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Investigation of the Urban Heat Islands Formation within the Ivano-Frankivsk Region

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SUMMARY

This research investigates the formation of urban heat islands within the Ivano-Frankivsk region of Ukraine. As global temperatures rise and urbanisation intensifies, cities increasingly experience higher temperatures than their rural surroundings, posing significant risks to public health, energy consumption, and ecosystem stability. This study addresses the problem of identifying and quantifying these local temperature anomalies to support sustainable urban development. The methodology employs a remote sensing approach using the Google Earth Engine cloud platform. The researcher analysed Landsat 8 satellite imagery and ERA5-Land climate reanalysis data spanning 2013 to 2025. Key metrics calculated include Land Surface Temperature (LST) and the Normalised Difference Vegetation Index (NDVI) to assess the relationship between urban surfaces and vegetation cover. The results confirm the presence of distinct heat islands in cities such as Ivano-Frankivsk, Kalush, and Kolomyia. Surface temperatures in these urban centres were up to 6°C higher than in the natural forest control area of Chornyi Lis. A strong inverse correlation was established between vegetation density and surface heat, proving that areas with higher plant biomass significantly lower local temperatures through transpiration and shading. In conclusion, the study highlights the critical role of green infrastructure in cooling. To mitigate the negative impacts of urban heat, the research recommends practical urban planning measures, such as expanding parks, implementing green roofs, and using reflective building materials. The work demonstrates that combining satellite monitoring with cloud-based data processing is an effective tool for regional environmental management.

Keywords: Land Surface Temperature; NDVI; Google Earth Engine; Landsat 8; ERA5-Land.

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Introduction

In the second half of the 20th and early 21st centuries, global climate change has become a critical challenge for sustainable development. One of the most prominent local manifestations of these changes is the formation of urban heat islands (UHIs) – a phenomenon in which temperatures in urban areas are significantly higher than in surrounding rural or natural areas. This thermal anomaly is driven by intensive urbanisation, the proliferation of artificial surfaces with low albedo, the reduction of green spaces, and the concentration of anthropogenic heat (Ju et al., 2024).

The impact of UHI is particularly severe during summer, leading to thermal stress, increased mortality among vulnerable groups, higher cooling-related electricity consumption, and degraded air quality. Furthermore, elevated temperatures can suppress urban vegetation, alter local ecosystems, and create specific microcirculations that trap pollutants (Polianskyi & Kukhar, 2025).

Despite its global prevalence, the UHI effect manifests differently in different local geographies (Kokosha, 2024; Ngarambe, Raj & Yun, 2025). The Ivano-Frankivsk region offers a compelling area for study, combining the plain, urbanised territories of the Precarpathian region with the mountainous, forested landscapes of the Carpathians. This diversity enables robust comparative analysis of temperature characteristics and the identification of regional UHI formation patterns.

Traditional meteorological monitoring often lacks the spatial resolution necessary to map these anomalies comprehensively. However, modern remote sensing technologies and cloud platforms like Google Earth Engine now provide high-resolution data to monitor Land Surface Temperature (LST) and vegetation health (NDVI) (Khatri et al., 2025; Nahirnyi & Davybida, 2025).

The objective of this research is to investigate the formation and dynamics of urban heat islands within the Ivano-Frankivsk region. By leveraging Landsat 8 satellite imagery and ERA5-Land climate reanalysis data from 2013 to 2025, this study aims to quantify local temperature anomalies, assess the cooling role of green infrastructure, and provide a scientific basis for sustainable urban planning and environmental management in the region.

Method and Theory

The methodological framework combines satellite remote sensing, geographic information systems (GIS), cloud-based geospatial processing, and statistical analysis to assess the spatial and temporal variability of the Urban Heat Island (UHI) effect. The approach integrates land surface temperature (LST), vegetation indicators, and climate reanalysis data, enabling the evaluation of relationships among urbanisation, vegetation cover, and surface thermal conditions.

The analysis utilised Landsat 8 imagery as the primary source of thermal information. Land Surface Temperature (LST) was derived from the Thermal Infrared Sensor (TIRS), which provides thermal observations at approximately 100 m spatial resolution (resampled to 30 m in standard products). Atmospheric conditions were characterised using ERA5-Land climate reanalysis data, specifically 2 m air temperature, enabling comparison between surface and near-surface temperatures.

Vegetation characteristics were evaluated using the Normalised Difference Vegetation Index (NDVI), calculated from the near-infrared (NIR) and red (RED) spectral bands of Landsat imagery according to:

$$NDVI = \frac{NIR - RED}{NIR + RED} \tag{1}$$

where NIR and RED denote surface reflectance in the near-infrared and red spectral bands, respectively.

All geospatial processing was performed in the Google Earth Engine (GEE) cloud platform. Landsat 8 images acquired during the summer months (June–August) between 2013 and 2025 were filtered to retain only scenes with cloud cover below 30%, ensuring consistent thermal observations during the period when the UHI effect is most pronounced. Median values of LST and NDVI were calculated to minimise the influence of short-term meteorological variability and outliers.

To evaluate spatial differences in thermal conditions, median LST values were compared across the principal urban centres (Ivano-Frankivsk, Kalush, and Kolomyia) and a natural reference area, the Chornyi Lis forest massif. The relationship between vegetation cover, land surface temperature, and air temperature was examined using Pearson's correlation coefficient:

$$r=\frac{\sum_{i=1}^{n}(x_i-\overline{x})(y_i-\overline{y})}{\sqrt{\sum_{i=1}^{n}(x_i-\overline{x})^2\sum_{i=1}^{n}(y_i-\overline{y})^2}} \tag{2}$$

where x_i and y_i are paired observations and $\overline{x}$ and $\overline{y}$ are their corresponding mean values.

This integrated methodology enables a comprehensive assessment of surface thermal patterns and provides a basis for evaluating the cooling potential of vegetation and green infrastructure in urban environments.

Results

Geoinformation analysis of the Ivano-Frankivsk region reveals clear spatial differentiation in the temperature field, as illustrated in the regional Land Surface Temperature (LST) map (Figure 1). The lowest surface temperatures are consistently observed in the mountainous areas of the Ukrainian Carpathians. This cooling effect is driven by higher altitudes, expansive forest cover, and lower building density, which facilitate moisture evaporation and create a relatively cool microclimate.

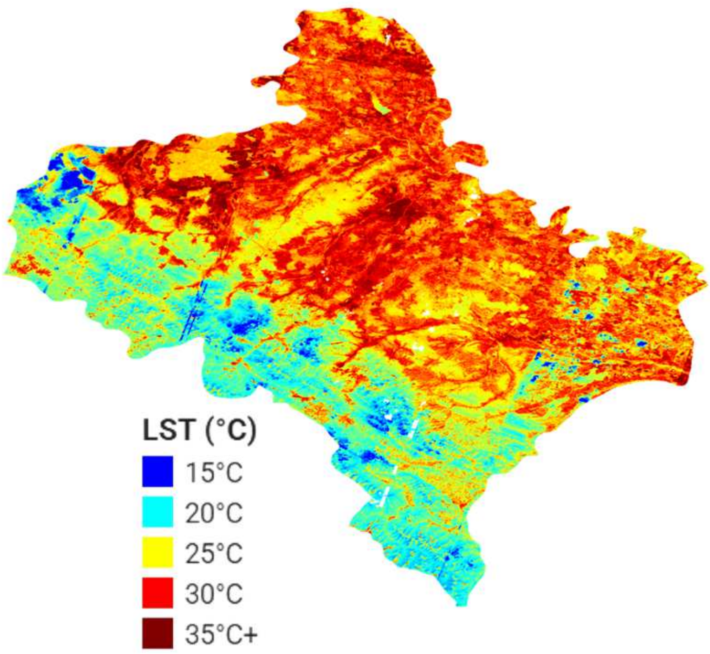

Figure 1. *Land Surface Temperature (LST) in the Ivano-Frankivsk Region during Summer 2025*

In contrast, elevated temperatures are concentrated in the plain territories, particularly within urban centres and industrial zones. Specific "hot spots" clearly visible on the map include the cities of Ivano-Frankivsk, Kalush, and Kolomyia, as well as industrial facilities. These urbanised areas, characterised by artificial surfaces like asphalt and concrete, accumulate solar heat during the day due to their high heat capacity and low albedo. To quantify the urban heat island (UHI) effect, the study compared temperatures in major cities with those in the Chornyi Lis forest massif, serving as a natural control area. The findings indicate Ivano-Frankivsk exhibits the region's most intense UHI effect. While Kalush and Kolomyia have slightly lower temperatures than the regional centre, with LST values up to 4°C lower and air temperatures up to 1°C lower, they remain significantly warmer than the natural forest control. The maximum recorded difference in LST between these urban centres and the natural forest reached approximately 6°C, proving that even medium-sized cities form distinct thermal islands. A comparison of the LST and NDVI spatial distributions confirms a strong inverse relationship: areas with high vegetation density (the Carpathians) exhibit the lowest temperatures, while urban and industrial zones with minimal greenery exhibit the highest temperatures.

The research established a positive correlation between Land Surface Temperature (LST) and air temperature at 2 meters (ERA5-Land climate reanalysis data), as shown in the correlation graphs for each studied zone (Figure 2).

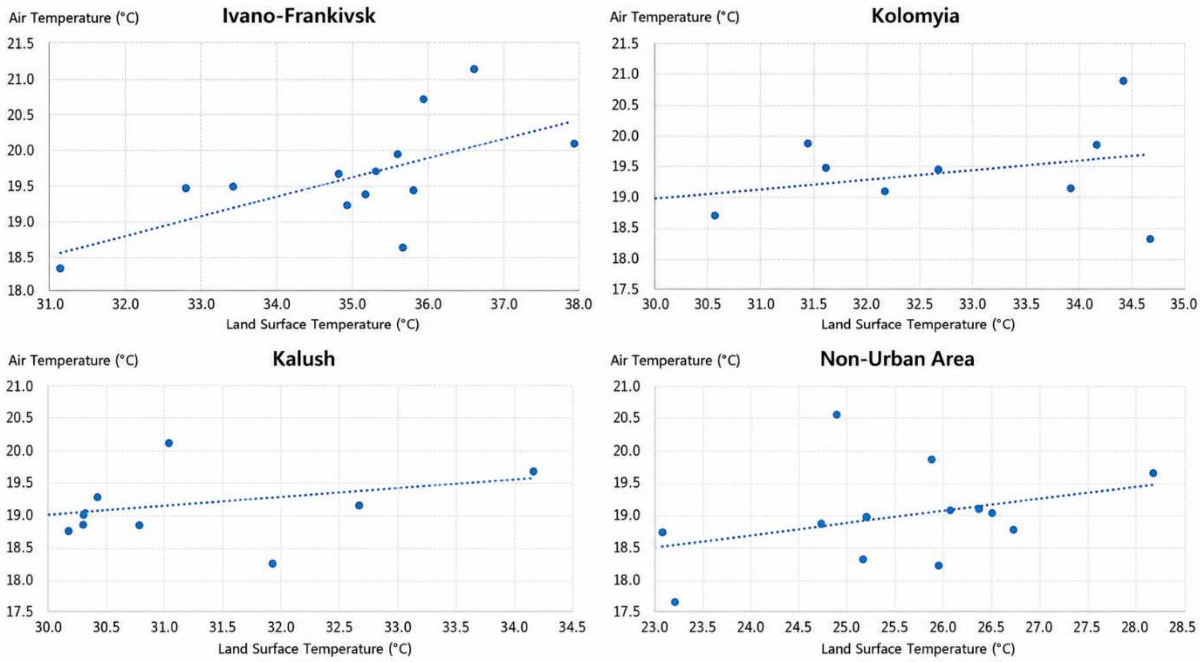

Figure 2. *Relationship between LST and air temperature for Ivano-Frankivsk, Kolomyia, Kalush, and the non-urban reference area during the summer period (2013–2025)*

While there is a general trend toward increasing summer temperatures across all zones between 2013 and 2025, the thermal gap between urban and natural landscapes has remained stable (Figure 3). This suggests that local land-use patterns and urban infrastructure are the primary drivers of the regional UHI effect, even as global warming elevates the baseline regional temperature.

Conclusions

There is a distinct spatial differentiation in surface temperatures across the region. The most intense thermal anomalies are concentrated in urban and industrial centres such as Ivano-Frankivsk, Kalush, and Kolomyia, where LST can be up to 6°C higher than in natural control areas, such as the Chornyi Lis forest. This proves that even medium-sized cities form significant heat islands.

A strong inverse correlation exists between the NDVI (vegetation density) and LST. Dense forest cover and urban green zones act as critical cooling sinks through transpiration and shading, while artificial surfaces with low albedo drive heat accumulation.

Analysis of the 2013–2025 period shows a consistent trend toward increasing summer temperatures across all studied zones, reflecting regional manifestations of global warming. Despite this rising baseline, the thermal gap between urban and natural landscapes remains stable, highlighting the dominant role of local land-use patterns.

To mitigate these rising temperatures, urban planning must prioritise nature-based solutions. Effective measures include implementing green roofs, increasing vertical greenery, using high-albedo (reflective) materials for infrastructure, and preserving urban water bodies and ventilation corridors. Ultimately, these findings provide a scientific foundation for sustainable urban development and environmental management, emphasising that expanding green infrastructure is vital for reducing thermal stress in the region's cities.

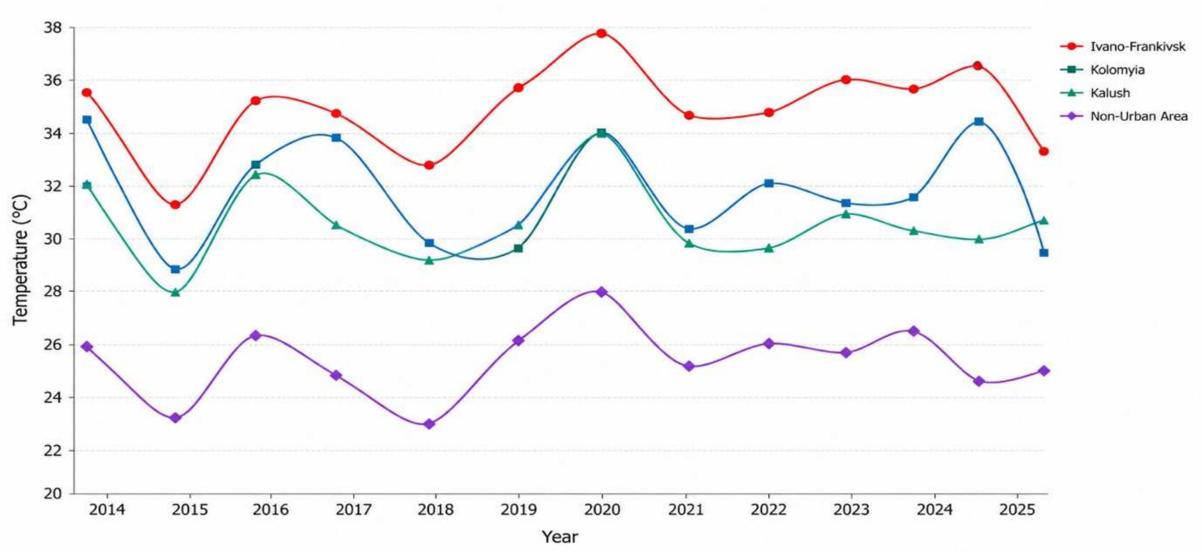

Figure 3. *Median summer LST in the study areas (2013–2025)*

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