# Case Study 2.B

## Application of Satellite-Based Data for Assessing Vulnerability of Urban Populations to Heat Waves

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|---|---|
| **Keywords** | Heat wave, social sensitivity, health impacts, urban heat island, adaptation, vulnerability, remote sensing |
| **Population (Metropolitan Region)** | 1,567,442 (U.S. Census, 2015) |
| **Area (Metropolitan Region)** | 347.3 km² (U.S. Census, 2010) |
| **Income per capita** | US$56,180 (World Bank, 2017) |
| **Climate zone** | Dfa – Cold, without dry season, hot summer (Peel et al., 2007) |

Extreme heat, exacerbated by the urban heat island (UHI) effect, is a leading cause of weather-related mortality in the United States and many other countries (Wilhelmi et al., 2012). From 2006 to 2010, an average of 620 U.S. residents died each year owing to heat stroke and/or sun stroke (Barko et al., 2014). The U.S. National Climate Assessment (NCA) and the IPCC Fifth Assessment identify warmer and more extreme temperatures as one of the impacts of anthropogenic climate change (USGCRP, 2014; IPCC, 2014). Compounding the rising air temperatures and increased variability that is occurring with climate change, UHI effects can add 6–8°C to urban air temperatures when compared to surrounding rural areas for many mid-latitude cities (Imhoff et al., 2010). High population densities in urban areas and their social stratification mean that vulnerability to climate change is also high in certain neighborhoods (Romero Lankao and Qin, 2010). Evidence shows that urban populations with higher levels of sensitivity and lower levels of adaptive capacity generally suffer greater impacts from a range of climate-related hazards (Reckien et al., 2013; Cutter and Emrich, 2006; Laska, 2006) including heat stress (Ueijo et al., 2011; Johnson and Wilson, 2009).

To help local and regional governments understand the vulnerability of urban populations to heat waves, we developed a set of indicators, listed in Table 1. These indicators map the elements of vulnerability and can be used to target adaptation measures and track their effectiveness.

Guided by an advisory group of local planners and experts in the pilot city of Philadelphia, Pennsylvania (listed in Table 2), we constructed the indicators to leverage the benefits of block group-level socioeconomic data and multi-decadal meteorological station data, along with the broad coverage provided by satellite remote sensing land surface temperatures (LST), land cover, and urban vegetation products.

**Table 2** *Advisory group members.*

| | Name | Organization |
|---|---|---|
| Academic and Private Sector | Dana Tomlin | Department of Planning, University of Pennsylvania |
| | Robert Cheetham | Azavea (geospatial analysis firm) |
| | Shannon Marquez | Drexel University |
| | Raluca Ellis | Franklin Institute |
| | Thomas Bonner | Philadelphia Electric Company (PECO) |
| Policy and Urban Planning | Jeff Moran | City of Philadelphia Department of Public Health |
| | Palak Raval-Nelson | City of Philadelphia Department of Public Health |
| | Keith Davis | City of Philadelphia, City Planning Commission |
| | Mark Wheeler | City of Philadelphia, City Planning Commission |
| | Scott Schwarz | City of Philadelphia Water Department |
| | Mami Hara | City of Philadelphia Water Department |
| | Sarah Wu | City of Philadelphia, Office of Sustainability |

Our methods of calculating and mapping indicators covered the three components of vulnerability: exposure of urban populations to heat waves (using NASA-derived LST and National Climatic Data Center-derived air temperature data [NCDC, 2014]), social sensitivity to heat wave impacts (tied to age, educational achievement, and race, using U.S. Census Bureau data), and adaptive capacity to cope with urban heat waves (using NASA Normalized Difference Vegetation Index [NDVI] and LST to detect results of adaptive urban "greening" projects). We calculated these indicators for a ten-year period for satellite-based data and a thirty-year period for ground-based temperature data, for Philadelphia.

Since heat-wave health impacts are tied to the duration and intensity of extreme heat, we identified heat wave periods, defined as exceeding the 85th percentile of historical average July and August temperature for Philadelphia (81°F) for three or more consecutive days. We calculated the number of heat wave days per year separately for ground-based weather stations identified as urban (6 locations) versus suburban/rural (13 locations). The monitors show that the total duration (number and length combined) of heat waves per year have been increasing from 4 to 12 days per year in urban areas and staying relatively constant at 5 days per year in suburban/rural areas from 1980 to 2010.

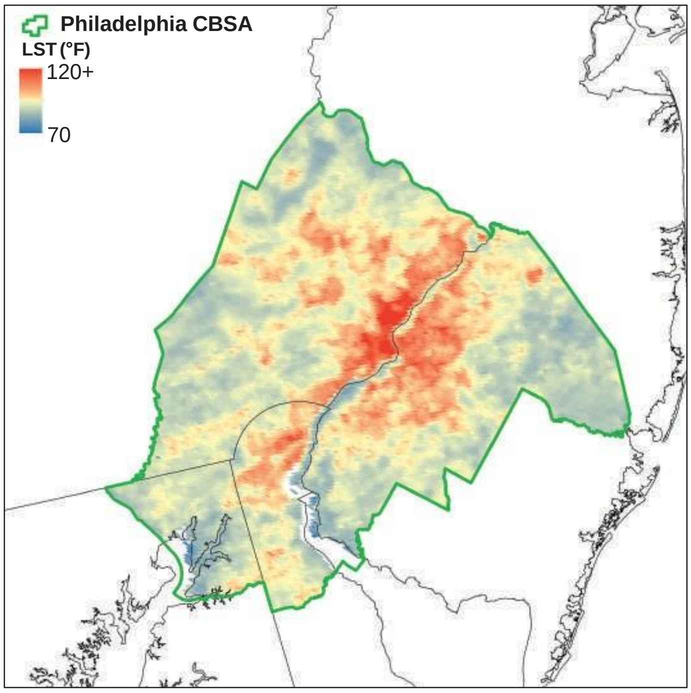
**Table 1** *Indicators of vulnerability of urban populations to heat waves.*

| Issue | Indicator name |
|---|---|
| Exposure | • *Urban Heat Wave Indicator:* An estimate of the intensity and total duration of heat waves for a city<br>• *Urban Heat Island Indicator:* An estimate of the average land surface temperature (LST) difference between urban areas and rural areas for periods of extreme heat |
| Sensitivity | • *Urban Socioeconomic and Hotspot Indicator:* Classification of sensitivity of census units based on socioeconomic census and urban greenness data |
| Vulnerability | • *Vulnerability of Urban Populations to Heat Health Impacts Indicator:* Overlap of highly exposed and highly sensitive populations |
| Adaptive Capacity | • *Urban Adaptation Effectiveness Indicator:* Measured reductions in LST or increases in Normalized Difference Vegetation Index (NDVI) in neighborhoods related to UHI reduction measures |

Complete spatial coverage of measures of LST using NASA Moderate Resolution Imaging Spectroradiometer (MODIS) Aqua data confirm elevated temperatures and upward trends in areas flagged as urban, while opposite trends are seen in surrounding suburban and rural areas. Case Study 2.B Figure 1 shows higher LSTs in urban areas, using the example of average July LSTs in 2012. Note that LST, while correlated to ambient air temperature, is not an exact indicator of sidewalk level temperature of interest in this study since the relationship between land and sidewalk-level air temperatures depends on surface type, building height, and other factors (Zhang et al., 2014).

We also mapped areas of high social sensitivity to guide adaptation efforts. Sensitive populations in Philadelphia were identified through U.S. Census American Community Survey (ACS) data and defined using the following population parameters (Ueijo et al., 2011, Johnson and Wilson, 2009):

- % below the poverty line
- % of households with a person over 65 living alone
- % of housing units built before 1960
- % of the population that did not graduate from high school

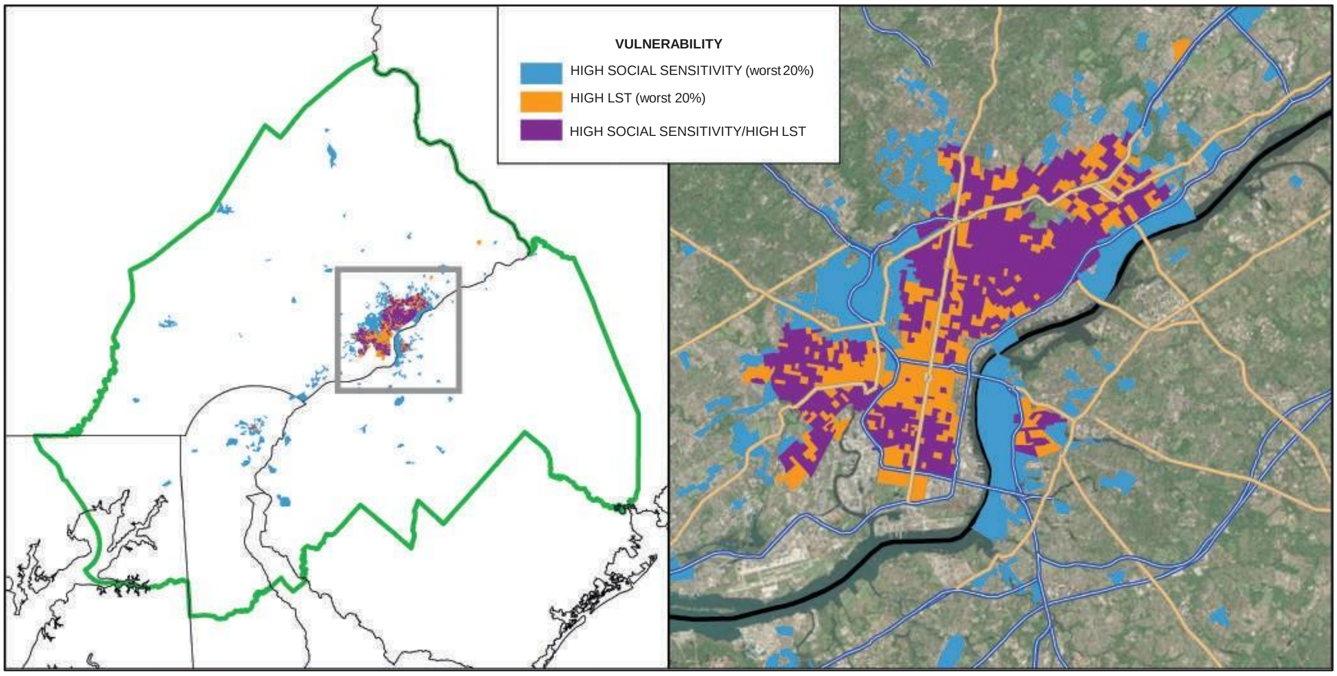



**Case Study 2.B Figure 1** *Land Surface Temperature.*

*Source: NASA Aqua MODIS LST, 2012*

An overall Social Sensitivity Index was calculated for each census block group, dividing each sensitivity factor into deciles and averaging the factors. The results in Case Study 2.B Figure 2 show the location of the most sensitive population to heat waves.

Approximately 10% of Philadelphia's population lives within the most vulnerable areas to heat wave health impacts based on our established thresholds for vulnerability, thus facilitating targeting of cooling adaptation measures. One such cooling adaptation measure with a long-term benefit could be increasing urban vegetation, which can provide shade and localized cooling effects (a measure of adaptive capacity of the city to reduce vulnerability). We mapped vegetation in Philadelphia (using NASA MODIS NDVI) to identify which areas currently contain higher and lower levels of vegetation. Tracking changes in NDVI over time could highlight increases in vegetation, particularly resulting from a targeted urban greening or cooling program, or decreases in vegetation, potentially leading to increases in vulnerability. Isolated examples of urban cooling measures were




**Case Study 2.B Figure 2** *Overlaying the areas with highest LST (2012, shown in orange) and the residential locations of the most sensitive populations (shown in blue) reveals the most vulnerable populations overall to heat wave impacts in Philadelphia (shown in purple).*

provided by Philadelphia officials, but none is yet at the scale that can be measured by the satellite data used (1 km). A "reverse" example was found of the increase in LST and decrease in NDVI associated with building a large warehouse in a formerly green area, which also provides useful information on potential negative impacts of zoning policies and land-use changes.

The indicators can be used by local decision-makers in Philadelphia to better understand patterns of vulnerability, target adaptation measures, and measure results (LST reduction or NDVI increase) from existing adaptation measures (e.g., tree planting, green/white roofs). Subkilometer-scale data are needed to make these indicators more applicable in mixed decision-making urban landscapes, although the availability of such products is limited, especially for the relatively short time frame (within a few months of data collection) that is most useful to city managers

The indicator methodology was vetted with stakeholders for different display and visualization options, such as through an interactive tool, and was applied in a second pilot city (New York) as a test of scale-up. That scale-up test showed that modifications to methods (such as the selection of temperature thresholds and designation of urban and suburban locations) may be required based on local contextual factors.

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