Mapping Heat Vulnerability and Temperature Monitoring Sensor Suitability in Rhode Island

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Abstract

Heat vulnerability across Rhode Island was evaluated at the block group level, integrating socio-demographic, housing, health, temperature, and landcover data to construct a heat vulnerability index (HVI), utilizing a principal component analysis. Results revealed substantial spatial heterogeneity, with higher vulnerability concentrated in urban centers, while rural areas generally showed lower risk. Suitability analysis for temperature sensors placement highlighted gaps in current monitoring infrastructure and identified optimal locations to enhance coverage, equity, and future adaptation.

1 Introduction and Background

Globally, temperatures are expected to rise between 2.5-2.9 °C, without any current emission reduction plans (Bell et al., 2024). Extreme heat events, as a result of climate change, have doubled since the 1980s, coupled with increased duration, frequency, and intensity (Bell et al., 2024; Khatana et al., 2022). New England is equally experiencing notable warming trends, with an average increase in annual temperatures by 1.5 °C from 1900 to 2020 (Young & Young, 2021). In 2020, Rhode Island experienced three heat waves, in addition to 23 days above 90 degrees, and in 2022, two heat waves and 16 days above 90 (Resilient Rhody, 2024).

Nevertheless, climate change is additionally expected to impact human health via direct and indirect pathways (Bell et al., 2024; Burkart et al., 2021). In Rhode Island alone, increases in daily maximum temperatures (75 to 85 °F) were associated with 1.3 and 23.9% higher rates of all-cause and heat-related ED visits (Kingsley et al., 2015), and increased EMS encounters (Moretti et al., 2021).

However, vulnerability to heat is not evenly distributed. Marginalized communities, such as racial/ethnic groups and/or low-income populations, tend to face higher heat-related risks (Bell et al., 2024). Likewise, the built environment plays a role in heat exposure, with a lack of proper cooling indoors, a ratio of buildings to open space, and the absence of greenery all contributing to increased intensity of effects (GP et al., 2024; Somvanshi et al., 2025). A study done at Yale University (Manware et al., 2022) developed a heat vulnerability index (HVI) at a census tract level across the contiguous U.S., offering a framework for identifying populations at risk. While census tract-level results provide critical results for national-scale assessments, they can obscure important heterogeneity, particularly in smaller states like Rhode Island. Block groups provide finer spatial resolution that allows for more precise identification of vulnerable populations and risk hotspots.

At the same time, the growing number of extreme heat events highlights the importance of a robust monitoring infrastructure. Rhode Island currently lacks such a network, leaving notable gaps in monitoring localized heat exposure. Expanding sensor coverage is therefore crucial to capture neighborhood-level variability and ensure equitable representation and protection for communities at higher risk. Therefore, this study aims to evaluate heat vulnerability across Rhode Island at a finer spatial resolution and determine temperature sensor placement that would maximize monitoring effectiveness and equity.

2 Methods and Data

The study site included the entire state of Rhode Island, and analysis was performed on a block group level. Data was selected based on peer-reviewed literature and the Manware et al., 2022 study, and included demographic, economic, social, housing, diabetes, temperature, and landcover. Each was aggregated or calculated at the block group level.

2.1 Socio-Demographic and Housing Data

All socio-demographic and housing data were collected from the American Community Survey (ACS) 5-Year Estimates from 2018-2022. Variables included Hispanic or Latino, non-Hispanic African American or Black, elderly population, individuals living below poverty levels, individuals living alone, elderly and living alone, and limited English proficiency. Housing variables consisted of homes built before 1980. Manware et al., 2022 included foreign-born and disability variables, but due to data accessibility, these were excluded. The prevalence of diabetes was determined by gathering sex-specific county-level diabetes data from the Center for Disease Control (CDC). Data was combined with block group ACS age (individuals over 20) and sex distributions to estimate the number of diabetic adults per block group. Totals were summed and divided by the adult population to calculate 5-year averages.

2.2 Air Temperature Data

2-m height air temperature data were collected from NASA's Daymet (Version 4, 1 km2) dataset. 4-year averages of summer air temperature (June 1 to August 31, between 2018 and 2022) were calculated for each grid cell and aggregated at the block group level by using the area-weighted mean. The 20-year most frequent temperature (MFT) was determined for temperature data between January 1, 2002, and December 31, 2022. Data was obtained from NASA's Daymet dataset, and monthly averages were extracted due to data availability. Modal temperatures were calculated per grid cell and aggregated at the block group level by using the area-weighted mean. Heat exposure was computed by taking the difference between summer averages and the 20-year MFT.

2.3 Landcover Variables

Landcover usage, tree canopy cover, and impervious surface percentages were obtained from the National Land Cover Database (NLCD). Proportion of land classified as "high density," average tree canopy cover, and impervious surface. The fraction of non-green space was calculated by the relative area not covered by deciduous forest, evergreen forest, mixed forest, shrub/scrub, herbaceous, grassland, hay/pasture, cultivated crops, woody wetlands, and emergent herbaceous wetlands. All were determined on a block group level. The average enhanced vegetation index (EVI) was determined using NASA's MOD13A2 Version 6 (MODIS, 250 m2) product. 4-year averages of summer months (June 1 to August 31, between 2018 and 2022) were calculated using 16-day scores and aggregated at the block group level by using the area-weighted mean.

2.4 Calculating HVI

HVI was constructed using the methodology provided by Manware et al., 2022. Principal component analysis (PCA) with varimax rotation was used to reduce multicollinearity among the input variables and to identify the dominant dimensions of heat vulnerability. Three components were retained based on standard PCA criteria (Eigenvalue > 1, scree break, and cumulative variance explained), representing: (1) Socioeconomic & Environmental Exposure; (2) Elderly/Social Isolation; (3) Heat Exposure & Underlying Conditions. Normalized factor scores were rescaled from 1 to 6 based on deviation from the mean. Scores were summed to produce an index ranging from 3 to 18.

2.5 ADI Scores

Area Deprivation Index (ADI) for Rhode Island was obtained from Neighborhood Atlas (CITE), to further assess heat disparities. ADI and HVI scores were compared on a block group basis, using a hexbin visualization.

2.6 Station Locations

Locations of temperature sensors and weather stations were collected from the National Oceanic and Atmospheric Administration (NOAA), the National Weather Service (NWS), and Brown University's Network for Environmental Sensing & Technology (NEST). Stations were filtered out to those that collected air temperature (on a minute, hourly, or daily basis) and had long-term contemporary data (20+ years of continuous data, or actively recoding).

2.7 Suitability for Sensor Placement

Selection of novel temperature sensing stations was accomplished on a state- and city-wide basis. State proposed sites guided by spatial rational (e.g., current placement of active stations) rather than quantitative criteria or analysis. Site suitability for additional temperature sensors in Providence was created using a multi-criteria analysis (MCA) based on four criteria: (1) distance to sidewalks, (2) distance to buildings, (3) tree canopy cover, and (4) solar radiation. Sidewalk, building footprint, and tree canopy cover spread were obtained from the Providence GIS Hub. Solar radiation (e.g., aspect) was calculated using a digital elevation model (DEM) collected from the U.S. Geological Survey (USGS). Criteria were determined using guidelines provided by the NWS (NWS, 2016). Areas within direct proximity to sidewalks (considering potential utility or light poles available for sensor attachment, and accessibility factor), away from buildings, not directly under canopy spread, and south-facing (for optimal direct sunlight) were scaled as most preferable. All four components were equally weighed. Final selection for new locations considered suitability results, in addition to current station placement and HVI scores.

3 Key Findings

Findings of the analysis reveal a spatial heterogeneity of heat vulnerability across the state. HVI values ranged from 0 to 18, with a mean and STD of 10.50 and ±3.14, respectively (Figure 1). Vulnerability varies around Rhode Island, but higher values are clustered around the northern portion and around more urbanized regions. As such, urban centers, including Providence and Pawtucket, were determined to have higher vulnerability due to coupled socio-economic and environmental stressors, while rural areas had generally lower vulnerability. Higher ADI scores were concentrated around Woonsocket, Providence, Pawtucket, and Warwick. While certain block groups had equally high ADI and HVI values, there was a weak correlation between the two factors (Pearson correlation = 0.158) (Figure 2).

Current weather stations in Rhode Island are concentrated along the western and southern portions of the state, predominantly lining the coast and in urban centers. With the exception of one station (North Foster), there is a disparity in stations more inland and in rural areas. The suitability analysis with and without building footprint consideration revealed several highly suitable spots for sensors, including around Brown University's campus, Fox Point, Wayland, Olneyville, Valley, Washington Park, and Charles (Figure 3).

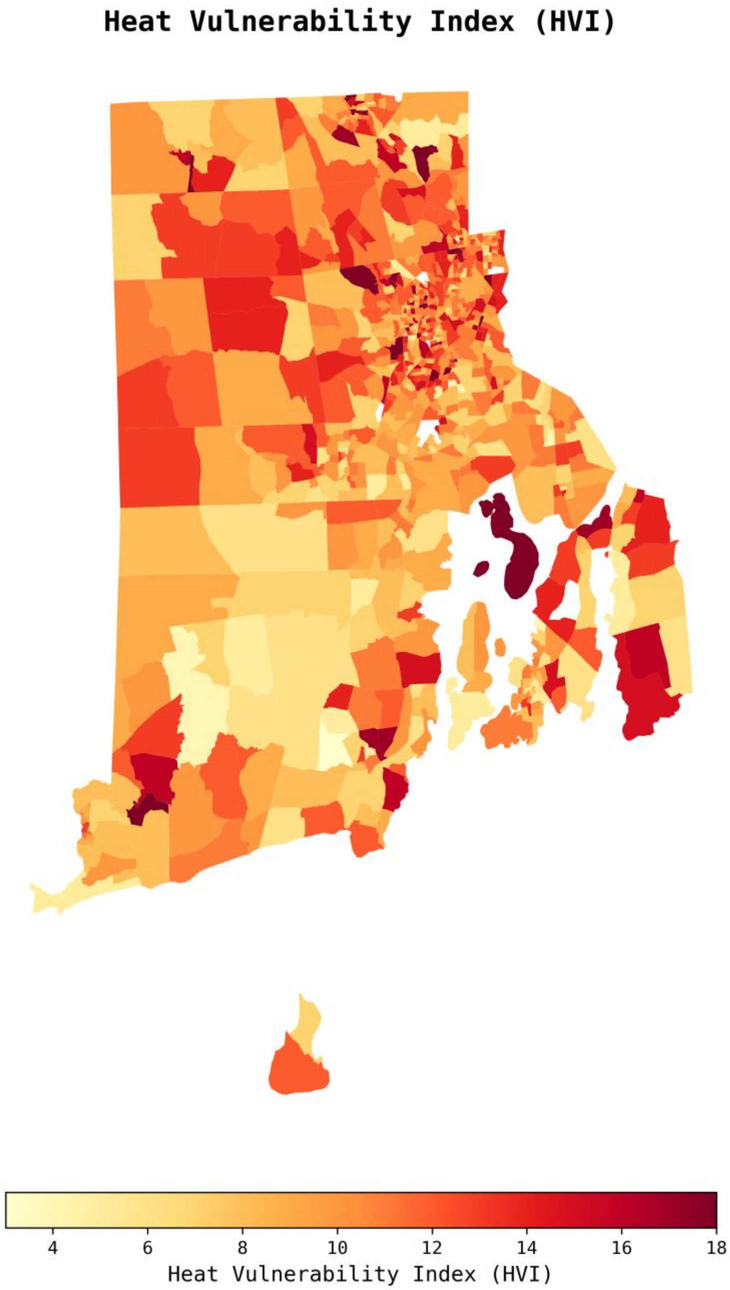

Figure 1 Calculated heat vulnerability index (HVI) across Rhode Island.

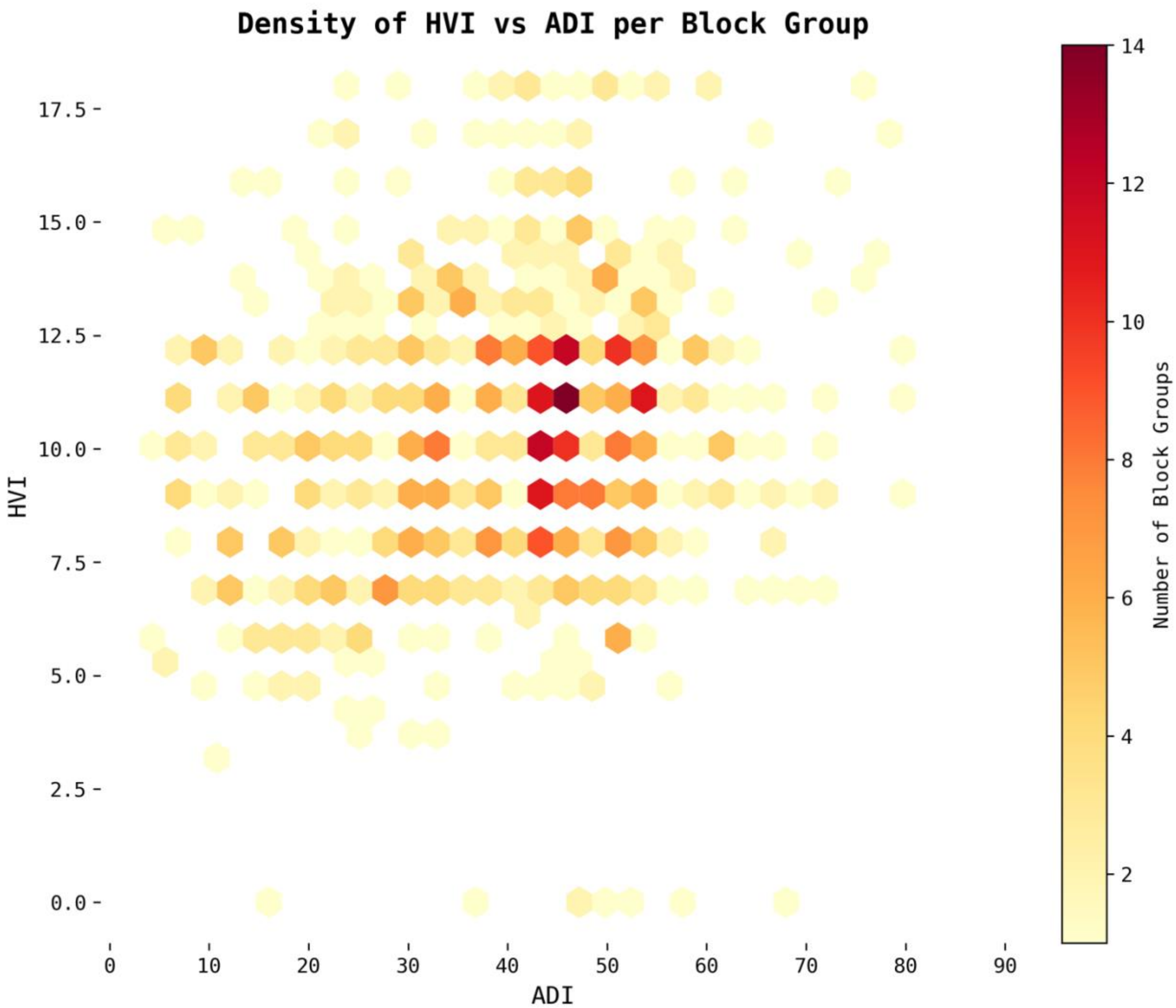

Figure 2 Hexbin plot of HVI and ADI scores across block groups in Rhode Island.

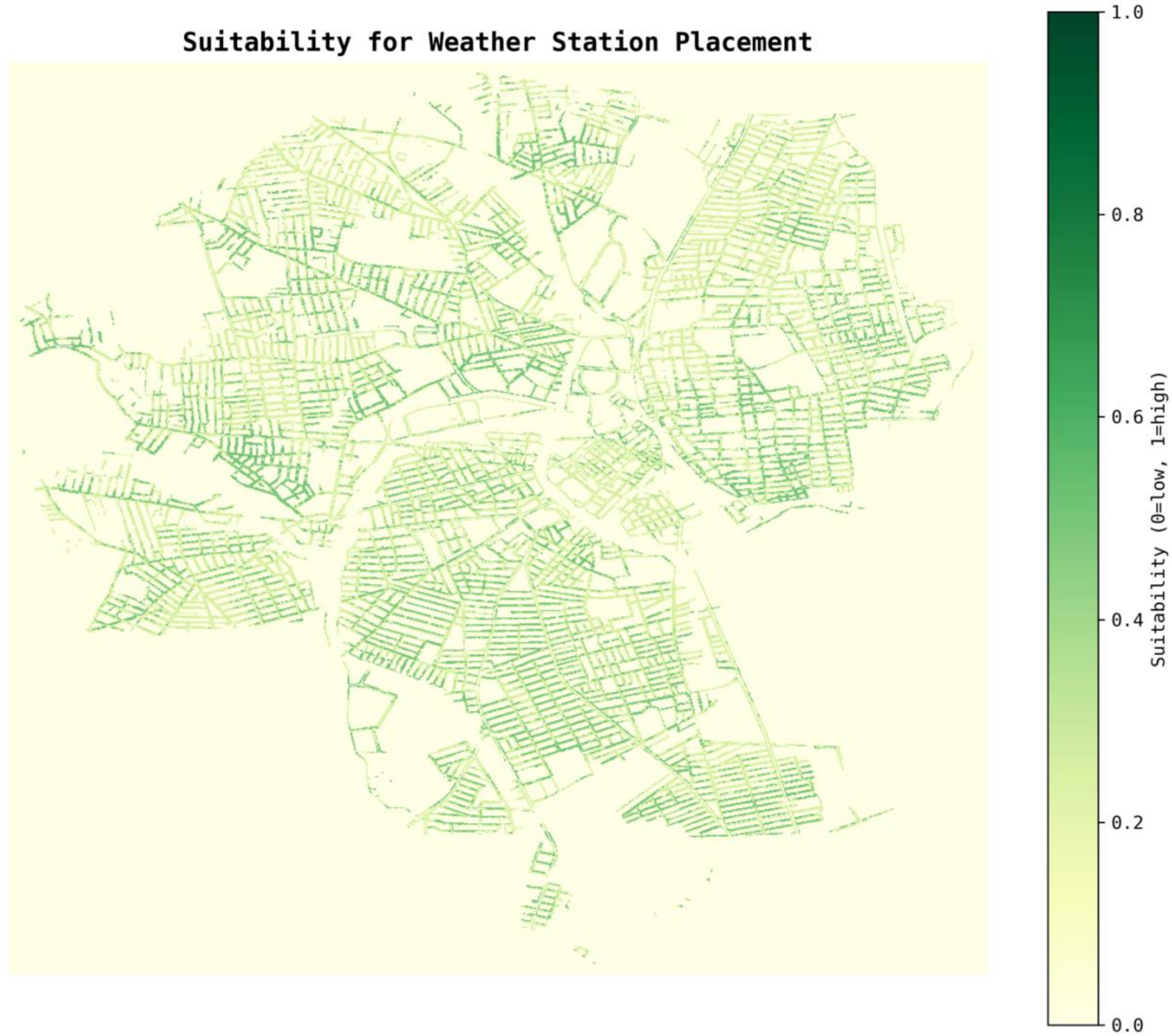

Figure 3: Suitability analysis across Providence, Rhode Island (*building distance criteria included*).

4 Discussion and Conclusion

Utilizing block groups allowed for a fine-scale analysis of heat vulnerability across Rhode Island. As such, vulnerability was not uniform, and a smaller level of geometry revealed underlying clusters. Overall, based on current station locations, suitability analysis, and HVI scores, across the state, placement around Woonsocket, Hopkinton, Glocester, and Coventry, and in Providence, nearby Elmwood, Charles/Pawtucket, Elmhurst, College Hill, and Wayland/Fox Point should be considered. Nevertheless, local communities should be likewise consulted regarding placement, to be comprehensively represented.

Further studies should incorporate other variables when calculating the HVI score and consider utilizing projected heat and temperature trends to assess potential vulnerability. Having baseline metrics could aid in facilitating and driving adaptation strategies.

5 Geoethics

When working with socio-demographic and health-related data, issues of privacy violation need to be considered. Geomasking and/or aggregating individual-level data on a large geography, such as block groups or census tracts, can reduce such concern. Nevertheless, smaller geographies can make certain populations more identifiable. Furthermore, certain data may come with constraints, such as ACS data, where missing values, misreporting, and changes in surveying methodologies may bring a margin of error. Overall, by identifying vulnerable populations and recommending strategic sensor deployment, this project seeks to advance resilience and environmental justice.

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