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# Heat vulnerability index mapping across spatial scales: effects of data sources and resolution in urban environments

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**Abstract:**

The risk of heat-related mortality and hospitalisations is increasing due to both climate change and population ageing. Spatial risk mapping is therefore essential for planning mitigation measures such as urban greening, cooling centres, and social services. Heat Vulnerability Index (HVI) methods enable the spatial assessment of risk based on indicators of exposure, sensitivity, and adaptive capacity:

$$Vulnerability = Exposure + Sensitivity + Adaptive\ capacity$$

These indicators are typically combined using principal component analysis or weighted aggregation. In recent years, HVI has been widely applied (Szagri et al. 2023); however, a key limitation remains the use of data with insufficient spatial resolution, which fails to capture intra-urban heterogeneity in temperature, vegetation, and socio-economic conditions (Qian and Liu 2025).

This study presents a systematic comparison of HVIs derived from multiple data sources in different spatial resolutions (Table 1), using Bratislava (Slovakia) as a case study. Bratislava is located on the Danube River near the borders with Austria and Hungary and has a population of almost 500,000. The methodological framework compares HVIs computed at two main spatial scales: census tracts and individual buildings. Heat exposure is represented by land surface temperature derived from Landsat 8/9 imagery in Google Earth Engine (GEE). In a selected district, we also calculated mean radiant temperature, which better reflects human thermal comfort, using the Urban Multi-scale Environmental Predictor (UMEP) tool. Sensitivity is represented by the proportions of vulnerable population groups (children under 5, seniors over 65, and seniors living alone) derived from the 2021 census and, alternatively, from WorldPop data (www.worldpop.org). Adaptive capacity is characterised by available green space and accessibility to services, including hospitals, air-conditioned shopping centres, and public transport, derived from OpenStreetMap (OSM). Neighborhood greenery is quantified using the Sentinel-2 Forest index or using the LiDAR-derived canopy height model (CHM), while accessibility to urban parks emphasizes the importance of larger green areas with amenities.

| Factor | Indicator | Data source | Resolution |
|---|---|---|---|
| **Exposure** | Land surface temperature (LST) | Landsat 8/9 (GEE) | 30 m |
| | Mean radiant temperature (MRT) | UMEP | 1 m |
| **Sensitivity** | Seniors (65+) / living alone | 2021 Census | census tract level |
| | Children (0-5) | 2021 Census | census tract level |
| | Seniors (65+), Children (0-5) | WorldPop (GEE) | 100 m |
| **Adaptive capacity** | Greenery (Forest index) | Sentinel-2 (GEE) | 10 m |
| | Greenery (canopy cover / volume) | LiDAR-derived CHM | 1 m |
| | Greenery (accessibility to parks) | OSM, Urban Atlas | 1 m |
| | Accessibility to hospitals | OSM | 1 m |
| | Accessibility to shopping centres | OSM | 1 m |
| | Accessibility to public transport | OSM | 1 m |

Table 1. Indicators, data sources, and spatial resolution used for HVI construction.

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At the building level, heat exposure and neighborhood greenery indicators are evaluated within a 100 m buffer, corresponding to the native resolution of Landsat thermal data and supported by previous studies linking local greenery to perceived health. Accessibility indicators are calculated directly for individual buildings, while the share of population in residential buildings is derived from population data of higher spatial units according to the volume of the building. To address potential bias toward larger buildings, spatial clustering is applied to identify hotspots and coldspots of the HVI.

When constructing the HVI, we used an equal weighting approach for all three factors of exposure, sensitivity, and adaptive capacity. Exposure and sensitivity were represented by one selected indicator (LST/MRT and the population of seniors/children, respectively), while adaptive capacity consisted of multiple indicators with equal weights. All HVIs share a consistent composite structure, allowing the isolation of effects related to the data source and spatial resolution. The comparison between census-based and building-level HVIs aims to reveal how spatial aggregation influences the identification of vulnerable areas. Preliminary results suggest that building-level HVIs reveal substantially higher spatial variability and identify localised hotspots that remain undetected at the census-tract level (Fig.1). HVI hotspots are located mainly in the eastern part of the city with high surface temperatures such as the eastern part of the Old Town and Rača, Trnávka, or the area on the border of Vrakuňa and Podunajské Biskupice.

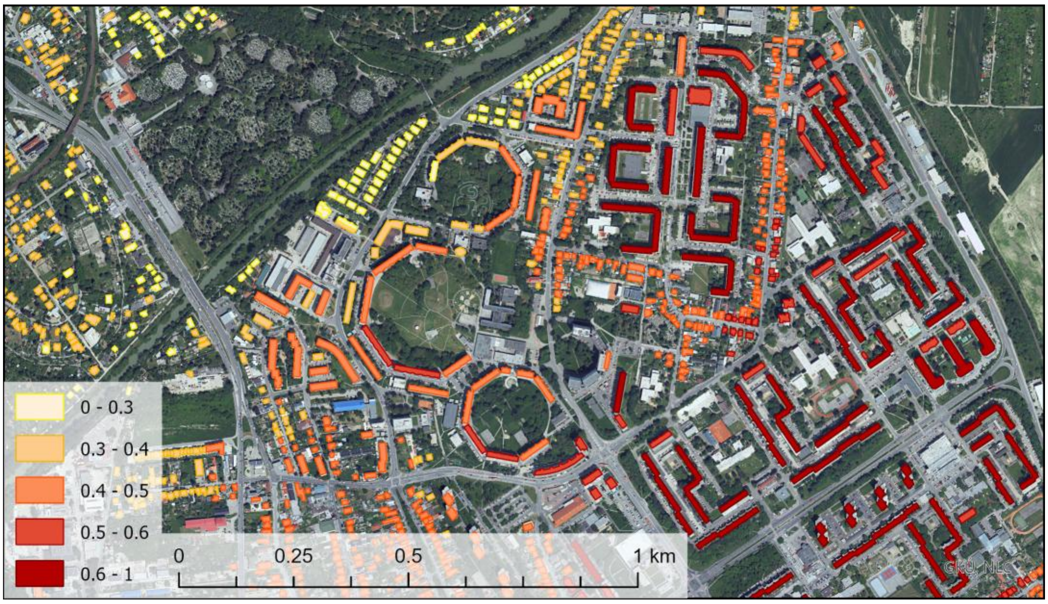


Figure 1. Example of the heat vulnerability index (HVI) calculated from land surface temperature, neighbourhood greenery (forest index), and population aged 65+, shown for a selected area of Bratislava, Slovakia. The map illustrates spatial variability in vulnerability and highlights localised hotspots associated with low greenery and high concentrations of the elderly population.

The broader objective is to provide evidence on how different resolutions and data types – such as satellite-based versus modelled exposure, 2D greenness versus 3D canopy structure, and global population grid versus local census data – influence the spatial representation of heat vulnerability. The findings will support more informed decisions in urban heat-adaptation planning by clarifying the trade-offs between data availability, computational cost, and spatial representativeness in HVI mapping.

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