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A Multi-Scale Comparison of Heat Stress Metrics in Lyon using meteorological, reanalysis and remote sensing datasets

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Heat extremes significantly impact human health, causing heat stroke, reduced productivity, and heat-related mortality. In Europe, the increasing frequency of intense heat waves results from a combination of natural climate variability and anthropogenic climate change. Urbanization exacerbates these extremes through the urban heat island (UHI) effect, intensifying warming in cities and their surroundings. Since the 2000s, France has experienced severe heat waves leading to substantial loss of life, with Lyon experiencing a significant mortality increase after Paris, as reported by the EM-DAT database.

Heat stress exhibits high spatiotemporal variability influenced by morphological and climatic conditions. While heat stress classifications based on climate and urban development provide a general overview of population impacts, they lack the detailed resolution needed to understand intra-urban temperature intensification.

This study investigates the complex dynamics of heat stress at a micro-scale by analyzing three heat stress indices over the Lyon region from 2000 to 2022 during summer (June-August): 1) a temperature-based heat index, 2) the Universal Thermal Climate Index (UTCI), and 3) UHI intensity. A comparative spatiotemporal analysis was conducted across these datasets.

Maximum and minimum air temperature and relative humidity data were obtained from Météo-France's ground observation network. Hourly data were converted to daily values for heat stress index (HSI) calculation. High-resolution (0.25° x 0.25°) daily UTCI data were extracted from the ERA5 reanalysis dataset. Landsat 5, 7, and 8 satellite images covering Lyon were acquired and processed using a single-channel method, including radiometric and geometric corrections, and NDVI-based emissivity corrections, to derive land surface temperature (LST). Image fusion techniques were applied to combine the multi-temporal satellite data into a single dataset.

Cubic interpolation was used to standardize the temporal resolution of the LST, ground observation, and reanalysis data and to address data gaps. The HSI was calculated using Steadman’s index, using daily air temperature and relative humidity. Spatial and temporal analysis of surface temperatures was performed over urban and rural areas of Lyon to calculate UHI intensity. Using the HSI derived from direct temperature data as a benchmark, bias correction, root mean square error, and correlation analyses were conducted to validate the UTCI and UHI. Spatial mapping of the derived HSI was performed using QGIS, and temporal analysis was

conducted to compare seasonal, annual, and decadal HSI patterns.

Results revealed significant discrepancies between air temperature-based and thermal data-derived metrics, particularly in urbanized areas where land surface characteristics and anthropogenic activities enhance heat retention. Urban areas exhibited significantly higher temperatures and increased heat stress compared to rural areas due to the UHI effect. Remote sensing data provided more localized and detailed information on heat stress than traditional temperature-based indices. Despite some disparities, the datasets complemented each other by enabling necessary spatial and temporal adjustments. This research highlights the need for multi-dimensional approaches to heat stress assessment, integrating both meteorological and remotely sensed data. These findings have crucial implications for urban planning and climate adaptation strategies in Lyon and other European cities facing increasing heat stress risks.