# Accuracy of a Heat Vulnerability Index for Estimating Heat Mortality in Dallas, Texas

Megan French
Advisor: Brian Stone, Jr., Ph.D.
April 27, 2018

## Table of Contents

INTRODUCTION 3

Relevance of Heat and Human Health 3
Increasing Risk 4

LITERATURE REVIEW 5

Heat Vulnerability and Heat Vulnerability Indices (HVIs) 5
HVIs in Public Health 7
Extreme Heat and Vulnerability in Dallas 8

METHODS 9

Data 10

RESULTS 16

DISCUSSION 17

POLICY RECOMMENDATIONS 19

Heat Plan 19
Response to EHEs 20
Understanding Vulnerability 20
Environmental Mitigation 21

CONCLUSION 21

# Introduction

Significant research has been done to explore the effects of heat on human health and comfort, particularly as this relationship becomes more pronounced in the face of increasing temperatures due to global warming and urban heat island effect. Identifying and quantifying the relationship between heat and health is becoming an increasingly important focus of public health officials and others working to improve human health outcomes.

There have been numerous studies in the Dallas region on the causes and effects of urban heat island. However, fewer studies have focused on identifying the populations most vulnerable and those most affected by heat within the city. This should be a priority for the City of Dallas in the coming years due to the projected temperature increase. According to Habeeb et al., "Dallas-Fort Worth experienced the greatest change in heat wave duration, increasing the length of its average heat wave by 0.7 days per decade (±0.15), with heat waves on average 3.5 days longer in the 2000s as compared to 1960s."[1]

The goal of this paper is to examine the accuracy of a heat vulnerability index (HVI) in estimating heat mortality within the City of Dallas in Dallas County. A comparison of the HVI to modeled mortality will be performed by census tract to evaluate how the HVI performs relative to a more sophisticated modeling approach. Subsequently, policy recommendations are provided to guide the city in reducing heat vulnerability among its citizens.

## Relevance of Heat and Human Health

Extreme heat events (EHE) are defined by the U.S. Environmental Protection Agency (EPA) as "periods of summertime weather that are substantially hotter and/or more humid than typical for a given location at that time of year."[2] EHEs can be further characterized by stationary masses of warm air and repeated nights with elevated minimum temperatures and can vary based on numerous factors.[3] These factors include location, time of year, and weather conditions such as temperature, cloud cover, and humidity. Extreme heat can be measured with the heat index, which factors in relative humidity with actual air temperature to measure how hot it actually feels. Humidity is an important factor in how hot it feels as the more water in the air, the less evaporation takes place, making it more difficult for the body to cool itself through evaporation.[4] EHEs are a significant threat to public health including increased hospitalization, illness and death.[5]

Extreme temperatures most directly affect health by limiting the body's ability to control its internal temperature. A number of illnesses including heat cramps, heat exhaustion, heatstroke, and hyperthermia in the presence of extreme heat are the result of the body's loss of internal temperature control. Extreme temperatures can also worsen chronic conditions including cardiovascular disease, respiratory disease, cerebrovascular disease, and diabetes related conditions. Additionally, increased hospital admissions for cardiovascular, kidney, and respiratory disorders can be associated with prolonged exposure to high temperatures.[6] A total of 28,000 heat-related hospitalizations were recorded across 20 states from 2001 to 2010. Annual heat-related hospitalization rates ranged from one case per 100,000 people to nearly four cases per 100,000 people across these states.[7] A number of risk factors can increase the likelihood of health effects from extreme temperatures including high levels of humidity, obesity, fever, dehydration, prescription drug use, mental illness, poor circulation, sunburn, and alcohol use.[8]

Exposure to extreme heat can also result in death. From 2000 to 2009, EHEs or heat waves were the most common cause of weather-related death in the U.S.[9] According to the EPA, since 1979, more than 9,000 Americans were reported to have died as a direct result of heat-related illnesses such as heat stroke. The annual death rate is higher when accounting for deaths in which heat was reported as a contributing factor, including the interaction of heat and cardiovascular disease." [10] One of the most severe heat events in recent U.S. history took place in Chicago in July 1995 with an estimated result of more than 650 deaths.[11] Worldwide, cities are experiencing considerable effects of EHEs, including 14,800 heat-deaths from a 2003 severe heat wave in France. Most deaths occurred in urban areas where temperatures reached record highs. [12]

## Increasing Risk

A number of factors are increasing the effects and importance of addressing EHEs worldwide. Global warming, increasing urban populations, extended number of EHEs and extreme heat days, aging populations, and a lack of concern or understanding regarding the impacts of EHEs are key drivers for communities in developing resilience strategies.

Globally, the annual average temperature has been increasing since the early part of the 20th century with temperatures expected to rise through the end of the century. Since 2000, 15 of the 16 warmest years on record have occurred, with the exception of 1998. [13] In the U.S., average temperatures have increased by 1.3°F to 1.9°F since 1985 and the warmest decade on record was from 2000-2009. [14]

According to the CDC, in addition to global warming, an increase in the number of EHEs and heat waves is expected to occur. In the U.S. since the 1970s, there has been an increase in the number of (highs) or unusually hot summer days and an even faster rate of increase in the (lows) or unusually hot summer nights, leading to less cooling at night. [15] This trend is expected to continue with increasing greenhouse gas emissions. Heat waves are predicted to become "more common, more severe, and longer-lasting" and even small increases in extreme heat may lead to increased health risk.[16] In the U.S., the average number of extremely hot days is projected to more than triple from 2050 to 2100 without global greenhouse gas mitigation efforts. [17]

Along with increasing temperatures, there has been a rise in the number of people living in urban populations where the urban heat island effect exacerbates effects of EHEs. This could result in a larger population at risk for heat related illness and death.[18] Globally, urban areas are gaining approximately 67 million people each year (about 1.3 million per week). It is estimated that by 2030, "approximately 60% of the projected global population of 8.3 billion will live in cities." [19]

Along with the increase in urban populations, it is anticipated that older populations (ages 65+) will nearly double from 2015 through 2050 from approximately 48 million to 88 million. [20,21] From 2001 to 2010, the 65+ population accounted for more heat related hospitalizations than any other age group and were "several times more likely to die of heat-related cardiovascular disease than the general population." [22]

Lastly, there is a lack of concern surrounding EHEs and difficulty in gathering data on heat illness and death due to the difficulty of identifying heat related illness and death. Because of this, heatwaves can be silent killers and once heatwaves have passed, memories quickly disappear. [23] Many heat related deaths are not identified as such and therefore may not be properly recorded on the death certificate. [24]

Additionally, due to variability of the underlying data, it is difficult to determine overall, if the U.S. has experienced long-term trends heat related deaths.[25]

## Literature Review

The following section highlights previous research and data on defining heat vulnerability, the development of the heat vulnerability index, how heat vulnerability indices are integrated into public health, and the ways in which health impacts of temperature are measured.

### Heat Vulnerability and Heat Vulnerability Indices (HVIs)

Exposure, sensitivity, and adaptive capacity are the three components of vulnerability for populations' elevated risk to EHEs.[26][27] Full explanations of these terms can be seen in Figure 1 from the US Global Change Research Program.

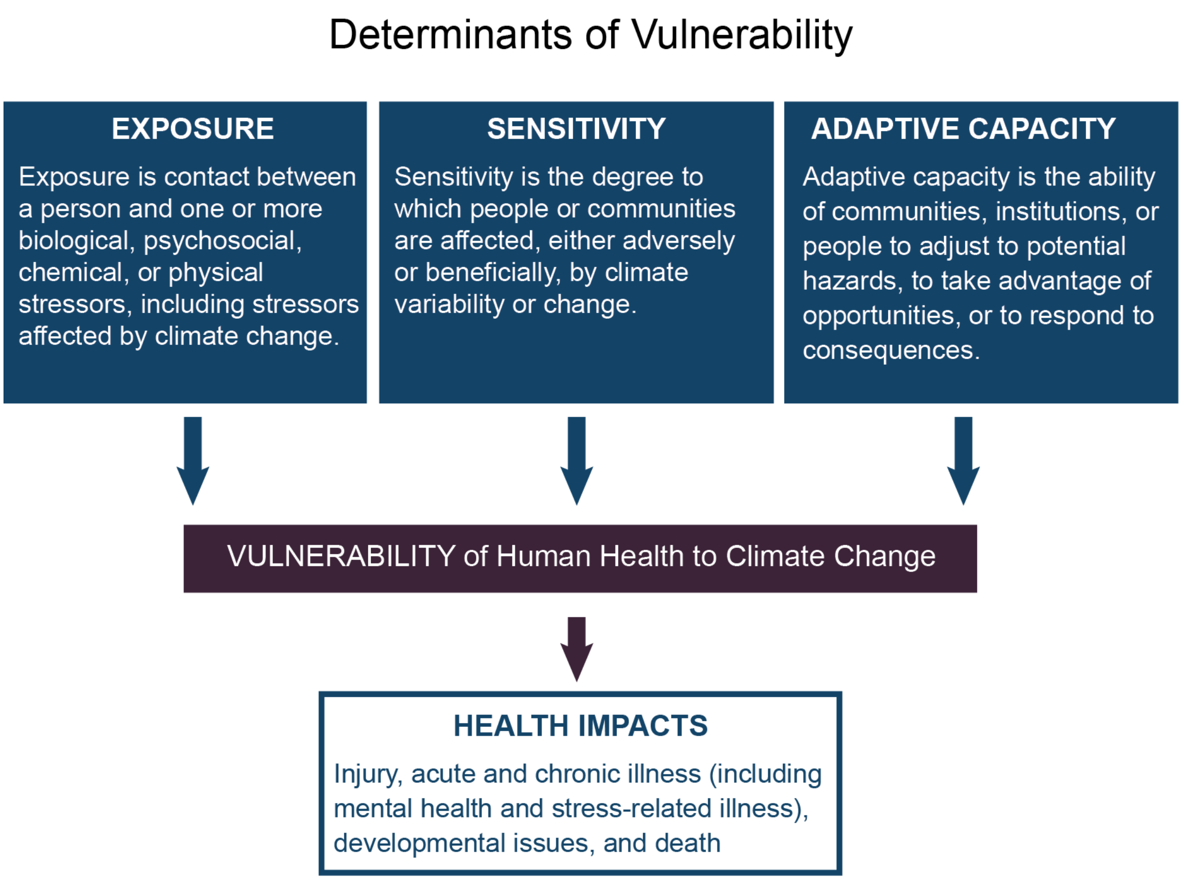



Figure 1: Determinates of Vulnerability Source: US Global Change Research Program Chapter 1: Climate Change and Human Health: Defining the determinants of vulnerability to health impacts associated with climate change, including exposure, sensitivity, and adaptive capacity.[28] (Figure source: adapted from Turner et al. 2003)[29]

The determinants of vulnerability are associated with social and demographic factors such as education and level of wealth, along with other characteristics of people and places, such as the state of infrastructure and ecosystems.[30] Particular vulnerable populations show an increased risk of mortality including the elderly, people of lower socioeconomic status, people who live alone, people with less education, people of races other than white, people with preexisting health conditions such as cardiovascular disease, diabetes, renal disease, nervous disorders, cerebrovascular disease, pulmonary conditions, and mental health conditions, people without access to cooling devices such as air conditioning, and people in neighborhoods with less green space.[31] Other vulnerable populations include infants and children, athletes, outdoor workers.[32]

Vulnerability has been studied for decades. Definitions for vulnerability are seen from 1974 as "degree to which a system, subsystem, or system component is likely to experience harm due to exposure to a hazard, either a perturbation of stress/stressor."[33] Since, a number of techniques have been developed for measuring the variables that make populations most vulnerable including the development of the HVI. The framework and methodologies vary greatly for HVIs yet most studies include components that address exposure, sensitivity, and adaptive capacity.[34] The overall goals are often similar: providing data on the most vulnerable populations, locations, and projections for areas of potentially high impact due to EHEs to more effectively protect people's health.

As early as the 1930s, research on heat-related mortality began to identify vulnerable populations and geographic distribution of deaths in a number of cities across the U.S.[35] Research in the 1960s and 1970s further investigated the spatial relationship of heat-related mortality as well as socioeconomic and environmental factors relevant in heat-related mortality.[36] In following years, researchers broadened the study on how regional characteristics may lead to an individual's vulnerability to heat-related illness, expanding research on relevant environmental and socio-economic factors.[37] It wasn't until more recently that indices or maps have been proposed and implemented specifically focused on heat vulnerability and risk.[38] In 2009, Reid et. all created the first national map of county-level heat vulnerability "using variables shown in the epidemiologic literature to increase vulnerability to heat-related health effects in urban areas."[39]

To date, there have been a limited number of studies to evaluate the performance of heat vulnerability indices.[40] Wolf et al. (2014) validated the performance of their HVI in London using daily mortality and ambulance dispatch data; Reid et al. (2012) evaluated HVIs in five states, California, New Mexico, Washington, Oregon, and Massachusetts by determining if areas with high HVI scores had higher rates of morbidity and mortality on abnormally hot days than on other days; Chow et al. (2012) evaluated geographical change in heat stress risk and heat vulnerability among different ethnic populations in Phoenix; Harlan et al. (2013) used heat-death data and binary regression to validate HVIs in Maricopa County; and Chuang & Grober (2015) evaluated hospital admissions for heat stress to validate HVIs in Phoenix.[41]

Beyond academic research, the CDC has recently published a guide for health departments titled, *Assessing Health Vulnerability to Climate Change*. Its purpose is to assist health departments in creating their own vulnerability assessments to implement more targeted action to reduce impacts of climate change on people. The report highlighted an HVI for Georgia as a case study on heat vulnerability, identifying heat in Georgia as the "most important climate-sensitive health outcome of concern in a survey of the eighteen grantees of the CDC's Climate-Ready States and Cities Initiative."[42] This case study serves as the basis for methods conducted in this study due to the accessibility of data and practical application of methodology proposed for local public health practitioners.

## HVIs in Public Health

City government officials are increasingly aware of the importance of heat warning plans and have acknowledged their need for additional information and resources to help develop and implement such plans.[43] Luber and McGeehin state, “Public health practitioners can play an active role in developing adaptation measures such as city-specific heat response plans. The development and implementation of these plans should be guided by the best evidence, generated by epidemiologic studies and ecologic models, on the relationship between hazard and health outcomes.”[44]

HVIs could help fill this data gap. According to the CDC, “A climate and health vulnerability assessment using an overlay analysis approach can identify communities and places susceptible to climate-sensitive health outcomes by incorporating data on sensitive populations, exposures to hazardous conditions, and measures on the ability to limit or cope with hazardous exposures.”[45] With this information, a number of more targeted approaches can be developed to better assist highly vulnerable populations and areas within a city.[46] HVIs can assist local governments in developing better and more focused early warning systems.[47] Mapping can provide emergency response personnel tools to improve heatwave planning and preparation by allowing more precise resource allocation and targeted health outreach communication among diverse ethnic or demographic populations. Additionally, mapping can be used during EHEs for state and local energy policy managers prioritizing locations for electricity suspensions or cut-offs or for finding the areas in most need of Low Income Home Energy Assistance Program (LIHEAP) cooling assistance. [48] HIAs and mapping can also help local governments identify the most effective locations for cooling centers. [49]

While HVIs have great potential in public health outcomes, additional efforts by local governments, researchers, and practitioners can be done in validating the results of HVIs with measured health impact data. It is important for decision makers to reflect on the characteristics of their cities to see how well actual risk is identified by vulnerability maps. In Phoenix for example, “the variables used on a national scale allowed us to accurately classify only about 54% of the census tracts based on heat hospitalizations.”[50] Cities can consider collecting more hospitalization data to better help characterize impacts of EHEs on different parts of their cities. [51] Lastly, it will be important to “explore how future adaptive measures and behaviors can be included in quantitative models of health impacts associated with extreme temperatures”.[52]

## Measuring Health Impacts of Temperature

According to the U.S. Global Research Program, “Two broad approaches are used to study the relationship between temperatures and illness and death: direct attribution and statistical methods.” [53] In direct attribution studies, diagnosis codes from medical records are used to create links between health outcomes and temperatures. This type of approach is commonly known to produce underestimates of mortality from temperature extremes due to a lack in consistent diagnosis criteria and lack of reporting or difficulty in identifying temperature as factor in exacerbated preexisting medical conditions. [54] In statistical studies, researchers use the number of cases that relate to an observed weather condition or socio-demographic factors to measure the impact of temperature on health. The relationship between temperature and premature illness and premature illness or death is established through varying modeling methods. [55] The differences in the methods make comparing mortality data across studies complicated and can often lead to very different results. [56]

## Extreme Heat and Vulnerability in Dallas

According to Green Dallas, a City of Dallas website focused on sustainability and environmental management, "By the end of this century, models predict that we will have around 100 days over 100°F every year".[57] The growing number of days over 100°F pose health threats and create stagnant air conditions resulting in poor air quality. Dallas is also concerned with the impacts of extreme heat leading to an increased stress on the energy supply, a shortened lifespan of transportation infrastructure, and a contributor to drought.[58] The city is actively taking steps to better understand the growing threat of extreme heat for the city and its residents. A number of studies have been performed to detail the relationship of the city and heat. These include the following:

> 2009 – *Dallas Urban Heat Island Study*, showing Dallas had the third most rapidly growing heat island in the U.S. from 1961-2010.
>
> 2010 – *Roadmap to Tree Planting and Planning*, assessing the overall tree canopy of Dallas.
>
> 2013 – *Evaluating Open Space and the Impact of Canopy Change*, analyzing the impact of canopy change on undeveloped properties.
>
> 2014 – *i-Tree Eco Study*, provides urban and community forestry analysis and benefit assessment tools.
>
> 2015 – *Climate Change/Extreme Weather Vulnerability and Risk Assessment for Transportation Infrastructure in Dallas and Tarrant Counties Report*, investigating infrastructure vulnerability to the impacts of extreme weather and climate change.
>
> 2015 – *State of the Dallas Urban Forest*, provides an overview on the current urban canopy.
>
> 2017 – *Dallas Urban Heat Island Management Study*, analyzing to what extent rising temperatures will impact health and recommendations for minimizing the urban heat island effect in Dallas.

Additionally, there have been at least two HVIs constructed for Dallas. The initial HVI was part of a national study conducted in 2009 by Reid et al. to determine highest correlation among previously identified vulnerability factors. This study stated that although Dallas showed less overall heat vulnerability than other cities, it had a higher vulnerability in the central area.[59] More recently, a thesis examined tree planting suitability for Dallas which included the basis of an HVI. The methods were based on the CDC's BRACE framework through an overlay analysis. This study evaluates areas of highest heat vulnerability among residents and the most suitable locations for tree plantings and tree preservation to minimize vulnerability.

Neither of these studies, however, validated the results of the HVI for Dallas. Without this step, there is less certainty that the policy recommendations or infrastructure changes that take place as a result of vulnerabilities identified through an HVI, are done in the areas of highest risk. This study can help provide an initial analysis about whether the CDC's proposed methods for creating an HVI accurately reflect the areas of highest mortality for the City of Dallas.

# Methods

In this study, an HVI is produced and a validation is performed to test accuracy of the HVI in estimating mortality for the City Dallas within Dallas County. The determinates and methodology used in this study closely follow those recommended by the CDC in their guide for health departments, *Assessing Health Vulnerability to Climate Change: A Guide for Health Departments*. Based on available information, there has yet to be a validation of the CDC's HVI methodology. Validation, however, is proposed as a last step in the sample HVI of Georgia, but was not performed in their assessment.

The CDC's guide was developed to help health departments prepare for climate change and its impacts on human health. It follows a framework called Building Resilience Against Climate Effects (BRACE). This five-step process is intended to guide health departments through a systematic, evidence based process for identifying vulnerabilities and customizing the response to local needs.[60] The following sequence lists the suggested steps for assessing health vulnerabilities associated with climate change:

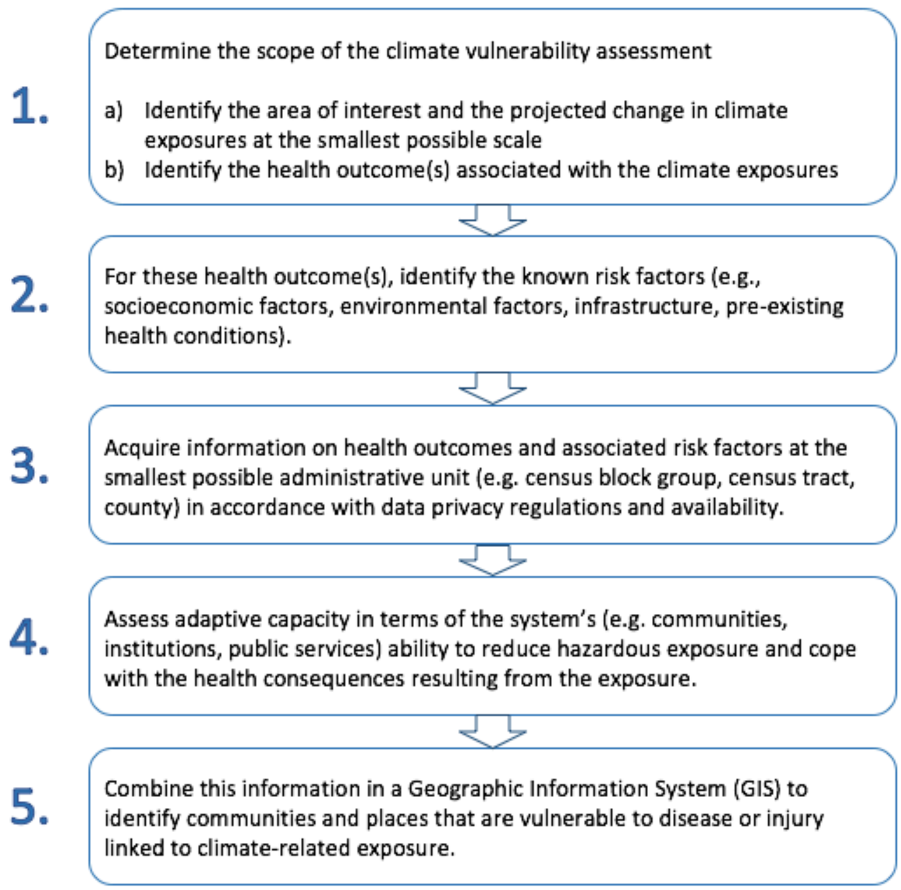



Figure: 2 Adapted from CDC's BRACE Framework[61]

The CDC's methodology was developed for use by public health practitioners. The proposed methodology for a quantitative approach to vulnerability assessment is to use GIS and perform either an overlay analysis of factors or spatial regression. The CDC suggests the overlay analysis method is the underlying technique for numerous risk factor analysis methodologies, including environmental justice screening and social and medical vulnerability indices.[62] Other HVI methods include a statistical based approach through using principal component analysis to "create a smaller number of hybrid factors" developed through a reduction process that groups independent variables based on covariance.[63] Both the spatial regression technique and the PCA approach require more statistical expertise. HVIs often address exposure, sensitivity, and adaptive capacity even if they don't explicitly state these categories. Most HVIs address socioeconomic variables, environmental factors, and health conditions that are known to impact vulnerability.

## Data

Availability of data informed the location of this study. All data for the HVI was publicly accessible and mortality rates were provided by the Urban Climate Lab within Georgia Institute of Technology's School of City and Regional Planning. The study area encompassed a total of 254 census tracts, highlighted in Figure 3. Tracts were limited to those within Dallas County and completely within the City of Dallas boundary. The determinates employed and data sources for the HVI can be found in Figure 4.

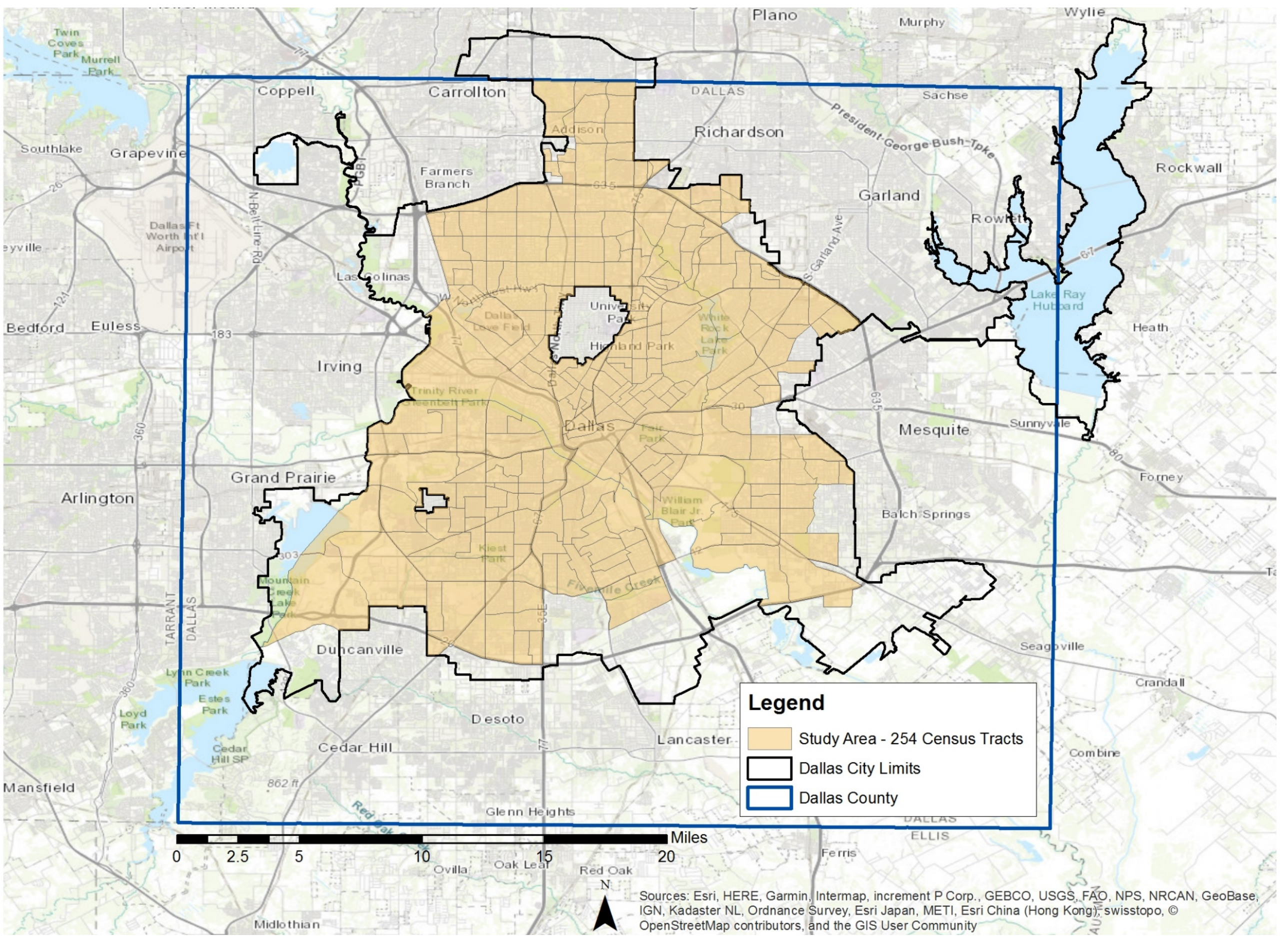


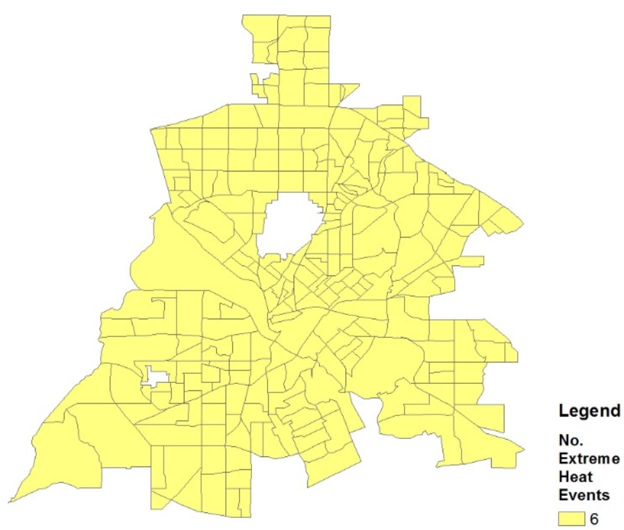
Figure 3: Study area highlighted

| Determinate | Source / (Resolution) |
|---|---|
| **EXPOSURE:** | |
| Number of heat events | National Environmental Public Health Tracking Network – 2011 (County) |
| **SENSITIVITY:** | |
| Percent population >65 living alone | US Census - 2010 (Tract) |
| Percent population living below poverty line | US Census - 2010 (Tract) |
| Prevalence of diabetes | 500 Cities: CDC (Tract) |
| Percent impervious surface | National Land Cover Database (NLCD) 2011 (30m) |
| **ADAPTIVE CAPACITY:** | |
| Number of medical infrastructure facilities | Homeland Infrastructure Program (X,Y Coordinates) |

Figure 4: Determinates and Sources

## *Exposure*

Exposure was determined by the CDC as the number of heat events experienced per county, defined as "two or more consecutive days when the heat index was >100°F"[64]. However, definitions of extreme heat events vary from region to region. The thresholds specific to North Texas have been used in this study, defined as daytime heat index expected to meet or exceed 110°F, *or*, daytime air temperature expected to meet or exceed 105°F for at least two consecutive days.[65,66] Daytime air temperatures were evaluated on this basis which indicated a total of six EHEs for Dallas during the summer of 2011. Because of the scale of this data, each census tract has the same vulnerability in terms of extreme heat exposure:




The extent of the EHE is not factored into the exposure rate, however, which may further impact vulnerable populations. The longest stretch of consecutive days over 105°F was 15, which occurred from August 16th to August 30th, 2011.

## *Sensitivity*

Sensitivity was calculated by the CDC as a weighted combination of four determinates:

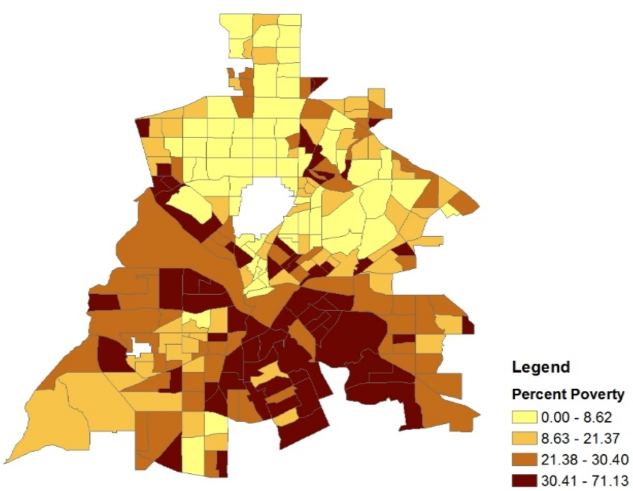
| Determinant | Determinant Type | Source / (Resolution) | Literature Source |
|---|---|---|---|
| % population below poverty line | Social | US Census (Tract) | (Currero et al. 2002; Reid, O'Neil et al. 2009) |
| % population ≥ 65 years of age living alone | Social | US Census (Tract) | (Naughton et al 2002; Reid, O'Neill et al. 2009) |
| Non-vegetated areas (e.g. impervious surfaces, non-green space) | Environmental | USGS (30m) | (Harlan, Brazel et al. 2006; Reid, O'Neill et al. 2009) |
| Prevalence of renal Diseases | Biological | Medicare (Zipcode) | (Semenza, Rubin et al. 1999) |

Figure 5: Table 2 Sensitivity factors for extreme heat used in the overlay analysis[67]

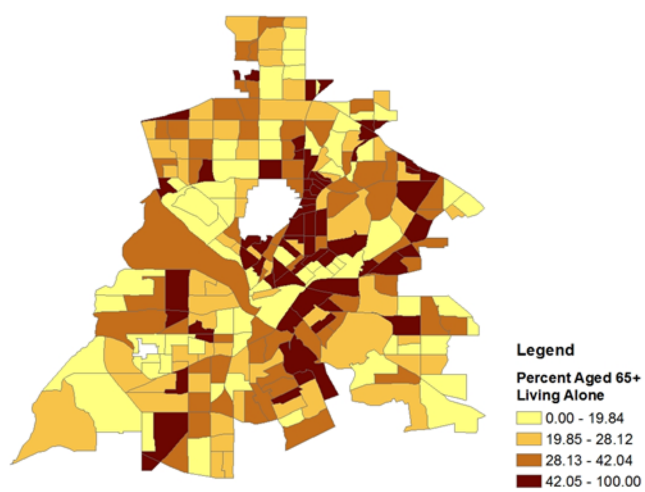
This study used the first three determinates based on data availability; however, renal disease rates were not publically available. As an alternative biological measure, prevalence of diabetes was included due to a positive relationship in previous studies between higher mortality risk and diabetes.[68] Non-vegetated areas (impervious surface) was included but data was taken from the National Land Cover Database as impervious surface coverage had already been calculated for 2011.

Weights within the sensitivity layer were applied based on a quartile classification and assigned a weighting factor according to risk (0.25, 0.5, 0.75, 1.0). The highest risk categories received a weight of 1.0 while the lowest risk received a 0.25. Once the weights were assigned, an overlay was performed to combine the four variables into a cumulative sensitivity layer, with each category accounting for one-fourth of the total sum. The following maps are represented using quantile classification with 4 categories:

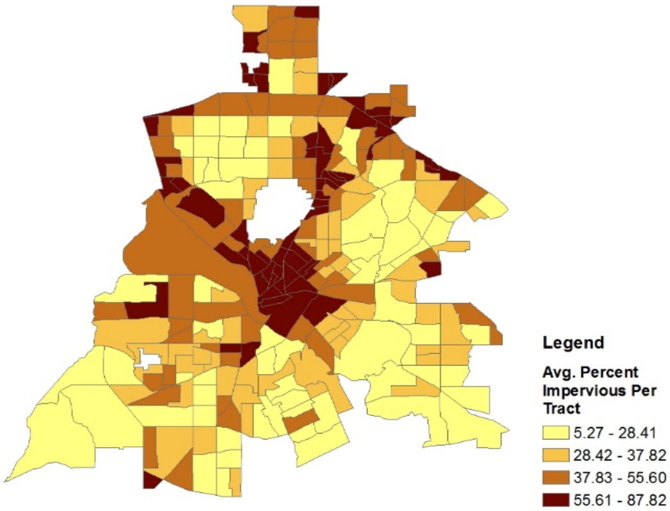
Percent Population in Poverty

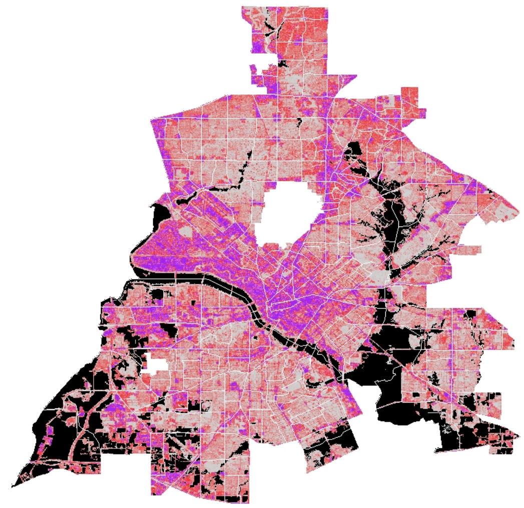



Percent Population Older than 65 Living Alone



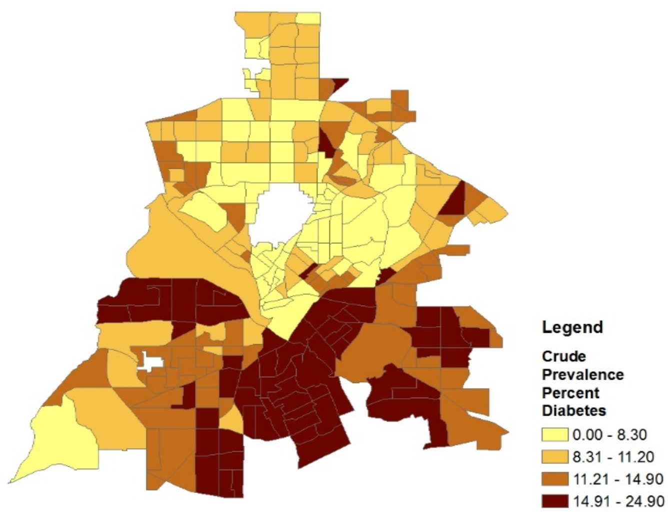
Percent Impervious Surface



Raster data from NLCD was intersected with census tract geography in ArcGIS to determine percent impervious per tract. Within the raster dataset, each pixel was given a value from 1-100 indicating percent imperviousness. A count of pixels per parcel was calculated along with a total sum of values indicating imperviousness. A percentage of impervious surface was calculated by taking sum/count*100 to derive the average percent imperviousness per tract.

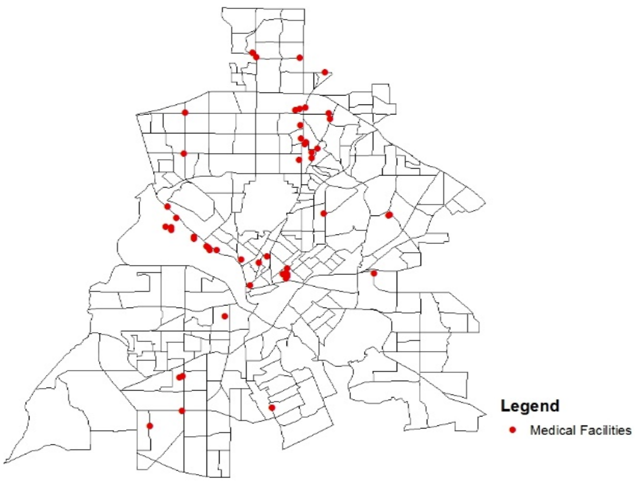
Crude Prevalence of Diabetes



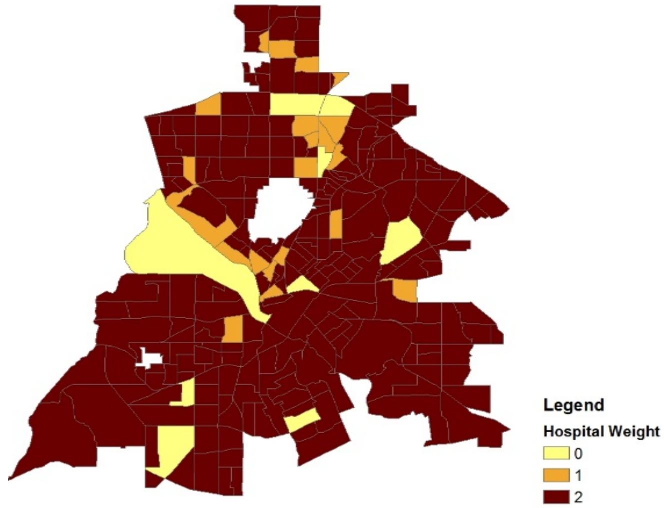

### *Adaptive Capacity*

Hospital insufficiency was the CDC's determinate for addressing adaptive capacity. This measure was defined as the total number of medical infrastructure facilities per county, which included total number of hospitals, surgical facilities, ambulatory services, and Red Cross shelters. Because the scale of the initial study was at the state scale, a total number of medical facilities per county may have been sufficient. However, for this study, county level information was insufficient in determining vulnerability at a census tract level. The total count of medical infrastructure facilities was thus calculated per census tract. Values were assigned for each census tract based on the number or medical facilities present, where a tract with zero facilities received a three (yellow), one facility received a two (orange), and tracts with two or more facilities received a zero (brown).

Medical Facilities

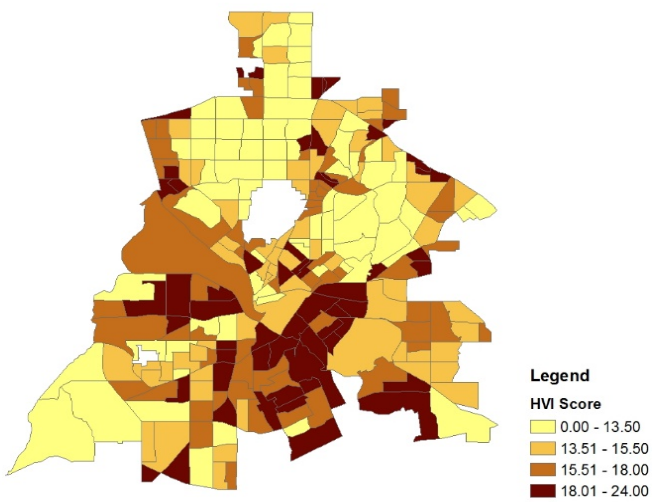



Hospital Insufficiency




### *Heat Vulnerability Index Results*

HVI Results




The methods for generating the composite HVI closely followed those of the CDC study. Once the cumulative sensitivity layer was summed based on the initial weighting, the heat exposure, hospital insufficiency, and sensitivity layers were summed with equal weights through an overlay function in GIS.

To generate the HVI score per census tract, the composite raster file for the HVI was assigned points for each pixel. These were spatially joined to the census tracts based on centroids. All points within each census tract had uniform values since all input data into the HVI was at the tract level. All values were dissolved to create a singular value per census tract, indicating the cumulative HVI score per tract.

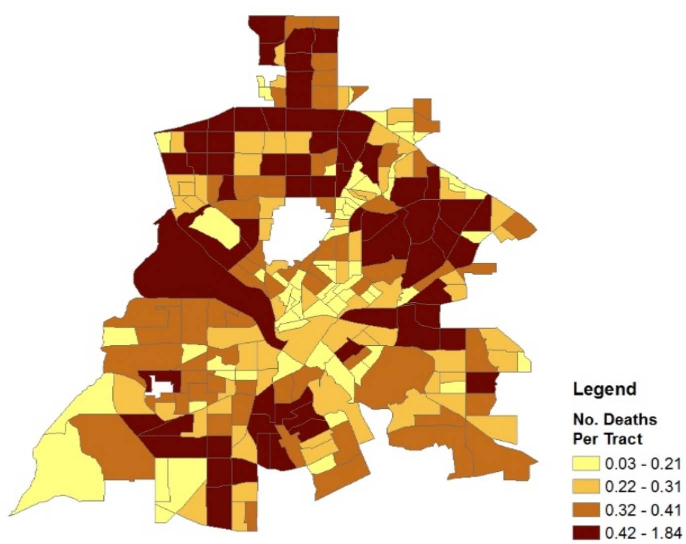
This approach gives equal weight to adaptive capacity, exposure and sensitivity.  This may not be an appropriate weighting for this scale of study as the exposure layer has no variability and the adaptive capacity layer has very limited variability with a methodology that is best suited for larger scales.

### *Mortality Data*

The comparison method employed in this paper uses an exposure response function based on observed mortality in Dallas.  The mortality data was developed by the Urban Climate Lab through a statistical attribution method done through the use of an advanced model to predict mortality at the ½ $km^2$ grid cell – geographically locating the estimated number of deaths due to heat for 2011. Total population by age and sex along with average daily mortality data were allocated to each grid cell.  Mortality risk was developed through an exposure-response relationship from data of 348 cities around the world, including Dallas. Lastly, the grid cell daily temperatures from the climate scenario modeling were used to estimate the number of heat-related deaths.[69]

Mortality rates were calculated for each census tract through a series of functions in GIS. Each grid cell provided had a value associated with total number of deaths. Mortality rates were assumed to be constant over the gridded area. An intersect function provided an integration of the grid cell and tract layer.  In cases where the grid cell was split by two or more census tracts, mortality rates were calculated by determining the percentage of grid cell within each tract. All values per tract were summed and this result provided the overall number of deaths per census tract.

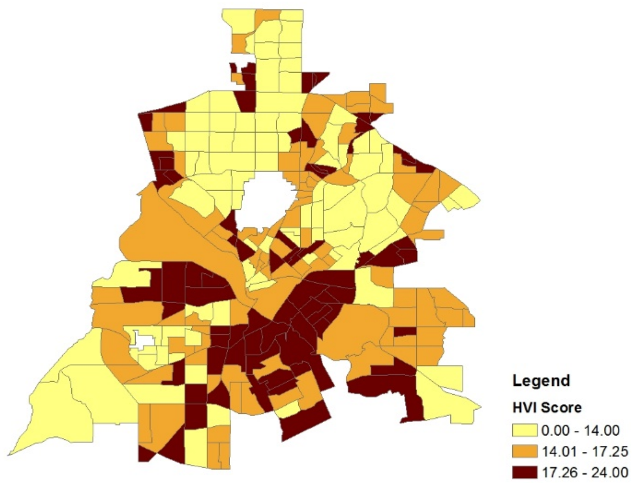
<u>Mortality</u>



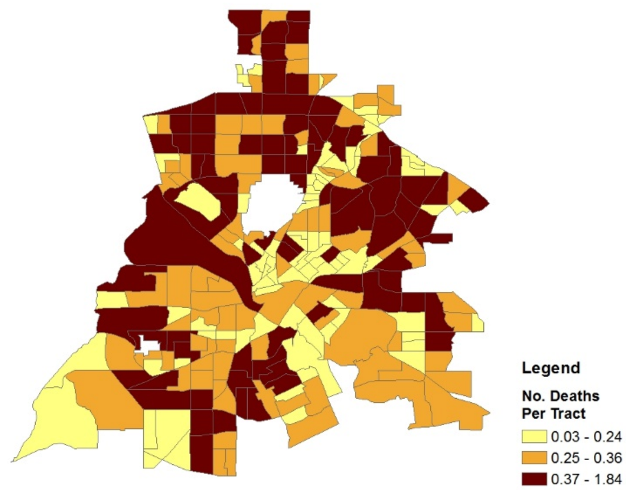

### *HVI Validation*

The validation of the HVI is based on a comparison of the outcomes of the HVI with the modeled mortality at the census tract level.  This can provide an assessment of the accuracy of the HVI in estimating mortality based on a more sophisticated modeling approach. This validation method assumes that the model estimates, which are based on actual mortality, can approximate actual heat mortality, which cannot be measured. Maps are represented by quintile indicating low, medium and high vulnerability and mortality.

<u>Composite HVI</u>




<u>Mortality</u>




## Results

The results produced by this study indicate the HVI developed through the proposed methodology has a low accuracy rate in estimating modeled mortality. Visual inspection indicates there is little overlap in areas of high heat vulnerability and areas of high mortality. Figure 7 displays the results of this type of comparison. When looking at the outcomes in terms of percentages broken down by three quintiles (low, medium, and high), fourteen tracts indicate both high vulnerability and high mortality. A larger number of tracts indicate medium to low vulnerability and mortality. Overall, there were a total of 66 tracts in the HVI that exhibited the same percentage range as those of mortality, indicating a 25.98% overlap among the breakdown of quintiles.

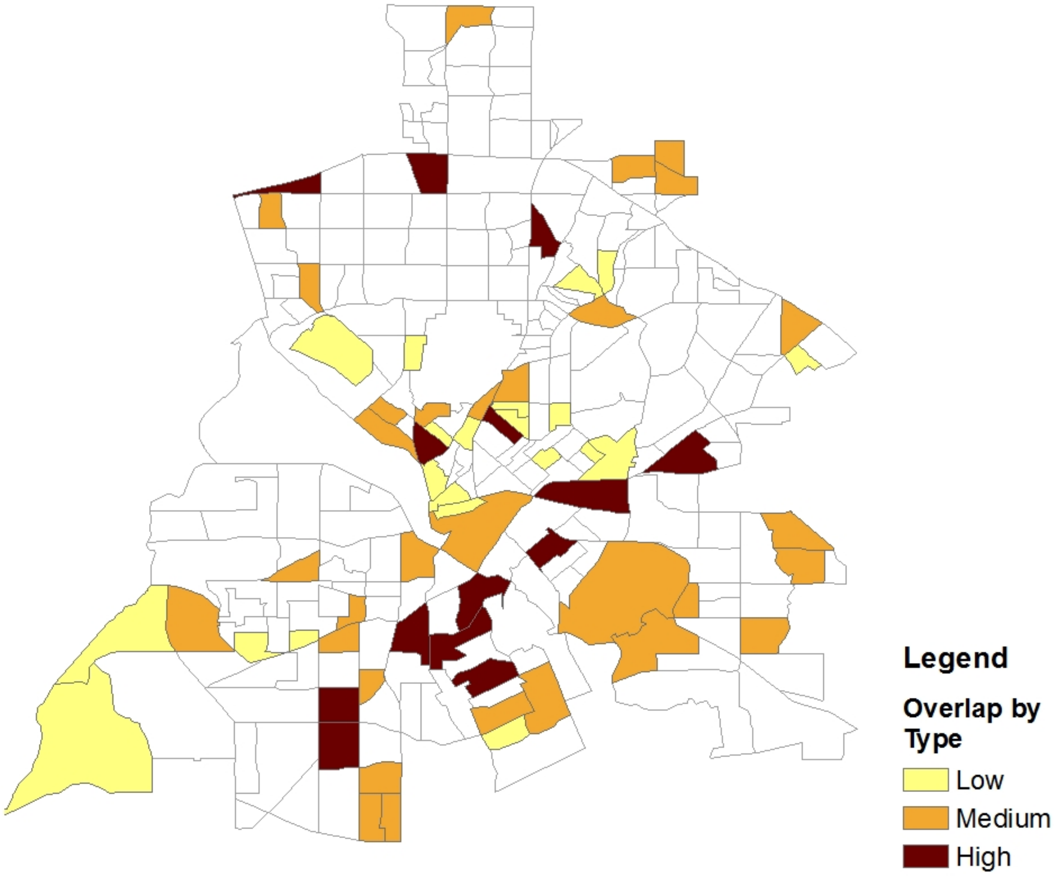



Figure 6: Overlap between HVI and Mortality

| Ranking HVI / Mortality | Quintile Ranking by Number | Quintile Ranking by % | No. Tracts with Overlap |
|---|---|---|---|
| Low / Low | 1 | Less than 33 | 21 |
| Medium / Medium | 2 | 33-66 | 31 |
| High / High | 3 | 66-100 | 14 |
| | | Total | 66 |

Total % Overlap
25.98

Figure 7: HVI Accuracy Evaluation

# Discussion

While the results of this study do not indicate a high accuracy of this HVI in estimating mortality, a number of observations can be made and further work may be proposed for improving the HVI and its use in increasing positive health outcomes.

## Observations

The resultant overlay map may provide a good basis and information for considering how and where to best invest in mitigation efforts and targeted EHE outreach.  For areas exhibiting high values in both the HVI and Mortality map, the city may more reasonably assume that the factors included in this HVI have a larger effect on mortality. The HVI results can be used by cities who have applied the exposure response function as a way to establish a system for prioritizing mitigation by location and type. Additionally, the results may indicate the areas for targeted public outreach during an EHE to reduce vulnerability to heat related morbidity and mortality. Similarly, the areas of low vulnerability and low mortality are understood to offer less threat to public health during EHE and may be prioritized as such.

A more detailed analysis may be performed on the areas of high vulnerability and high mortality to better understand the specific factors that produced this result. 14 census tracts exhibited values in the top third of the HVI and mortality studies.

The following information offers a further look into the high-ranking census tracts. The city's average rates are found at the far left of the chart under Dallas as a comparison to the tracts that exhibited high vulnerability and mortality.

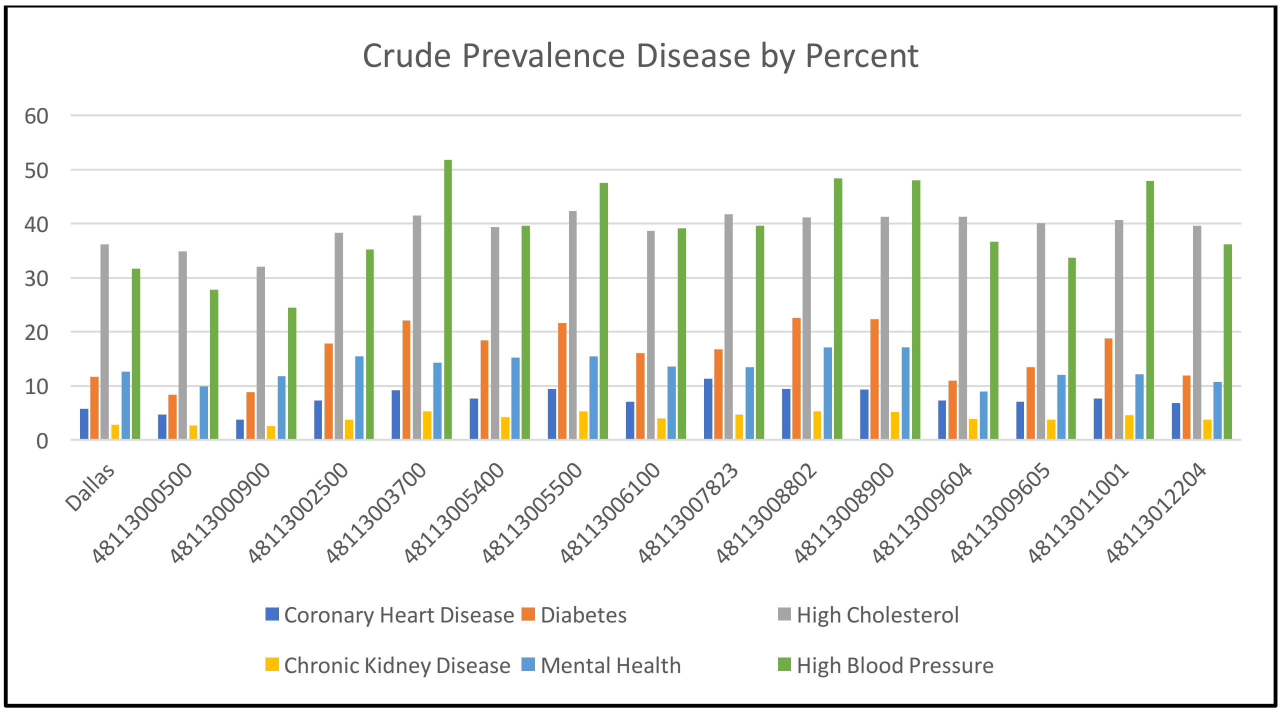



Figure 8: Health Outcomes, Source: CDC's 500 Cities

## Improvements

For this type of methodology to be applicable to other cities which may not have the resources to have a mortality study performed, it is reasonable to assume that improvements to the HVI are needed to provide a more accurate assessment. A couple of methods may be proposed to increase accuracy for the HVI and potentially improve estimates of mortality.

First, revisions to the methodology would be useful to target a more granular set of data for use by cities and counties. The methodology proposed by the CDC is performed at a state scale with results at a county level. This scale of analysis provides little valuable information to cities or counties who have the power to enact policies that may impact land use, development, and public health outcomes. A more granular study to provide results at the census tract would allow cities and counties the ability to know where specific populations may be at risk of heat related morbidity or mortality and make concerted efforts to minimize risk in targeted locations.

Second, based on the results of this study, it is possible to assume that key variables indicating heat vulnerability may not have been included or the ones that were included did not have much explanatory power. A number of other studies have looked at rates of homes with air conditioning, or proxies since this is data is not available nationally or publicly accessible. There may be other variables that would be worth including based on regression analysis from previous studies. For those included in this study, a more rigorous determination of adaptive capacity may be needed beyond hospital insufficiency, or at least a methodology for determining this at the census tract level.

# Policy Recommendations

While the City and County are currently incorporating heat into plans and policies, a number of strategies can be implemented to improve health outcomes from extreme heat events and create a more resilient city. This would include further preparation of a city heat plan under the emergency response plan. Second, a broadening of the public health response to extreme heat. Third, a broader understanding of vulnerability will assist planning officials in targeting outreach and mitigation efforts. And lastly, enhancing infrastructure resilience will play an essential role in reducing environmental factors that increase vulnerability and heat.

## Heat Plan

Both the City of Dallas and Dallas County include extreme heat in their emergency response plans. The city's plan, Master Emergency Operations Basic Plan, lists Extreme Heat as a natural hazard that is highly likely to occur, will have a moderate estimated impact on public health and safety and a limited estimated impact to property. The plan details responsibilities of various parties based on the threat of emergency. There are no specific plans listed for response to an extreme heat event, only the general protocol for an emergency situation.

The Dallas County PLAN details the threat of extreme heat for the county, provides deaths related to heat for the previous five years, and briefly discusses particular vulnerability for residents over 65 and low-income residents. The death toll provided for 2011 was the highest of any years reported from 2008 to 2013 with a total of 19 deaths attributed to heat. However, based on the mortality provided in this study, the total number of deaths modeled in 2011 was 111, showing a difference of 92 between recorded and predicted. This is a significant difference and identifies the need for improved action during EHEs.

The city can look to Philadelphia as an example of one city that has developed a specific heat plan that outlines actions to perform during an EHE, referred to as a heat/health watch warning system (HHWWS). The policy is based on historical data of health outcomes and how particular heat events may impact health. This plan has a formalized process provides city departments a specific set of actions to be taken during an EHE. One study showed 117 lives were saved because of this plan during a period of four years.[70]

One portion of this plan ensures utility shutoffs are halted during EHEs. Currently, the Public Utility Commission of Texas states that Retail Electric Providers (REP) may not authorize disconnection of electric service, "For non-payment during an extreme weather emergency, and upon request, the REP must offer you a deferred payment plan for bills due during the emergency."[71] This language for this policy could be strengthened to include that REPs may not authorize disconnection of electrical service during extreme weather emergencies. This would require that EHEs fall into the definition of an extreme weather emergency.

## Response to EHEs

As part of a formalized heat plan, the city should consider broadening the public health response to EHEs. Using the Philadelphia example again, the city could implement a number of public health outreach responses prior to and during EHEs. Prior to an EHE, these may include organizing awareness campaigns and mobile workshops throughout the city, particularly in vulnerable communities, on the dangers of heat and how communities can prepare for and protect their health during EHEs.

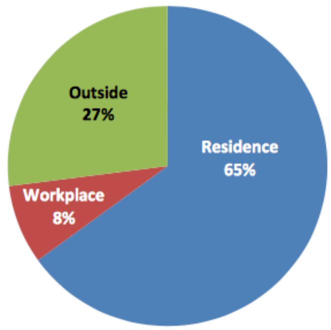
Additionally, the city can work with the health department to develop a permanent location for resources where individuals can locate information related to EHEs, namely health symptoms of heat related health problems, cooling center locations, hours, and resources available at the cooling centers. This would mean working with the current provider of cooling centers, The Salvation Army, to ensure certain locations would remain open and available during any particular EHE, and possibly expanding cooling centers to city run facilities such as libraries, swimming pools, etc. to ensure coverage throughout the city.

During an EHE, the public health outreach can be expanded to provide services such as a heat hotline where public health nurses would be available to answer questions about symptoms and provide information about resources available to individuals and communities. Additionally, public health dispatch or mobile teams may be made available to check on particularly vulnerable populations. The city may also consider developing partnership with organizations providing shelter for homeless individuals to extend shelter hours or provide additional services.

## Understanding Vulnerability

Mortality data can be used in a number of ways to identify vulnerability within the city. The data used in this study for example can be useful in seeing the areas of highest impact. This can provide insights into locations where mitigation efforts may prove most effective. Additionally, the city can perform in-depth analyses on deaths attributed to heat. The New York City Department of Health and Mental Hygiene performed a review of death certificates and medical examiner investigation reports to better understand the characteristics and circumstances that lead to death during the 2013 summer season. Excerpts of the analysis performed can be seen in Figure 9. An understanding of this level of mortality data can help improve HVIs and the ability of the city to better prepare for and respond to future EHEs.

**Percent of heat-related deaths by place of exposure, New York City, 2013**




*Source: 2013 OCME case investigation records*

**Number and percentage of heat-related deaths among adults ages 18 and older in New York City (n=24) by selected risk factors, 2013**

| Characteristic | n | % |
|---|---|---|
| Ages 65 years and older | 8 | 33% |
| **Specific conditions** | | |
| Cardiovascular disease | 14 | 58% |
| Obese (BMI = 30 or higher) | 6 | 25% |
| Diabetes | 7 | 29% |
| Drug or alcohol abuse | 9 | 38% |
| Cognitive or mental health condition | 5 | 21% |
| Respiratory conditions | 1 | 4% |

*Source: 2013 NYC DOHMH Vital Records data and OCME case investigation records*

Figure 9: Source EPI Data Brief[72]

HVIs may play an important role in determining vulnerable populations. Because mortality data can be difficult to attribute to heat, knowing the factors that lead to morbidity and mortality in the population may still improve targeted approaches to reaching the most vulnerable populations. As more data becomes available and at more granular scales, the accuracy of the HVI may also be improved.

### Environmental Mitigation

Lastly, the environmental factors leading to vulnerability will be important to monitor and implement physical changes to improve cooling. The city currently has a number of adaptive mitigation techniques in place to combat urban heat island. These include the Adopt-a-Median program, the Green Building Program and Standards, and the Sustainable Skylines Initiative.[73] Additional mitigation measures can be found in the *Dallas Urban Heat Island Management Study*. The study indicates the most effective approach to promote cooling and health benefits is a combination of a greening and cooling strategy, implemented separately and in combination based on land use and feasibility. The study states that to achieve the energy efficiency outcomes and land cover changes modeled in the study, "a combination of new regulatory and economic incentive programs will be needed".[74]

## Conclusion

The results from this comparison of an HVI and mortality data show that the HVI did not have a high accuracy in estimating mortality, modeled through more sophisticated measures. The HVI methodology needs improvement at a more granular level to improve accuracy and be of more use to city and county policymakers. However, results from this HVI may still be useful in helping the city prioritize areas that indicate both high vulnerability and high mortality for mitigation efforts. Lastly, regardless of the HVI outcomes, there are still a number of steps the city can take to become a more resilient city in the face of increasing heat and EHEs.

[1] Habeeb, Vargo, and Stone, “Rising Heat Wave Trends in Large US Cities.”
[2] “Excessive Heat Events Guidebook.”
[3] Luber and McGeehin, “Climate Change and Extreme Heat Events.”
[4] “Climate Change and Extreme Heat Events.”
[5] “Climate Change and Extreme Heat: What You Can Do to Prepare.”
[6] Sarofim et al., “Ch. 2.”
[7] US EPA, “Climate Change Indicators.”
[8] Center for Disease Control and Prevention, “About Extreme Heat.”
[9] “Climate Change and Extreme Heat Events.”
[10] US EPA, “Climate Change Indicators.”
[11] “Climate Change and Extreme Heat Events.”
[12] Argaud et al., “Short- and Long-Term Outcomes of Heatstroke Following the 2003 Heat Wave in Lyon, France.”
[13] “Climate Change and Extreme Heat Events.”
[14] Balbus et al., “Ch. 1.”
[15] “Climate Change and Extreme Heat: What You Can Do to Prepare.”
[16] “Climate Change and Extreme Heat: What You Can Do to Prepare.”
[17] “Climate Change in the United States: Benefits of Global Action.”
[18] “National Health Statistics Reports.”
[19] Luber and McGeehin, “Climate Change and Extreme Heat Events.”
[20] US Census Bureau, “2014 National Population Projections Tables.”
[21] Vincent and Velkoff, “The Next Four Decades: The Older Population in the United States: 2010 to 2050.”
[22] US EPA, “Climate Change Indicators.”
[23] Luber and McGeehin, “Climate Change and Extreme Heat Events.”
[24] “Climate Change and Extreme Heat: What You Can Do to Prepare.”
[25] US EPA, “Climate Change Indicators.”
[26] Balbus et al., “Ch. 1.”
[27] Manangan et al., “Assessing Health Vulnerability to Climate Change: A Guide for Health Departments.”
[28] Balbus et al., “Ch. 1.”
[29] Turner et al., “A Framework for Vulnerability Analysis in Sustainability Science.”
[30] Balbus et al., “Ch. 1.”
[31] Reid et al., “Evaluation of a Heat Vulnerability Index on Abnormally Hot Days.”
[32] “Protecting Vulnerable Groups from Extreme Heat | Extreme Heat.”
[33] Preston, Yuen, and Westaway, “Putting Vulnerability to Climate Change on the Map.”
[34] Chuang and Gober, “Predicting Hospitalization for Heat-Related Illness at the Census-Tract Level.”
[35] Gover, “Mortality during Periods of Excessive Temperature.”
[36] Smoyer, “Putting Risk in Its Place.”
[37] Bradford et al., “A Heat Vulnerability Index and Adaptation Solutions for Pittsburgh, Pennsylvania.”
[38] Maier et al., “Assessing the Performance of a Vulnerability Index during Oppressive Heat across Georgia, United States.”
Reid et al., “Mapping Community Determinants of Heat Vulnerability.”Reid et al., “Mapping Community Determinants of Heat Vulnerability.”Colleen E. Reid et al., “Mapping Community Determinants of Heat Vulnerability,” *Environmental Health Perspectives* 117, no. 11 (November 2009): 1730–36, https://doi.org/10.1289/ehp.0900683.Reid et al., “Mapping Community Determinants of Heat Vulnerability.”Reid et al., “Mapping Community Determinants of Heat Vulnerability.”[39]Reid et al.
[40] Chuang and Gober, “Predicting Hospitalization for Heat-Related Illness at the Census-Tract Level.”
[41] Chuang and Gober.
[42] Manangan et al., “Assessing Health Vulnerability to Climate Change: A Guide for Health Departments.”
[43] Balbus et al., “Are We Ready? Preparing for the Public Health Challenges of Climate Change.”
[44] Luber and McGeehin, “Climate Change and Extreme Heat Events.”
[45] Manangan et al., “Assessing Health Vulnerability to Climate Change: A Guide for Health Departments.”
[46] Reid et al., “Evaluation of a Heat Vulnerability Index on Abnormally Hot Days.”

[47] "A Heat Vulnerability Index to Improve Urban Public Health Management in San Juan, Puerto Rico | SpringerLink."
[48] Luber and McGeehin, "Climate Change and Extreme Heat Events."
[49] Bradford et al., "A Heat Vulnerability Index and Adaptation Solutions for Pittsburgh, Pennsylvania."
[50] Chuang and Gober, "Predicting Hospitalization for Heat-Related Illness at the Census-Tract Level."
[51] Bradford et al., "A Heat Vulnerability Index and Adaptation Solutions for Pittsburgh, Pennsylvania."
[52] Sarofim et al., "Ch. 2."
[53] Sarofim et al.
[54] Sarofim et al.
[55] Sarofim et al.
[56] Sarofim et al.
[57] "What Are the Challenges?"
[58] "What Are the Challenges?"
[59] Reid et al., "Mapping Community Determinants of Heat Vulnerability."
[60] Manangan et al., "Assessing Health Vulnerability to Climate Change: A Guide for Health Departments."
[61] Manangan et al.
[62] Manangan et al.
[63] Manangan et al.
[64] Manangan et al.
[65] "DFW Heat Index & the Heat Advisory Criteria for North Texas."
[66] "Dallas County Health & Human Services."
[67] Manangan et al., "Assessing Health Vulnerability to Climate Change: A Guide for Health Departments."
[68] Schwartz, "Who Is Sensitive to Extremes of Temperature?"
[69] "Dallas Urban Heat Island Management Study."
[70] Kalkstein, Sheridan, and Kalkstein, "Heat/Health Warning Systems."
[71] "Utility Complaints: Know Your Rights."
[72] "Heat-Related Deaths in New York City, 2013."
[73] US EPA, "Heat Island Community Actions Database."
[74] "Dallas Urban Heat Island Management Study."

"A Heat Vulnerability Index to Improve Urban Public Health Management in San Juan, Puerto Rico | SpringerLink." Accessed October 7, 2017. https://doi.org/10.1007/s00484-017-1319-z.

Argaud, Laurent, Tristan Ferry, Quoc-Hung Le, Aurélia Marfisi, Diana Ciorba, Pierre Achache, Roland Ducluzeau, and Dominique Robert. "Short- and Long-Term Outcomes of Heatstroke Following the 2003 Heat Wave in Lyon, France." *Archives of Internal Medicine* 167, no. 20 (November 12, 2007): 2177–83. https://doi.org/10.1001/archinte.167.20.ioi70147.

Balbus, J., A. Crimmins, J. L. Gamble, D. R. Easterling, K. E. Kunkel, S. Saha, and M. C. Sarofim. "Ch. 1: Introduction: Climate Change and Human Health." U.S. Global Change Research Program, Washington, DC, April 4, 2016. /climate-change-and-human-health.

Balbus, John, Kristie Ebi, Lauren FInzer, Catherine Malina, Amy Chadwick, Dennis McBride, Michelle Chuk, and Ed Maibach. "Are We Ready? Preparing for the Public Health Challenges of Climate Change." Environmental Defense Fund, 2008. http://archived.naccho.org/topics/environmental/climatechange/upload/Are-we-ready_14_view.pdf.

Bradford, Kathryn, Leslie Abrahams, Miriam Hegglin, and Kelly Klima. "A Heat Vulnerability Index and Adaptation Solutions for Pittsburgh, Pennsylvania." *Environmental Science & Technology* 49, no. 19 (20151006): 11303–11. https://doi.org/10.1021/acs.est.5b03127.

Center for Disease Control and Prevention. "About Extreme Heat." Natural Disasters and Severe Weather, September 25, 2017. https://www.cdc.gov/disasters/extremeheat/heat_guide.html.
Chuang, Wen-Ching, and Patricia Gober. "Predicting Hospitalization for Heat-Related Illness at the Census-Tract Level: Accuracy of a Generic Heat Vulnerability Index in Phoenix, Arizona (USA)." *Environmental Health Perspectives* 123, no. 6 (June 2015): 606–12. https://doi.org/10.1289/ehp.1307868.
"Climate Change and Extreme Heat Events." Center for Disease Control and Prevention. Accessed October 7, 2017. https://www.cdc.gov/climateandhealth/pubs/climatechangeandextremeheatevents.pdf.
"Climate Change and Extreme Heat: What You Can Do to Prepare." US EPA and CDC, October 2016. https://www.cdc.gov/climateandhealth/pubs/extreme-heat-guidebook.pdf.
"Climate Change in the United States: Benefits of Global Action." U.S. Environmental Protection Agency. Accessed October 29, 2017. https://www.epa.gov/sites/production/files/2015-06/documents/cirareport.pdf.
"Dallas County Health & Human Services." Accessed March 31, 2018. https://www.dallascounty.org/department/hhs/heatsafety.html.
"Dallas Urban Heat Island Management Study." Urban Climate Lab Georgia Institute of Technology, 2017. https://texastrees.blob.core.windows.net/static/Texas%20Trees%20UHI%20Sudy_Final_v4_title%20change.pdf.
"DFW Heat Index & the Heat Advisory Criteria for North Texas." *IWeatherNet* (blog), June 18, 2016. http://www.iweathernet.com/dallas-fort-worth/criteria-for-heat-advisory-and-heat-warning-north-texas-dfw.
"Excessive Heat Events Guidebook." United States Environmental Protection Agency, June 2006. https://www.epa.gov/sites/production/files/2016-03/documents/eheguide_final.pdf.
Gover, Mary. "Mortality during Periods of Excessive Temperature." *Public Health Reports (1896-1970)* 53, no. 27 (1938): 1122–43. https://doi.org/10.2307/4582590.
Habeeb, Dana, Jason Vargo, and Brian Stone. "Rising Heat Wave Trends in Large US Cities." *Natural Hazards* 76, no. 3 (April 2015): 1651–65. https://doi.org/10.1007/s11069-014-1563-z.
"Heat-Related Deaths in New York City, 2013." New York City: New York City Department of Health and Mental Hygiene, August 2014. https://www1.nyc.gov/assets/doh/downloads/pdf/epi/databrief47.pdf.
Kalkstein, Laurence S., Scott C. Sheridan, and Adam J. Kalkstein. "Heat/Health Warning Systems: Development, Implementation, and Intervention Activities." In *Biometeorology for Adaptation to Climate Variability and Change*, edited by Kristie L. Ebi, Ian Burton, and Glenn R. McGregor, 1:33–48. Dordrecht: Springer Netherlands, 2009. https://doi.org/10.1007/978-1-4020-8921-3_3.
Luber, George, and Michael McGeehin. "Climate Change and Extreme Heat Events." *American Journal of Preventive Medicine*, Theme Issue: Climate Change and the Health of the

Public, 35, no. 5 (November 1, 2008): 429–35. https://doi.org/10.1016/j.amepre.2008.08.021.

Maier, George, Andrew Grundstein, Woncheol Jang, Chao Li, Luke P. Naeher, and Marshall Shepherd. "Assessing the Performance of a Vulnerability Index during Oppressive Heat across Georgia, United States." *Weather, Climate & Society* 6, no. 2 (April 2014): 253–63. https://doi.org/10.1175/WCAS-D-13-00037.1.

Manangan, Arie Ponce, Christopher K. Uejio, Shubhayu Shahal, Paul J. Schramm, Gino D. Marinucci, Claudia Langford Brown, Jeremy J. Hess, and George Luber. "Assessing Health Vulnerability to Climate Change: A Guide for Health Departments." Climate and Health Technical Report Series. Climate and Health Program, Centers for Disease Control and Prevention. Accessed November 25, 2017. https://www.cdc.gov/climateandhealth/pubs/AssessingHealthVulnerabilitytoClimateChange.pdf.

"National Health Statistics Reports." CDC, July 30, 2014. https://www.cdc.gov/nchs/data/nhsr/nhsr076.pdf.

Preston, Benjamin L., Emma J. Yuen, and Richard M. Westaway. "Putting Vulnerability to Climate Change on the Map: A Review of Approaches, Benefits, and Risks." *Sustainability Science* 6, no. 2 (July 1, 2011): 177–202. https://doi.org/10.1007/s11625-011-0129-1.

"Protecting Vulnerable Groups from Extreme Heat | Extreme Heat," September 15, 2017. https://www.cdc.gov/disasters/extremeheat/specificgroups.html.

Reid, Colleen E., Jennifer K. Mann, Ruth Alfasso, Paul B. English, Galatea C. King, Rebecca A. Lincoln, Helene G. Margolis, et al. "Evaluation of a Heat Vulnerability Index on Abnormally Hot Days: An Environmental Public Health Tracking Study." *Environmental Health Perspectives* 120, no. 5 (May 2012): 715–20. https://doi.org/10.1289/ehp.1103766.

Reid, Colleen E., Marie S. O'Neill, Carina J. Gronlund, Shannon J. Brines, Daniel G. Brown, Ana V. Diez-Roux, and Joel Schwartz. "Mapping Community Determinants of Heat Vulnerability." *Environmental Health Perspectives* 117, no. 11 (November 2009): 1730–36. https://doi.org/10.1289/ehp.0900683.

Sarofim, M. C., S. Saha, M. D. Hawkins, D. M. Mills, J. Hess, R. Horton, P. Kinney, J. Schwartz, and A. St Juliana. "Ch. 2: Temperature-Related Death and Illness." U.S. Global Change Research Program, Washington, DC, April 4, 2016. /temperature-related-death-and-illness.

Schwartz, Joel. "Who Is Sensitive to Extremes of Temperature? A Case-Only Analysis." *Epidemiology* 16, no. 1 (2005): 67–72. http://www.jstor.org/stable/20486001.

Smoyer, Karen E. "Putting Risk in Its Place: Methodological Considerations for Investigating Extreme Event Health Risk." *Social Science & Medicine* 47, no. 11 (December 1, 1998): 1809–24. https://doi.org/10.1016/S0277-9536(98)00237-8.

Turner, B. L., Roger E. Kasperson, Pamela A. Matson, James J. McCarthy, Robert W. Corell, Lindsey Christensen, Noelle Eckley, et al. "A Framework for Vulnerability Analysis in Sustainability Science." *Proceedings of the National Academy of Sciences* 100, no. 14 (July 8, 2003): 8074–79. https://doi.org/10.1073/pnas.1231335100.

US Census Bureau. "2014 National Population Projections Tables." 2014 National Population Projections Tables, May 9, 2017. https://www.census.gov/data/tables/2014/demo/popproj/2014-summary-tables.html.
US EPA, OA. "Climate Change Indicators: Weather and Climate." Reports and Assessments. Accessed October 29, 2017. /climate-indicators/weather-climate.
US EPA, OAR. "Heat Island Community Actions Database." Data and Tools. US EPA, June 17, 2014. https://www.epa.gov/heat-islands/heat-island-community-actions-database.
"Utility Complaints: Know Your Rights." Public Utility Commission of Texas. Accessed March 26, 2018. https://www.puc.texas.gov/consumer/complaint/Rights.aspx.
Vincent, Grayson, and Victoria Velkoff. "The Next Four Decades: The Older Population in the United States: 2010 to 2050," May 2010. https://www.census.gov/prod/2010pubs/p25-1138.pdf.
"What Are the Challenges?" *GreenDallas* (blog), December 16, 2015. http://greendallas.net/climate-change/challenges/.