30 m
    - Band 4 Red (0.64 - 0.67 µm) 30 m
    - Band 5 Near-Infrared (0.85 - 0.88 µm) 30 m
    - Band 6 SWIR 1(1.57 - 1.65 µm) 30 m
    - Band 7 SWIR 2 (2.11 - 2.29 µm) 30 m
    - Band 8 Panchromatic (PAN) (0.50 - 0.68 µm) 15 m
    - Band 9 Cirrus (1.36 - 1.38 µm) 30 m

Thermal Infrared Sensor (TIRS)

- Two spectral bands:
    - Band 10 TIRS 1 (10.6 - 11.19 µm) 100 m
    - Band 11 TIRS 2 (11.5 - 12.51 µm) 100 m

To determine the temporal development and spatial distribution of the Surface Urban Heat Island (SUHI) in the city of Plovdiv, remote sensing techniques, the Google Earth Engine Code Editor, and GIS analyses using ArcGIS Pro software were applied to calculate the Normalized Difference Vegetation Index (NDVI) and Land Surface Temperature (LST).

Because the temporal resolution of Landsat satellites is 16 days, average LST values for the summer period – from 1 June to 31 August – were calculated for the years 2025, 2015, 2005, 1995, and 1990. The code used for satellite image processing is presented in Fig. 3.

In addition, both the code and the corresponding results are accessible via the following links:

For Landsat 8: https://code.earthengine.google.com/4aa4b9a70f570cba0e5dc6a7c1f048b3

For Landsat 5: https://code.earthengine.google.com/b249b6b1dab291a094a9fd1686f2fe2b

To visualize the data for different years, the date range specified in the command .filterDate ('2025-06-01', '2025-08-31') can be modified to match the desired time period.

```
/**
 * Average Summer LST & NDVI - Plovdiv 2025
 * Sensor: Landsat 8 OLI/TIRS Collection 2 Level 2
 */

// 1. Define Area of Interest (AOI) - Plovdiv
var p_lat = 42.1354;
var p_lon = 24.7453;
var aoi = ee.Geometry.Point([p_lon, p_lat]).buffer(7000).bounds();

// 2. Load Landsat 8 Collection 2 Level 2 for Summer 2025 (June - August)
var summer2025 = ee.ImageCollection("LANDSAT/LC08/C02/T1_L2")
    .filterBounds(aoi)
    .filterDate('2025-06-01', '2025-08-31')
    .filter(ee.Filter.lt('CLOUD_COVER', 40));

// 3. Define Processing Function
var processImage = function(image) {
  // Scaling Factors for Collection 2
  var thermal = image.select('ST_B10').multiply(0.00341802).add(149.0); // Kelvin
  var optical = image.select('SR_B.').multiply(0.0000275).add(-0.2);

  // NDVI Calculation (NIR=B5, Red=B4)
  var ndvi = optical.normalizedDifference(['SR_B5', 'SR_B4']).rename('NDVI');

  // Emissivity based on NDVI
  var pv = ndvi.expression('((ndvi - 0.2) / (0.5 - 0.2))**2', {'ndvi': ndvi});
  var emissivity = pv.multiply(0.004).add(0.986);

  // LST Calculation (Celsius)
  var lst = thermal.expression(
    '(TB / (1 + (0.00115 * (TB / 1.438)) * log(em))) - 273.15', {
      'TB': thermal,
      'em': emissivity
    }).rename('LST');

  return image.addBands([lst, ndvi]);
};

// 4. Map Function and Calculate Mean
var processedCollection = summer2025.map(processImage);
var averageSummer2025 = processedCollection.mean().clip(aoi);

// 5. Visualizations
Map.centerObject(aoi, 12);

// LST Layer
var lstVis = {
  min: 25,
  max: 45,
  palette: ['blue', 'green', 'yellow', 'orange', 'red']
};
Map.addLayer(averageSummer2025.select('LST'), lstVis, 'Avg Summer LST 2025');

// NDVI Layer
var ndviVis = {
  min: 0,
  max: 0.8,
  palette: ['#FFFFFF', '#CE7E45', '#F18555', '#66A000', '#012E01']
};
Map.addLayer(averageSummer2025.select('NDVI'), ndviVis, 'Avg Summer NDVI 2025');

// 6. EXPORTS (Check "Tasks" tab to Run)
Export.image.toDrive({
  image: averageSummer2025.select('LST'),
  description: 'Plovdiv_Summer_LST_2025',
  scale: 30,
  region: aoi,
  fileFormat: 'GeoTIFF'
});

Export.image.toDrive({
  image: averageSummer2025.select('NDVI'),
  description: 'Plovdiv_Summer_NDVI_2025',
  scale: 30,
  region: aoi,
  fileFormat: 'GeoTIFF'
});

print('Images used for average:', processedCollection.size());
```

Fig. 3. Methodology for calculating urban heat islands (Opong J., 2021)

The calculation of the Normalized Difference Vegetation Index (NDVI) was performed using the Google Earth Engine Code Editor with Java-based coding (Fig. 2). The generated raster data were extracted and analyzed in ArcGIS Pro, where classified raster images representing NDVI values and average seasonal Land Surface Temperature (LST) were produced.

The resulting images were clipped to the boundaries of the Urban Development Master Plan of the Plovdiv Municipality, which encompass not only the urban areas of the municipality but also agricultural lands and natural habitats.

RESULTS

The values of the Normalized Difference Vegetation Index (NDVI) for the periods 1990–1995 (Fig. 4), 2005–2015 (Fig. 4), and for the year 2025 within the study area indicate that vegetation cover and green spaces are relatively well distributed both around the city and within its administrative boundaries. In 1990, the city was surrounded by well-defined agricultural lands and open spaces. However, NDVI values were generally lower in agricultural areas and along the green zones within the city, with prevailing values between 0.20 and 0.40. This can be attributed to dry climatic conditions observed in Bulgaria during the 1990s, as well as to agricultural activities such as crop harvesting or ploughing.

From a temporal perspective, the main components of green infrastructure within the central parts of the city of Plovdiv have remained largely intact throughout the study period. Nevertheless, after 2005, rapid urbanization became evident in the peripheral zones of the city, particularly in the southern, northern, and western districts, as well as within the northern, southern, and western industrial zones. This process has been accompanied by an increase in building density and a reduction of green areas within some high-density residential neighbourhoods that were planned and constructed prior to 1989.

The results further indicate that vegetation presence is less pronounced in the city centre. At the same time, some green areas located within older high-rise residential neighbourhoods, developed before 1989, remain partially preserved, although they are often inadequately maintained.

The analysis of Land Surface Temperature (LST) for the period 1990–2025 (Fig. 7, Fig. 8, Fig. 9) across the territory of the city of Plovdiv shows that areas with higher temperatures strongly overlap with zones lacking vegetation or characterized by sparse vegetation cover. Elevated temperatures are also observed in the historic city center and within industrial areas located around the city.

A clear increasing trend in LST is identified over the study period. The minimum average summer LST values increased from approximately 24 °C in 1990 to around 30 °C in 2025. A similar trend is observed for maximum LST values, which rose from 54.89 °C in 1990 to 56.31 °C in 2025.

This increase can be attributed to rapid urbanization in certain parts of the city and the expansion of industrial infrastructure, as well as to the overall warming trend of the regional climate, as Plovdiv has experienced a substantial temperature increase of approximately +1.5 to 2 °C since the 1970s (Stoyanov et al., 2025).

The temporal analysis of LST in Plovdiv between 1990 and 2025 reveals a gradual formation of a new heat island belt surrounding the urban core (Fig. 10), along with the development of localized micro heat islands within the most densely built-up areas of the city.

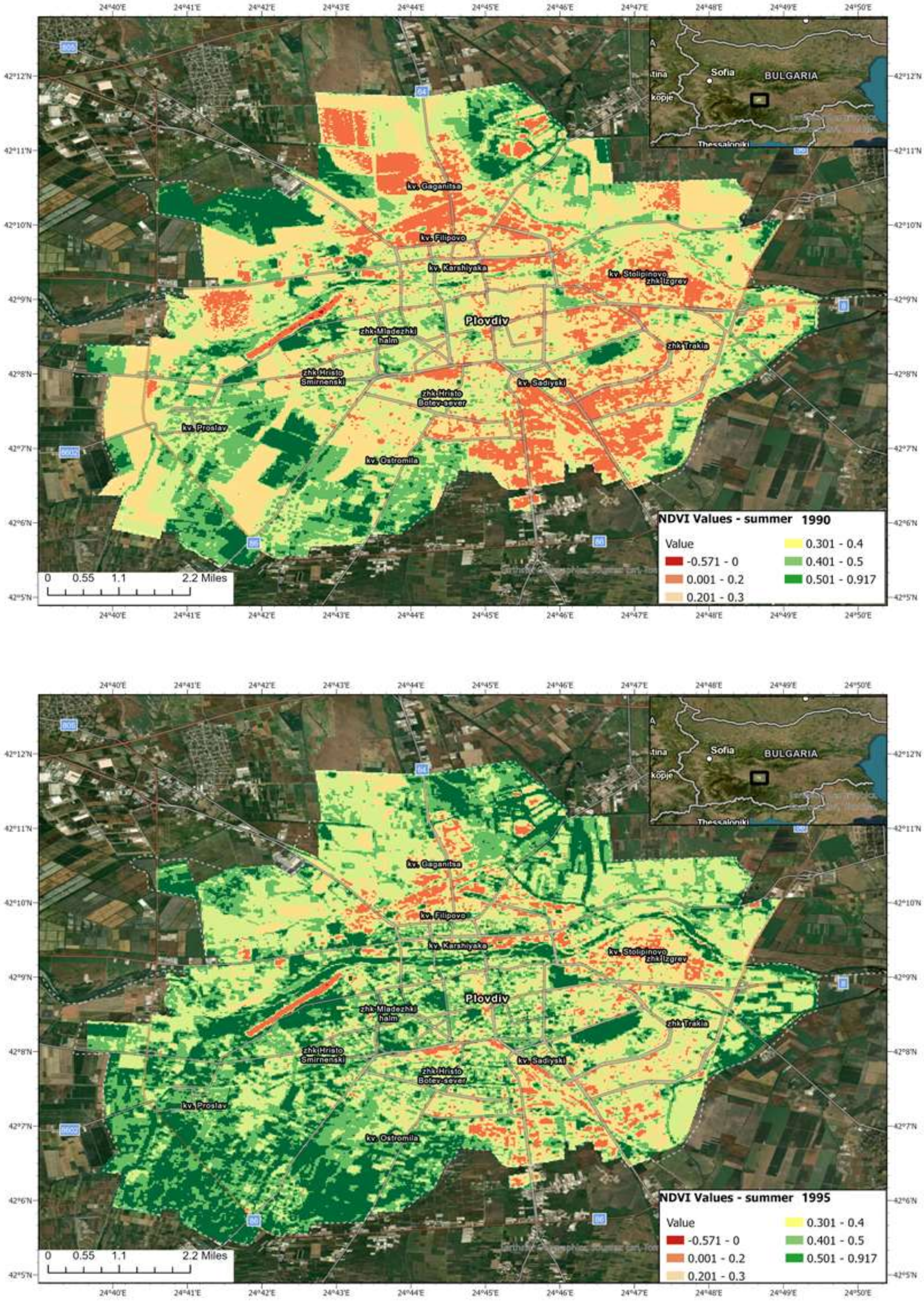
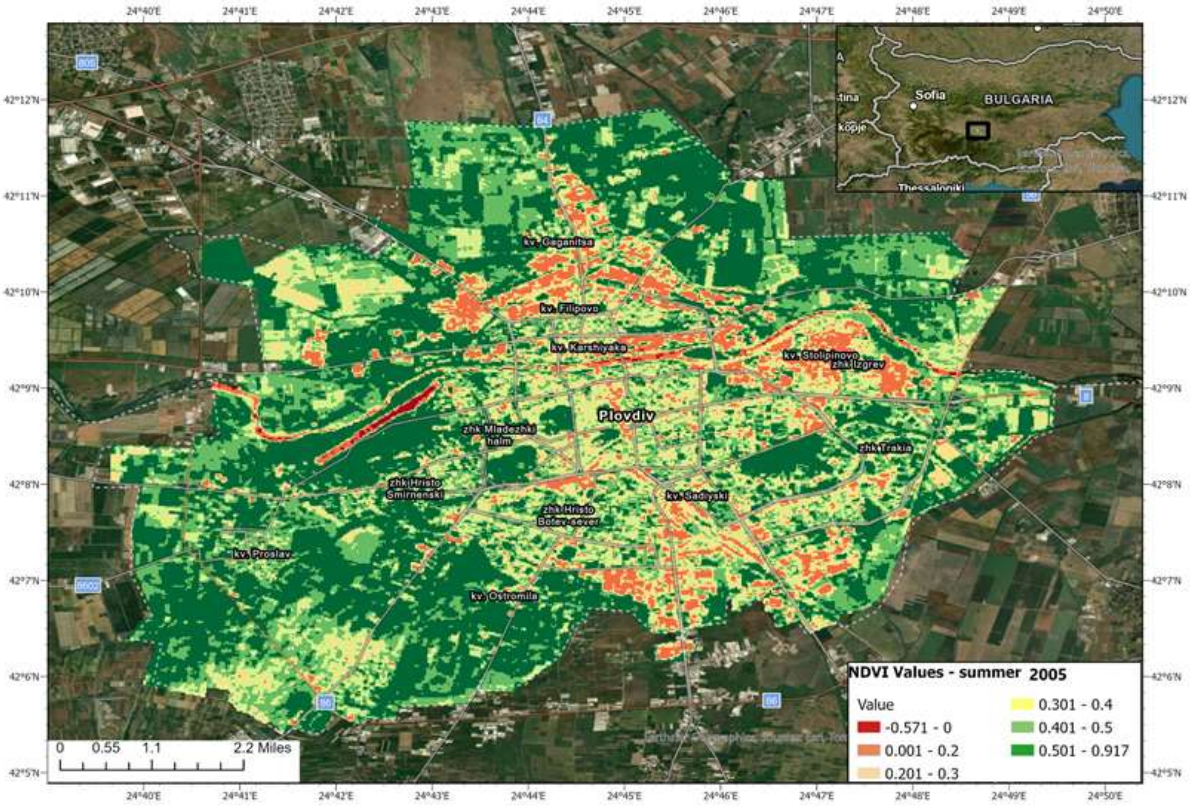


Fig. 4. Dynamics of NDVI values for the period 1990–1995; values above 0.50 represent dense and healthy vegetation.



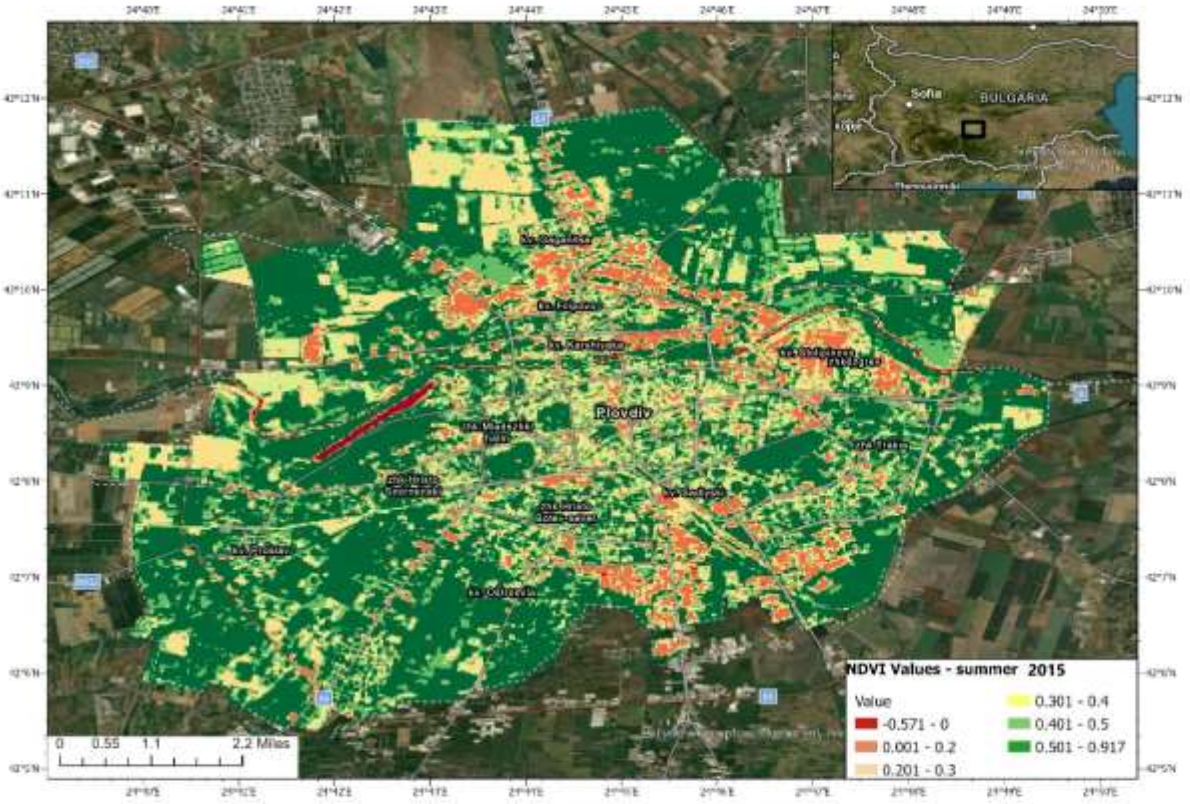


Fig. 5. Dynamics of NDVI values for the period 2005–2015; values above 0.50 represent dense and healthy vegetation.

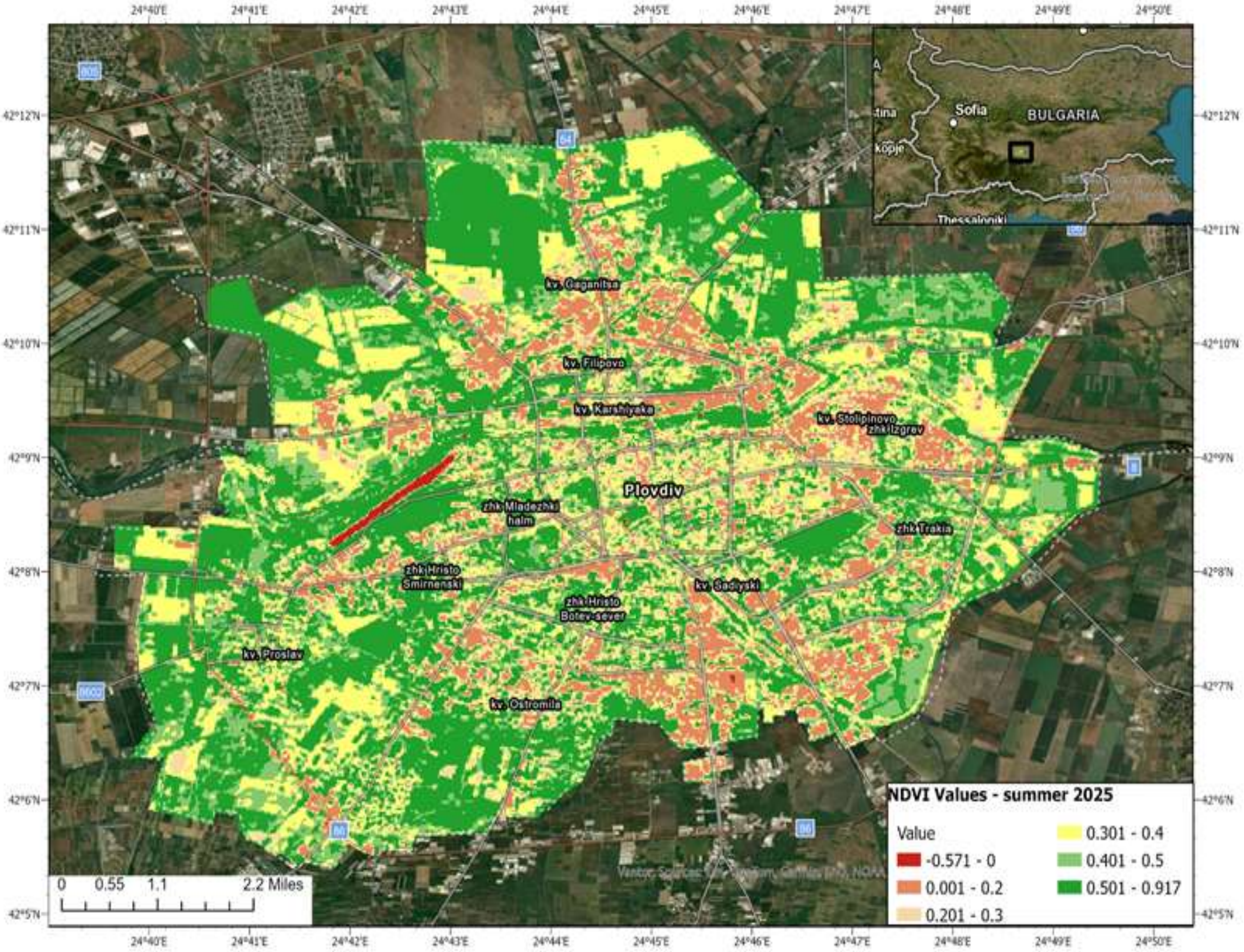


Fig. 6. Dynamics of NDVI values for the year 2025; values above 0.50 represent dense and healthy vegetation.

The well-developed green infrastructure within the central urban area, as well as the vegetated corridor along the Maritsa River, exerts a mitigating effect on heat vulnerability in certain parts of the city. However, a lack of green infrastructure is evident within the so-called heat island belt, which includes the industrial zones surrounding the city core, newly developed peripheral neighbourhoods, and socially vulnerable residential areas with lower population income levels, such as Stolipinovo (Fig. 10).

If current trends of building densification and rapid peripheral urbanization continue, combined with the expected rise in summer temperatures, the planning and implementation of new green infrastructure, along with additional measures to reduce the thermal footprint of existing buildings, will become increasingly necessary.

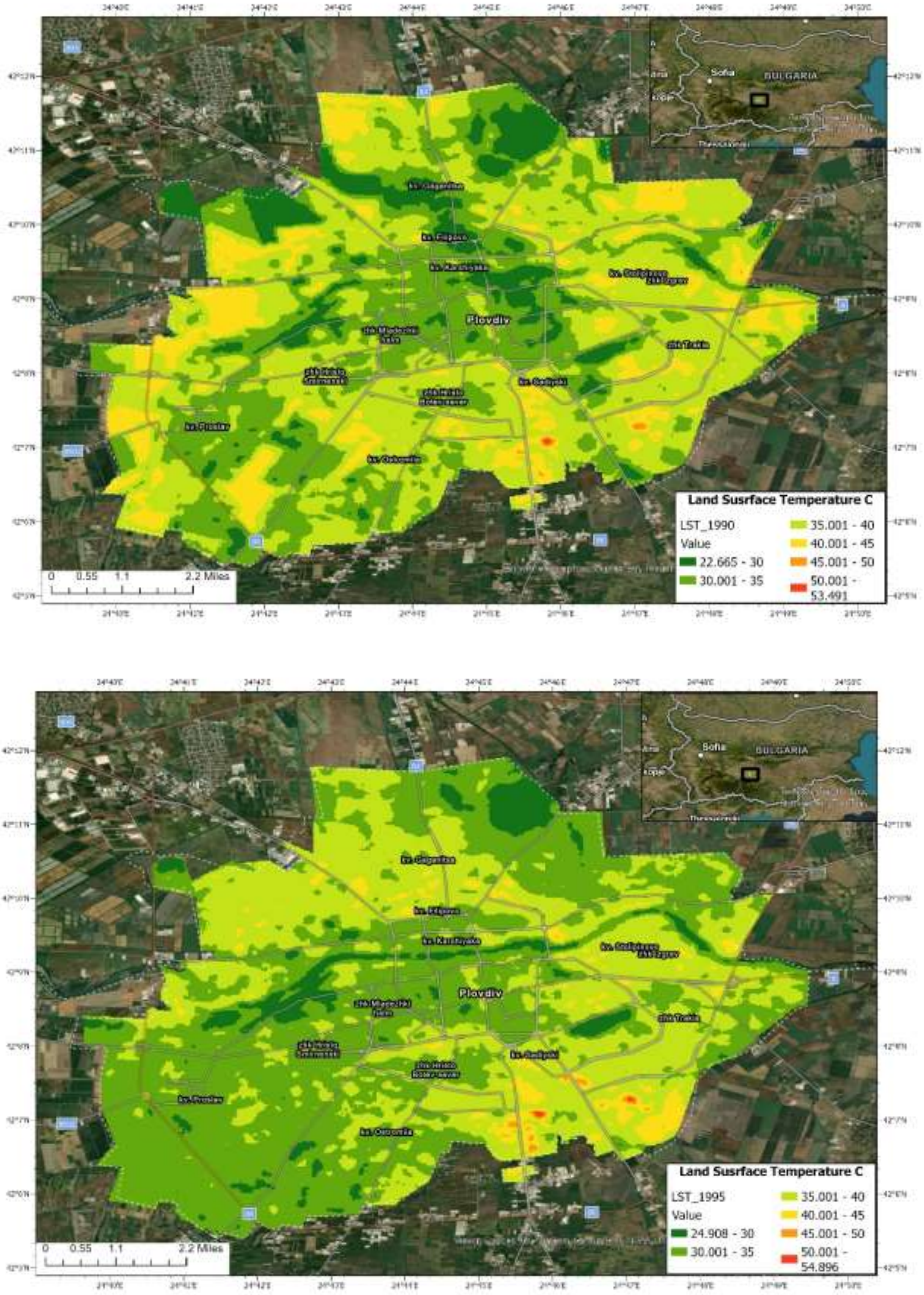


Fig. 7. Distribution of average summer land surface temperatures (LST) for the period 1990–1995.

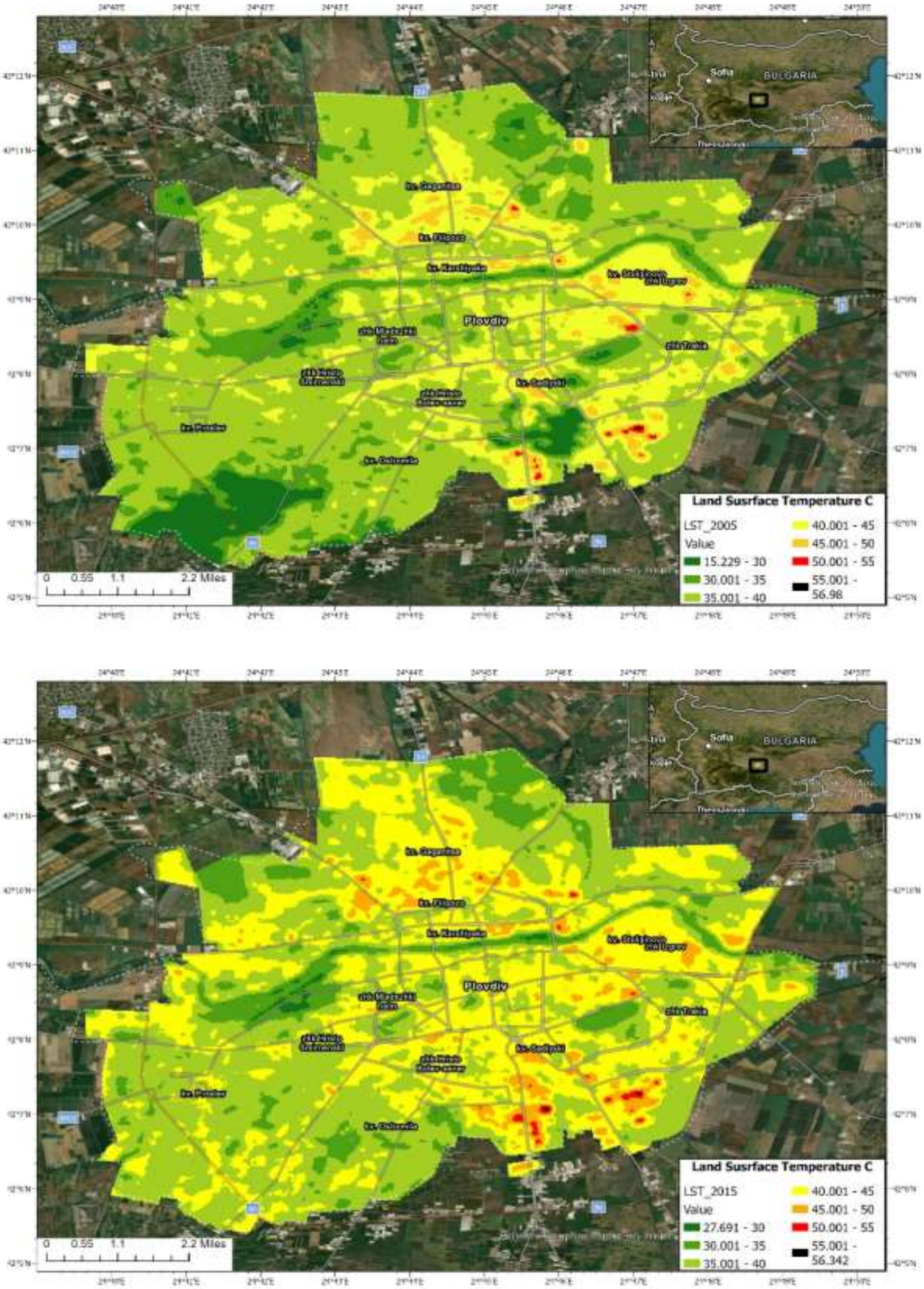


Fig. 8. Distribution of average summer land surface temperatures (LST) for the period 2005–2015.

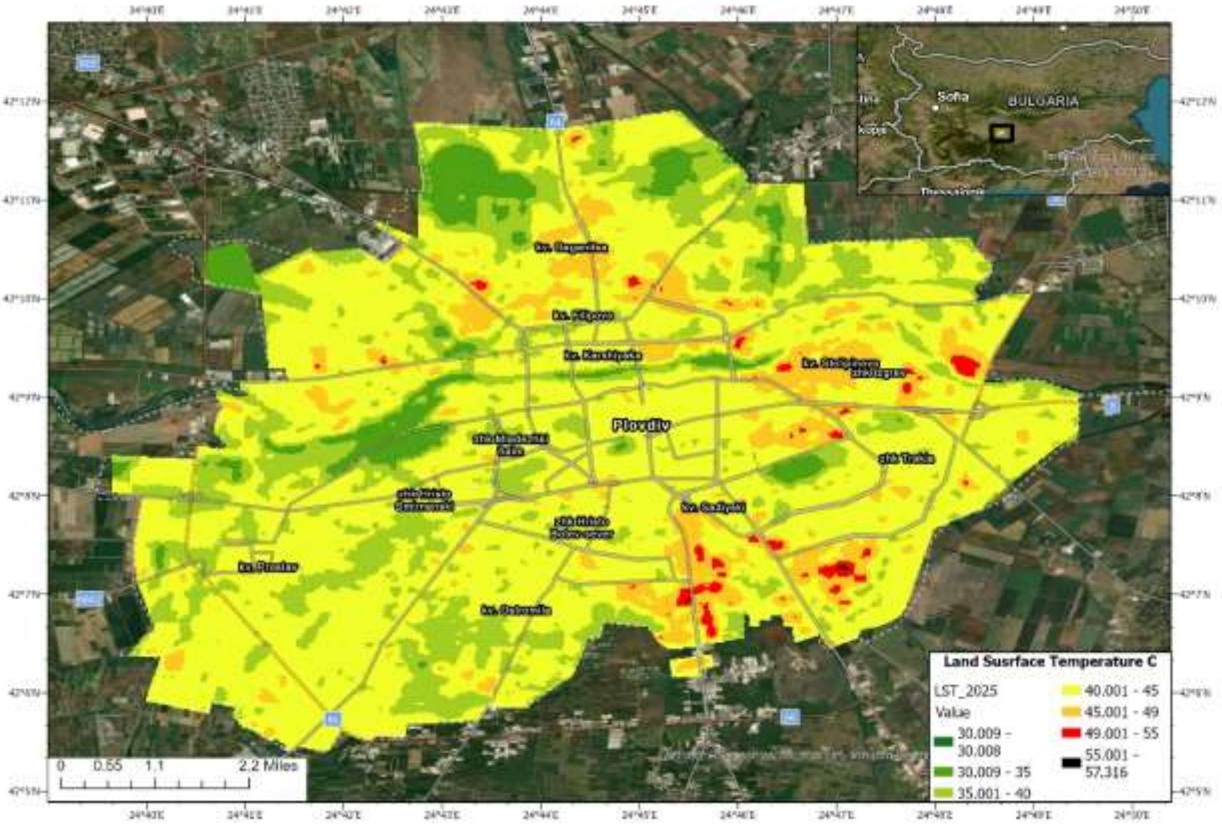


Fig. 9. Distribution of average summer land surface temperatures (LST) in 2025.

A more detailed view of vulnerability to high temperatures and the spatial distribution of surface urban heat islands is illustrated by the generated land surface temperature raster for 2025 (Fig. 9). The spatial analysis of heat vulnerability indicates that the most affected areas are those lacking vegetation or characterized by sparse vegetation cover.

Large industrial zones with extensive concrete surfaces, as well as sizable industrial and commercial buildings with flat roofs, act as major sources of elevated land surface temperatures. These elements negatively affect the urban microclimate and contribute to the formation of surface urban heat islands (Fig. 9).

In contrast, areas covered by vegetation or urban zones where buildings are separated by well-maintained green spaces exert a positive influence on the city microclimate. This mitigating effect is clearly demonstrated in Fig. 9, where vegetated areas correspond to lower land surface temperature values compared to densely built and industrialized zones.

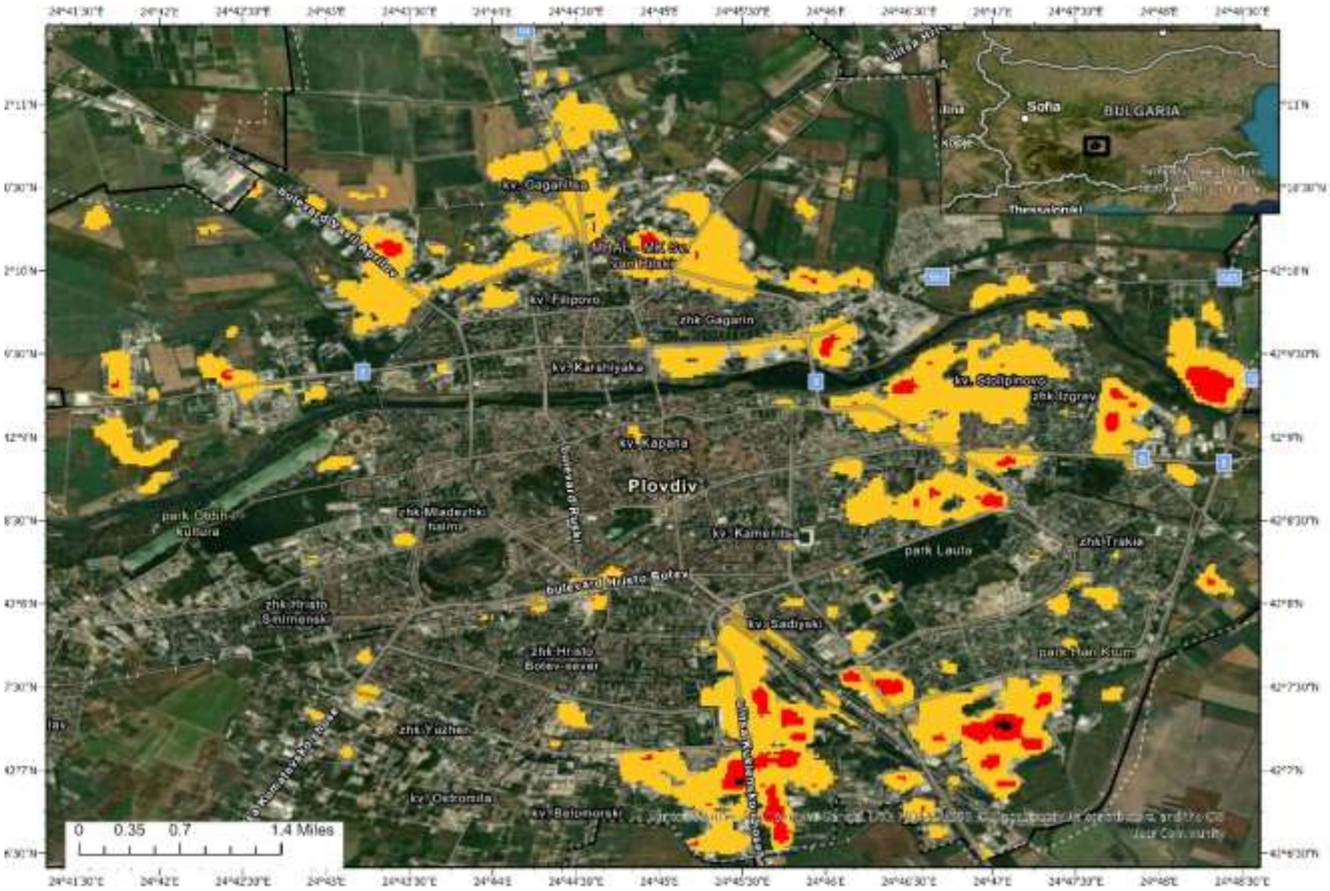


Fig. 10. Surface urban heat island belt surrounding the core of the city of Plovdiv.

DISCUSSION

The results of the present study clearly demonstrate a strong relationship between land surface temperature patterns, vegetation distribution, and the spatial structure of urban development in Plovdiv. The identified spatial overlap between high LST values, sparse vegetation cover, and densely built or industrialized areas confirms the key role of land-use characteristics in shaping the surface urban heat island (SUHI) effect. These findings align with established conceptual frameworks in urban climate research, which emphasize the influence of impervious surfaces, building density, and reduced evapotranspiration on urban thermal environments.

Interpretation of LST and SUHI spatial patterns

The gradual increase in both minimum and maximum summer LST values between 1990 and 2025 reflects the combined impact of accelerated urban expansion and regional climate warming. The formation of a distinct heat island belt around the urban core is particularly indicative of peripheral urbanization processes, where industrial zones, transport infrastructure, and newly developed residential areas replace natural or agricultural land cover. This spatial configuration contributes to intensified heat accumulation due to large expanses of concrete and asphalt surfaces, limited shading, and reduced vegetation cover.

In contrast, areas characterized by dense and continuous green infrastructure – such as urban parks and the vegetated corridor along the Maritsa River – consistently exhibit lower surface temperatures.

This highlights the important cooling function of urban green spaces through shading and evapotranspiration, reinforcing their role as critical mitigation elements within rapidly urbanizing environments.

Comparison with previous studies

The observed SUHI patterns in Plovdiv correspond well with findings from other urban studies conducted in Bulgaria. Similar temperature contrasts between densely built areas and vegetated or non-urban land cover have been reported for Sofia, Burgas, and other major cities using both satellite-based and airborne thermal data. Studies applying thermal photogrammetry and remote sensing techniques have likewise documented pronounced surface temperature differences between industrial zones, residential areas, and green spaces, confirming the robustness of remote sensing approaches for urban heat assessment.

Furthermore, the identified upward trend in LST is consistent with recent climate analyses for Plovdiv, which indicate a sustained increase in mean annual air temperatures and intensified environmental pressure in urban areas. These climatic trends amplify the SUHI effect and increase the vulnerability of cities to heat stress, particularly during extreme summer conditions.

Urbanization, green infrastructure, and social vulnerability

Beyond its physical determinants, the SUHI phenomenon in Plovdiv also reflects underlying socio-spatial inequalities. The study reveals that some of the most thermally vulnerable areas coincide with neighbourhoods characterized by limited green infrastructure and lower socio-economic status, such as Stolipinovo. In these areas, high building density, insufficient vegetation, and limited access to well-maintained public spaces exacerbate heat exposure and reduce adaptive capacity,

The observed expansion of the heat island belt around the urban core reflects broader spatial patterns of urbanization in Bulgaria, characterized by peripheral growth and increasing land-use pressure (Filatova & Patarchanova, 2025).

This finding underscores the importance of integrating social dimensions into urban climate analyses. Heat vulnerability is not solely a function of land cover but is also shaped by spatial planning decisions, infrastructure provision, and social conditions. Addressing urban heat therefore requires targeted interventions that prioritize both environmental and social resilience, particularly in marginalized or rapidly developing neighbourhoods.

Implications for urban planning and climate adaptation

The formation of a surface urban heat island belt around the city core presents a critical challenge for future urban development in Plovdiv. If current trends of peripheral expansion and building densification persist, combined with the anticipated continuation of summer temperature increases, heat-related risks are likely to intensify. In this context, the integration of green infrastructure into urban planning emerges as a key adaptation strategy.

A limitation of the study is the fixed temporal resolution of Landsat data, which may not fully capture short-term extreme heat events.

The results highlight the necessity for planning measures such as the expansion of urban green belts, the preservation of existing vegetated corridors, the introduction of climate-sensitive design in new developments, and the retrofitting of existing buildings to reduce their thermal footprint. From a broader perspective, satellite-based monitoring of LST and SUHI provides an effective decision-support tool for smart city initiatives, enabling evidence-based planning aimed at enhancing urban sustainability and thermal comfort.

CONCLUSION

This study demonstrates the effectiveness of satellite imagery and remote sensing techniques for the long-term assessment of land surface temperature (LST) dynamics and surface urban heat island (SUHI) development in urban environments. By applying Landsat data, Google Earth Engine processing, and GIS-based analysis, the research successfully mapped the temporal and spatial evolution of urban heat patterns in Plovdiv, Bulgaria, over the period 1990–2025.

The results reveal a clear increase in summer LST values, with the most intense heat accumulation occurring in densely built-up areas, industrial zones, and large open surfaces with limited or no vegetation. In contrast, areas with well-developed green infrastructure, including urban parks and the Maritsa River corridor, consistently exhibit lower surface temperatures, highlighting the important mitigating role of vegetation in regulating the urban thermal environment. The analysis also confirms the gradual formation of a surface urban heat island belt surrounding the city core, accompanied by the emergence of localized micro-scale heat islands in newly urbanized peripheral areas.

These findings underscore the relevance of satellite-based thermal monitoring as a decision-support tool for sustainable urban planning, climate adaptation, and smart city development. If current trends of building densification and peripheral urban expansion continue in parallel with rising summer temperatures, targeted planning measures – such as the expansion of green infrastructure, the preservation of vegetated corridors, and the reduction of the thermal footprint of existing and new buildings – will become increasingly necessary to mitigate future heat-related risks and enhance urban resilience.

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