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Risk factors and costs influencing hospitalizations due to heat-related illnesses: patterns of hospitalization

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Abstract

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Michael T. Schmeltz

Adviser: Professor Grace Sembajwe

The objective of this dissertation was to identify individual and environmental risk factors, investigate outcomes and hospital resource use, including costs, and document the pattern of heat-related illness hospitalizations in the United States. The main data source for the study population was the 2001-2010 Nationwide Inpatient Sample (NIS). The study population for heat-related illnesses (HRIs) consists of patients in the NIS with at least one diagnosis of a heat-related illness (ICD-9 codes 992.0 – 992.9) from 2001 to 2010. Outcome analysis included a study population of patients who had primary or secondary diagnoses of diabetes, cardiovascular diseases, respiratory illnesses, nephritic illnesses and acute renal failure along with a diagnosis of a heat-related illness. Outcomes for costs were calculated and adjusted using the medical consumer price index for 2013. Data on air conditioner use and total cost of electricity use from air conditioning was derived from the Residential Energy Consumption Survey. This study identified a number of previously unknown risk factors for heat morbidity HRI, including age greater than 40, males and hospitalization in rural areas and small urban clusters. Additionally, stratified analyses of outcomes further identified specific risk factors among vulnerable populations. Elevated risk of negative health outcomes and increased hospital resource use was seen in patients diagnosed with common comorbidities, in particular those of a lower socioeconomic status, minority and most age groups with diagnoses of cardiac and respiratory

diseases with a HRI. Analyses of costs showed substantial costs associated with hospitalizations due to heat-related illnesses with the average mean cost approximately $52.7 million while the total aggregate cost for the time period at just over half a billion dollars. Projected estimates for the average yearly cost of these hospitalizations in the future climate with estimates around half a billion US dollars by the late-21st century.

In conclusion, the study revealed a number of risk factors and negative health outcomes associated with hospitalizations of heat-related illnesses. These findings provide additional scientific evidence that heat-related illnesses will continue to rise and will continue to be a public health burden as climate changes increase in frequency and intensity of extreme weather events.

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Table of Contents

List of Tables

List of Figures

Chapter 1. Introduction

1.1. Climate change and extreme weather events

Global warming and climate change have increased the frequency and severity of weather-related hazards. This trend has prompted governments to research ways to adapt to our changing climate in order to reduce morbidity and mortality during extreme weather events. Studies by climate change researchers[1,2] indicate that the frequency and intensity of extreme climate events has increased in recent decades, and that adaptation to these rapid changes is more challenging than gradual climate change. Moreover, extreme climate events disproportionately affect vulnerable populations who experience higher exposure (e.g., low-income populations facing extreme heat often lack access to air conditioning and are more likely than the affluent to live in flood-prone areas) or higher susceptibility (e.g., elderly individuals are more physiologically vulnerable to heat-related illness) to such events.[3] Heat waves are one such extreme weather phenomena that have increased in frequency and are likely to have dire consequences for vulnerable populations.

Recent studies indicate that as global temperatures continue to rise due to the increase of greenhouse gases the frequency and intensity of extreme heat events are likely to increase.[4-7] Climate modeling also predicts that heat waves are likely to affect areas that had not previously experienced extreme heat events, increasing the geographic range and populations at risk of heat waves.[7] This increase in geographic areas prone to heat waves will in turn increase the incidence of heat-related illness and other public health impacts. Although, on average, there were only about 400 deaths were directly attributed to heat in the United States in 2002[8] an increase in ambient temperature can also exacerbate underlying chronic conditions such as cardiovascular, respiratory, and cerebrovascular diseases as well as psychiatric conditions.[9-11] Air pollution also increases during extreme heat events and may further exacerbating underlying medical conditions, particularly respiratory diseases.[11,12] Studies have found a 5-11% increase in hospital admissions as well as increased use of ambulances, telephone helplines and dispatches by fire departments during heat waves.[13,14] Hence, the expected increase in heat-related and exacerbated illness is likely to stress health care systems and emergency responders.

Although public health interventions may focus on the prevention of heat-related illness, public health practitioners and policymakers should also direct preventive measures to the community- and environment-level effects of extreme heat events.[15,16] Heat waves can have devastating effects on livestock and crops, and can damage electrical equipment, roads, bridges and other types of infrastructure.[16] In countries like Australia and western parts of the United States heat waves are often accompanied by brush and forest fires, which further stress limited emergency responder resources.[16] Heat waves also strain energy resources as many people use their air conditioners in an effort to combat the heat. This increase in use of air conditioners may stress power plants and electrical transfer stations, and in some cases, result in blackouts and brownouts. In 2004, 30% of California's peak electricity demand was due to air conditioning use alone and has been projected to increase annually.[17] Air conditioners also emit heat, increasing ambient temperatures as well as air pollutants due to the increased demand for electricity which is mainly produced by fossil fuel-burning power plants.[18,19]

Climate change, including increasing temperatures and related changes in other aspects of global climate change is likely to initiate a number of other harmful effects on public health. Principle concerns include contamination of water and food; changes in infectious disease transmission rates; increased allergen production; changes in populations due to loss of habitat and sea level rise; and nutritional shortages from disruptions in food production and transportation systems.[20] Rising temperature will likely increase the spread and transmission rate of some infectious diseases that proliferate at higher temperatures like cholera and salmonella. Vector-borne and rodent-borne disease rates are also likely to increase due to increased temperatures that allow for longer breeding times and the spread of the transmissible agent to higher latitudes.[21,22] In addition to the spread of vector-borne and rodent-borne disease to new areas, the distribution of plant species and pollen production is likely to undergo change triggering changes in the incidence of allergic symptoms. Increased temperatures may change the amount of time humans spend outdoors, also increasing their chance of exposure to allergens and allergic reactions.[11] Increased temperatures may indirectly affect population growth through the reduced availability of water and food sources, increasing economic disparities and migration to urban centers. Migration to urban areas may further increase heat-related illnesses as population growth puts additional stress on already weak health systems. Civil strife and wars due to lack of resources may also force populations to migrate to already congested locations. These changes, as well as the public health disparities listed above, will have the greatest impact on those who are already socially and economically disadvantaged.[21]

Climate change will exacerbate existing food insecurities in many locations. A recent study found that, in the US for every degree rise in temperature corn and soya bean yields fell by 17%.[23] Rising temperatures will take a toll on farmer's crops adding to food shortages in already food scarce locations like sub-Saharan Africa and south Asia. Increased temperatures are also likely to result in prolonged droughts and/or flooding destroying crops and interrupting the growing season at critical junctures.[22,23]

Although a rise in global temperatures will have a devastating effect in many public health arenas, the most thoroughly studied climate-health impact in developed countries are the acute effects of extreme heat events. Despite numerous studies there are gaps in knowledge surrounding population-level public health impacts of heat events, vulnerable populations, and effective public health protection strategies. For example, heat health warning systems (HHWS) have been implemented in a number of developed cities such as London, Chicago and Madrid though the protective capacity of these systems are reduced because of limited information regarding how the system should be triggered and concerns over the most effective messaging for vulnerable populations.[24] Researchers have also indicated that poor and developing countries will suffer the worst effects due to a global rise in temperatures and ensuing heat events, though most of this data comes from predictions based on climate modeling and current socioeconomic conditions.[21]

1.2. Heat-related illness

Excessive hot weather can induce illness and even death in humans.[25] As climate change increases the frequency and intensity of extreme heat events scientists and health officials should work towards improving our understanding of the causes for heat-related illnesses (HRIs). To fully understand HRIs initiated by extreme heat events we must first settle on a definition of a heat wave and a HRI. The definition of a heat wave varies by location, as risk is strongly dependent on climate and adaptation. For example, people living in colder climates are more adapted to cold weather while those living in hotter climates are more adapted to hot weather. In addition, improved infrastructure including better housing, availability of air conditioning and access to health care improves an individual’s ability to adapt to hot weather.

To arrive at a definition of a heat wave, we must first determine the threshold temperature which would be considered above normal and which may induce negative health effects. Maximum daytime temperature, minimum nighttime temperature and mean temperature are commonly used measures of heat exposure. Factors such as wind speed, humidity and barometric pressure are also used by some researchers in addition to temperature indices. Apparent temperature (AT) or heat index is one measure often used. This calculated temperature is an adjustment of the ambient temperature based on humidity and wind speed.[26]

Apparent temperature combined with weather patterns and duration of heat delineates when and where a heat wave occurs. For example, the United States defines a heat wave as two or more days of excessively hot weather in which the thresholds of daytime high and nighttime low heat indexes are exceeded (105°F and 80°F respectively).[27] Although a majority of studies take the approach of using AT (and defining a threshold) as an indicator for heat related morbidity and mortality, Barnett, et al. (2010) point out that there is no universally accepted measure of temperature that is used across heat morbidity and mortality studies.[28] This lack of a standardized definition is a significant disadvantage in comparative analysis among studies.

Heat-related illnesses are usually termed heat stroke, heat exhaustion and heat stress. Each is a variation of symptoms from physiological strain due to exposure to heat. Heat stress is defined as perceived discomfort and physiological strain associated with exposure to a hot environment. Heat exhaustion is a mild-to-moderate illness due to water or salt depletion. Heat stroke is a severe illness characterized by a core body temperature of >40.6°C.[29]

Heat stroke and resulting multi-organ failure is due to a complex interplay between the "acute physiological alterations associated with hyperthermia, the direct cytotoxicity of heat, and the inflammatory and coagulation responses of the host".[29,30] Until 1995, there was little consensus on the criteria that defined a HRI or heat-related death. The increasing frequency of heat waves, and particularly the 1995 heat wave in Chicago, caused medical examiners to take a closer look at the definition of a heat-related death. The criteria for diagnosing a heat-related illness remained largely unchanged based on patient symptoms. However, because of the number of people who died as a result of the 1995 Chicago heat wave, many of which were found hours or days after they died, a broader definition of a heat-related death was needed, outside of having a core body temperature of >40.6°C.

The new definition now considers deaths from heat waves that are attributed not only to an elevated core body temperature but also if exposure to high ambient heat either caused the death or significantly contributed to it by considering factors concerning the environment at the time the body was found based on the history of high ambient temperature and the exclusion of other causes of heat stroke.[31,32]

A recent meta-analysis indicated a number of prognostic factors for heat-related deaths: Living alone, unable to care for one-self, being confined to a bed and those that do not leave home were among the greatest prognostic factors for heat-related deaths.[29] A study analyzing prognostic factors from the 2003 heat wave in France found that in addition to the above listed factors, living in an institution and transportation time to a medical facility contributed significantly to whether an individual had a negative outcome after suffering from a heat-related illness.[33]

Post-mortem studies of heat-related deaths provide insight into risk factors to heat-related illness. Studies from the 1995 Chicago heat wave and the 2006 California heat wave have shown that individuals with a history of cardiovascular, cerebrovascular, respiratory, psychiatric or renal disorders and those with diabetes or secondary infections are at increased risk of heat-related illness. For example during the 1995 Chicago heat wave there were increased hospital admissions with excess inpatient admissions for cardiovascular (31%), respiratory (20%) and renal diseases (23%) and diabetes (30%).[34] In many cases a condition such as kidney disease is exacerbated by increased ambient temperatures forcing people to seek medical care. The prevalence of many of these underlying conditions increases with age which is the strongest risk factor for a HRI. The elderly, particularly those with an underlying medical condition, have impaired thermoregulation preventing normal body mechanisms from cooling them effectively. Moreover, medications that are commonly prescribed to the elderly such as diuretics increase this risk.[34,35]

A person's environment can play a significant role in susceptibility to HRIs. The urban heat island (UHI) effect exacerbates the risk of a HRI posed by the increase of thermal stress from the environment.[36] An UHI is characterized by increased temperatures in urban areas due to heat being retained by concrete and asphalt. This heat is then released back into the environment, particularly at night, depriving the urban environment of time to cool.[37] Living on the top floor of an apartment building also increases susceptibility to HRIs, as do forms of social isolation such as not leaving the home daily and living alone.[38]

Race and socioeconomic status also affect the risk of HRI. Minorities and the economically disadvantaged have an increased risk to heat-related illness due to factors such as lack of air conditioning, lower educational attainment and language barriers which may limit their ability to understand heat wave warning messages. A recent study in four US cities found air conditioner prevalence in White households was more than double that in Black households. This same study indicated that heat associated mortality was more than twice as high among Blacks as Whites.[39]

Once an individual starts suffering from heat stroke, how promptly body temperature is reduced to normal levels is a major determinant of the eventual outcome. Studies of the aftermath of the devastating 2003 heat wave in Europe found that 50-60% of patients admitted to the hospital for heat stroke died as a result. Once multi-organ failure starts it is difficult to reverse.[40] Even patients who survive an initial episode of heat stroke often succumb in the ensuing months. In the two studies from the 2003 heat wave in Europe and one from the 1995 Chicago heat wave, patients who were admitted, diagnosed with heat stroke and then discharged from the hospital had survival rate of 20-50% at 3 months.[40,41] A decreased chance of survival was associated with the level of disability after discharge. A study from Australia also found that approximately 20% of heat stroke patients were discharged to a rehabilitation facility or nursing home because they could no longer live independently. This Australian study along with one from the 2003 heat wave in France found that the length of hospitalization generally ranged from 3 to 10 days, with occasional longer stays when heat stroke was complicated by other medical conditions.[42,43]

The increased number of hospitalizations during heat waves, and the lengthy hospital stays associated with these events, raises the question of how much HRIs are costing both affected individuals and society at large. The cost of prevention may be less expensive than the high cost of hospitalization without preventative measures. However, few cost and benefit analyses for preventive systems like heat health warning systems have been implemented to explore this issue.[44] Bassil, et al. emphasize that the cost of heat illness prevention strategies such as educational material and cooling centers are relatively low compared to the high cost of hospitalization.[15]

Challenges in identifying health impact data and lack of consensus on health care cost validation methods has made it difficult to establish a well-accepted structure for quantifying the costs of human health effects to climate change. A study of cost effectiveness for heat events in Europe estimated that in the city of Rome inaction on the prevention of HRIs could cost €283 million

($388 million USD) annually by the year 2020.[45] Hospitalizations for HRI in Germany using various climate scenarios result in hospitalization costs predicted to be approximately €300 to 700 million ($400 to 930 million USD) annually by the latter part of the 21st century, six times higher than hospitalization costs today.[46,47]

Information concerning the prognostic or risk factors of HRIs and the outcomes and costs associated with heat-related illnesses and deaths has been reviewed though it is apparent additional research is still needed in these areas. Economic assessments of the costs associated with the health impacts due to heat events are limited and lacking in past research studies. Improving the standardization of calculations for cost estimates and capturing comprehensive health data will help to quantify human health effects and costs for heat events. Also, as the number of heat events increases it is important to improve predictive modeling to forecast extreme heat events. Collaboration between disciplines, including climatologists, geographers, social scientists and public health researchers is needed to describe the many variables that go into predictive modeling and to remove uncertainties and improve accuracy.

1.3. Vulnerable populations to extreme heat events

Many different definitions and conceptual frameworks for understanding vulnerability have been proposed. In 1993, Aday defined vulnerability as being "susceptible to harm or neglect, that is, acts of commission or omission on the part of others that can wound." Aday further explains that vulnerability is in part determined by the concepts of risks and exposure and there are certain key variables that play a role in predicting vulnerability and risk.[48]

The above definition of vulnerability can be applied to the topic of climate change and the hazards associated such as floods, coastal storms and heat waves. Blaikie defines vulnerability, in the context of natural hazard as "the characteristics of a person or group and their situation that influence their capacity to anticipate, cope with, resist and recover from the impact of a natural hazard".[49] Further the Intergovernmental Panel on Climate Change (IPCC) defines vulnerability by how a system is susceptible to, or unable to cope with changes and adverse effects from climate variation and how this system is exposed to climatic hazards, its risk, and the ability to adapt to climate change.[50] This idea of adaptation to climate change was previously thought of as adapting our physical environment and infrastructure to prevent disaster, though the most recent IPCC report has noted that vulnerability is related to both social and environmental processes. The system then can be thought of as susceptibility and sensitivity towards an event and the ability to improve the (adaptive) capacity of a response to these identified vulnerabilities.[51]

Although I have highlighted a few definitions of vulnerability, there are many scholarly disciplines with different definitions and concepts of vulnerability. Social geography, economics, political science, ecology and the physical sciences all have contributed to the definition of vulnerability and also have different ideas of what it means to be vulnerable. Some definitions of vulnerability only examine causal mechanisms to identify vulnerable populations (e.g. drought) while others incorporate ideas of coping, mitigation and recovery. Another difference between definitions of vulnerability is the categorizations of exposures and risks used in these definitions. A few definitions look at a combination of exposure variables (environmental, social and geographical) while others may only incorporate economic or socioeconomic variables as metrics of risk to define vulnerability. For example, researchers are trying to identify populations vulnerable to coastal storms; a sociologist may identify poor populations as being the most vulnerable while a geographer may define vulnerable populations as only those who live along rivers or coasts. When studying the effects of climate change on vulnerable populations researchers need to reach consensus on the definition of vulnerable populations; inconsistent definitions or misunderstandings will hinder interpretation and application of research findings if these ideas are not established before a study begins.[52-54]

In addition to many definitions of vulnerability, several different conceptual frameworks guide how to assess who or what are vulnerable to extreme weather events. Some researchers adopt an approach similar to risk assessment methodology; identifying the exposure; the amount a person has been exposed to a hazard (dose); and how to mitigate the response.[55] Others have developed a framework which incorporates ideas from both risk assessment and vulnerability assessment. Vulnerability assessment conceptualizes the definition of vulnerability by developing robust and credible measures on factors that mediate vulnerability. These measures can then be used to establish a fundamental framework for assessment. A number of frameworks to describe vulnerability have been developed, each slightly different, but largely follow four fundamental dimensions: defining the system or population; defining key variables of risk and exposure (i.e. age, location, housing); defining the hazard and degree to which the system has been exposed; and establishing a temporal reference.[49,53,56,57] In addition to the above fundamental framework researchers also include aspects of mitigation and adaptation to their framework as well as defining inherent ‘resiliencies’ of populations to natural disasters and extreme weather events.[57,58]

Within the vulnerability assessment framework some researchers have also adopted a taxonomic approach to classifying who is vulnerable to extreme weather events. Common indicators are age, gender, occupation, education level, ethnicity, type of housing, and socio-economic status. Although there are advantages to using a quantitative metric to identify vulnerable populations, these indices are not universal and may vary from study to study. Two quantitative studies assessing vulnerability to heat mortality both included measures of race and age, but air conditioner ownership and prevalence of pre-existing medical conditions were only collected in one study.[39,59] Picking and choosing a variable based on what data is available to the researcher is sometimes unavoidable, though a standardized list of 'vulnerability measures' would help comparative analyses between studies of heat-related morbidity and mortality and help to ascertain the strongest predictors of vulnerability.

However, some researchers suggest moving away from the quantitative approach and using qualitative methods to better understand the processes that contribute to vulnerability to climate change including underlying psychological factors and perceptions of vulnerability. Perceptions of vulnerability to anticipated heat events and derived experiences from these events are not easily measured. Each individual will have different perceptions and experiences of these events based on their own risk and level of exposure.[57,60] One approach, taken by Klinenberg in his 'social autopsy' of the 1995 Chicago heat wave was to use qualitative methods, through in-depth interviews, in discerning who and why individuals died as a result of the 1995 Chicago heat wave. Klinenberg found that both environmental and societal factors played major roles in determining who was vulnerable to this disaster. The elderly who were both poor and a racial/ethnic minority had the highest mortality because of social isolation, living alone, and not leaving home daily due to age and fear of the high crime rates in their neighborhoods.[61] Additional research using qualitative methods, such as face-to-face interviewing as well as focus groups can help identify vulnerable sub-populations that could be missed when doing only quantitative analyses of heat morbidity and mortality. Integrated quantitative and qualitative data on social vulnerability can be a methodological advancement in understanding and assessing vulnerable populations to extreme heat events.[62]

Researchers have also used retrospective cohort studies of mortality and hospitalizations during heat waves to identify who is vulnerable to extreme heat events. Risk factors identified include being elderly, a minority, having psychiatric conditions including depression (possibly due to medications that interfere with thermoregulation), having an underlying medical condition such as cardiovascular, respiratory or cerebrovascular disease and diabetes.[63-65] There is conflicting evidence as to whether children are more vulnerable to heat events, some researchers suggest they are while others argue they are not more vulnerable.[64,66] In an analysis of heat related mortality in California, children under 5 and infants under 1 year of age suffered higher mortality with increasing temperature. Mortality increased approximately 5% for these populations, over other populations, though failed to achieve any statistical significance.[67]

Socioeconomic factors, such as poverty, poor housing conditions, lack of higher education, and insufficient health care access are also listed as underlying causes of vulnerability.[68]

Poverty cannot cause a natural disaster though a natural disaster can exacerbate poverty, and in many cases we see that wealth is no barrier to extreme weather events. Events such as Hurricane Katrina in 2005 in the US and the 2003 European heat waves show that, even wealthy countries experience disastrous climatic events though vulnerability and risk are unevenly distributed. However, wealth does impact the process of recovery and the resilience of a population. For example, Bangladesh and The Netherlands share similar susceptibility to sea level rise but The Netherlands has greater economic resources, technology and stronger infrastructure while Bangladesh lacks these resources and may not recovery as quickly or fully as The Netherlands.[69]

The IPCC and other researchers, have noted that global warming, climate change, and the increase in frequency and intensity of extreme weather events will affect those who are already vulnerable to even small climatic changes, particularly those living in hardships in developing countries.[70] According to the International Federation of Red Cross and Red Crescent Societies (IFRC) 70% of natural disasters between 2004 and 2008 occurred in developing nations in Africa, the Pacific region, Asia and the Middle East.[71] There are already great inequities between developed and developing nations, in food safety, water sanitation and inadequate housing; with the threat of climate change and extreme weather events these inequities are likely to increase. While extreme heat events can contribute to famine and drought in areas of population vulnerability, other extreme weather events like coastal storms are a major concern in vulnerability assessment to climate change. As the world population grows these populations flock to urban areas, many of which are in coastal regions. Urbanization, in combination with the vulnerability characteristics of low socioeconomic status give little choice on where some people live. The most vulnerable populations, biophysically and socially are relegated to living in areas prone to flooding and other undesirable affects due to extreme weather events. These conditions have been seen in poor population both in Bangladesh and in New Orleans, particularly during Hurricane Katrina.[72]

A framework for understanding extreme heat vulnerability has recently been promoted using a local level bottom-up approach to vulnerability assessment. This framework incorporates ideas from scientific concepts in the climate change literature and highlights the process of identifying and understanding vulnerability of human health to heat waves and evaluating adaptive strategies.[73] Part of this framework is to understand how collective attitudes and decisions interact and build adaptive capacity to extreme heat events. Quantitative and qualitative data gathered at the local level can inform researchers on how local knowledge and traditional coping mechanism can influence the adaptation process. Building local level data using a mixed methods approach can incorporate quantitative date, such as heat mortality statistics and qualitative data, such as household surveys on preventive measures (e.g. air conditioning). Over time, a number of comparable case studies can help influence top-down (regional, nation and international) efforts that fill gaps left by local level efforts and improve bottom-up efforts.[73,74] As one researcher put it, “ultimately, vulnerability is expressed at the individual level, however important the social and neighborhood context”.[75] Public health researchers have agreed that there are gaps in knowledge to identifying vulnerable subpopulation[67] and that vulnerability assessments need to be comprehensive in identifying these populations as well as improving adaptive and mitigation efforts. As the number of extreme weather events continues to rise, more and more populations will be at risk from natural disasters. Although some populations may not be considered vulnerable now, after one extreme weather event, a population may become increasingly vulnerable each time such events occur. For example, in 1998 Hurricane Mitch devastated much of Honduras and Nicaragua causing damage equivalent to the countries' combined Gross Domestic Product, setting development efforts back many years.[73,76] Vulnerability is a multifaceted phenomenon and solutions must be multifaceted in addressing a broad range of social, cultural, demographic and economic conditions that often interact in complex ways. For example, structural mitigation includes protective engineering methods like seawalls, levees and dams while nonstructural mitigation can include regulating property development among at-risk areas and conserving features of the natural environment that provide protection. These adaptive efforts for addressing vulnerability require input from a variety of stakeholders including politicians, scientists, engineers and ultimately, the people who are vulnerable. Future research is needed and incorporating an interdisciplinary approach and approaches for identifying vulnerable populations may improve vulnerability assessment. New methods in geographical information systems (GIS) can help identify vulnerable populations and vulnerable systems in the built environment. Characteristics of each local region or neighborhood, in terms of social, economic and cultural factors, contribute to how that community will respond to a disaster.[77] Climate change is a global problem that requires not only a global solution, but local community solutions, especially when identifying and protecting vulnerable populations.[57,72,75]

To characterize heat vulerability for this study a simple conceptual framework was used. The framework is couched in the contextual hazard of global warming and climate change which influence the first component of heat vulnerability, the exposure (for this study, heat waves and high ambient temperatures) (Figure 1.1). Exposure is directly related to the potential outcomes, those populations exposed to extreme heat events, considering the instensity and duration have potential outcomes. The outcomes are directly influenced by sensitivity of individual and environmental characteristics. The second chapter of this dissertation will focus on identifying individual and environmental risk factors for hospitalizations of heat-related illnesses. Adaptive capacities and responses also influence potential outcomes. Interventions such as air coniditioning use and heat-health warning systems may reduce the potential negative health outcomes assocaited with exposure to extreme heat. Chapter two will also examine ait conditioner use among identified at risk populations. Examining outcomes will be the focus on chapter three which will explore health outcomes as well as hospital resource use. Common comorbidities will be examined to identify how populations with these underlying medical conditions and a heat-related illness diagnosis further understand at risk populations. The fourth chapter will look specifically at the potential outcome of costs assocaited with hospitalizations and the cost effectiveness of interventions such as air conditioning and heat-health warning systems. By using the conceptial framework of vulnerability assessment this disseration will attempt to further identify specific sensitivities, potential outcomes and review responses and adaptive capacities in interactions to better understand how vulnerable populations are impacted by climate change and heat events.

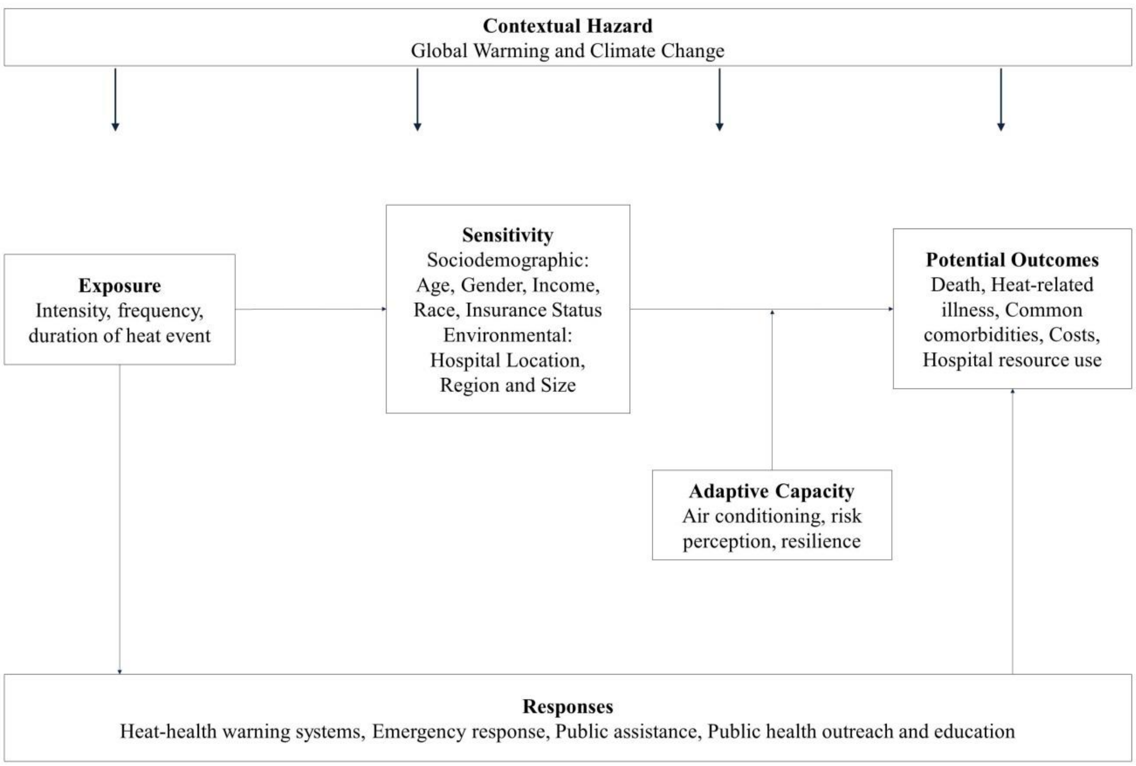


Figure 1.1. Heat –related illness vulnerability framework. Heat-related illness (outcome) is a result of exposure to extreme heat. Individual and environmental characteristics of hospitalizations (sensitivity) are examined to identify risk factors for vulnerable populations. At risk populations are also influenced by behaviors and interventions (adaptive capacities and responses), understanding responses helps to improve and reduce potential negative outcomes among populations vulnerable to heat-related illnesses.

1.4. Overview of the dissertation

1.4.1. Overall goals

To address limitations in the existing literature, this dissertation aims to identify risk factors for heat related morbidity and examine outcomes, such as hospital resource use and costs of hospitalizations due to heat-related illness in the United States from 2001-2010. Using a large administrative database that statistically represents all hospitalizations in the United States, this dissertation will give a robust description of risk factors for populations hospitalized and diagnosed with heat-related illnesses which may differ significantly from those of heat mortality. The risk factors identified will enhance the above conceptual framework of vulnerability assessment by improving the sensitivity of vulnerable populations allowing for a better insight into those who are vulnerable during extreme heat events. Additionally, understanding aspects of protective factors such as air conditioner use will be explored and spatial analyzed among a number of vulnerable populations identified. This again will help in identifying the sensitivity of vulnerable populations while giving us information on the positive and or negative effects of adaptive capacities that are in place.

Many hospitalizations due to extreme heat events are due to direct heat illnesses, such as heat stroke a number of hospitalizations are also due to the exacerbation of underlying medical conditions. This dissertation will examine the outcomes of these common exacerbated conditions (diabetes, cardiac, respiratory and renal diseases) associated with a heat-related illness compared to those without a heat-related illness diagnosis to help explain whether HRI induced common comorbidities result in greater negative outcomes. Then, focusing on specifically cost, this dissertation will analyze current costs and estimate future costs associated with hospitalizations due to heat-related illness and explore potential cost effective options of air conditioner use and heat-health warning systems to reduce hospitalizations. By examining the potential outcomes we can improve on the conceptual framework of the vulnerability assessment by examining the interactions between sensitivity, potential outcomes and responses to these outcomes. This in turn will help to improve both the positive impacts of our response to extreme heat events and further benefit our adaptive capacities, potentially reducing negative health outcomes associated with hospitalizations of heat-related illnesses. These associations will also be beneficial to economists and policy makers to determine true and future costs of the impact of climate change on public health.

1.4.2. Specific aims

Specific aims are:

Aim 1a: To identify individual risk factors and document the pattern of heat-related illnesses through hospitalizations.

Aim 1b: To Identify sociodemographic factors in household cooling.

> Hypothesis 1a: Regardless of etiology there is significant variability in HRI hospitalization patterning across sociodemographic and geographic catagories.
>
> Hypothesis 1b: Air conditioner use and availability is limited among the elderly, low income and minority populations, those of which are most vulnerable to heat-related illnesses

Aim 2: To investigate outcomes and hospital resource use of heat-related illness hospitalizations and common comorbidities.

> Hypothesis 2: Identified common comorbidities (i.e. diabetes, cardiac, respiratory and renal diseases) associated with HRIs have greater negative outcomes (e.g. death and

discharge status) and use more hospital resources (e.g. length of stay and total charges) compared to the comorbidities that were not associated with a HRI diagnosis.

Aim 3: To examine the association of heat-related illness morbidity patterns and costs related to heat-related illness hospitalizations.

Hypothesis 3: Costs associated with hospitalizations due to heat-related illness increase over study time period and will continue to increase as health impact due to climate change rise.

1.4.3. Organization of the dissertation

The subsequent part of the dissertation consists of four chapters. Chapter 2 introduces baseline demographic information on patient and hospital characteristics of the study population and used analytical approaches to identifying risk factors for hospitalizations and spatial patterns of air conditioning use (aim 1a and aim 1b). In Chapter 3, patient and hospital characteristics are analyzed for outcomes associated with heat-related illnesses and common comorbidities compared with just common comorbidities without a HRI diagnosis (aim 2). These analyses further refine characteristics of vulnerability established in Chapter 2. Chapter 4 focuses specifically on costs associated with hospitalizations due to heat-related illnesses by determining current costs and estimating future costs based on current predictive modeling of ambient temperature increases over time due to global warming (aim 3). Chapter 5 summarizes findings from Chapters 2-4 and discusses strengths and limitations of the study. The dissertation concludes with policy implications and recommendations for future research directions.

1.4.4. Significance of the dissertation

Individual and environmental risk factors for hospitalizations of heat-related illnesses identified in this dissertation add to the dearth of literature on heat morbidity. To my knowledge this is the first study to use a large administrative database of hospitalizations to identify risk factors for heat-related illnesses. As the science of matching large datasets improves, it will allow for more opportunities to explicate connections between theories and operationalization. This information can be used as a basis for understanding patterns of hospitalizations of heat-related illnesses which can be incorporated into vulnerability assessment models for extreme heat events. Additionally, by looking at both the risk factors for hospitalizations and the outcomes (discharge status, total charges, etc.) of heat-related illness, this dissertation will yield a more complete profile of demographic and environmental characteristics for risk factors and identify additional shortcomings in current research. Lastly, the inclusion of monetary data on the actual and estimated costs of health effects due to climate change gives substantive evidence on the economic impact climate change will have on public health. Findings will benefit public health practitioners to design and implement more effective public health interventions taking into consideration risk factors, outcomes, economic costs and the already limited resources available to combat the health impacts of climate change.

1.5. Data sources and study population

The main data source for the study population was of hospital discharge records 2001-2010 from the Nationwide Inpatient Sample (NIS) which was developed as part of the Healthcare Cost and Utilization Project (HCUP) in partnership with the Agency for Healthcare Research and Quality (AHRQ). The NIS is the largest all-payer care database, with data from approximately 8 million hospitalizations per year (about 20% of all hospital discharges in the United States).[78] The NIS includes data on patient demographics and hospital characteristics, primary and secondary diagnoses coded according to the *International Classification of Diseases, Ninth Revision* (ICD-9) (with up to 15 diagnoses available for the years 2001-2008 and up to 25 diagnoses for 2009-2010), primary and secondary procedures (ICD-9 coding up to 15 diagnoses available for the years 2001-2008 and up to 25 diagnoses for 2009-2010), type and source of admission, discharge disposition, primary payer type, total hospital charges, and length of stay. Stratification and weighting variables allow calculation of national estimates and account for the complex sampling design.[79]

For chapter 2 and chapter 4 the study population for HRI consists of patients in the 2001-2010 NIS with at least one diagnosis of a heat-related illness (ICD-9 codes 992.0 – 992.9) from 2001 to 2010. The control group for chapter 2 consisted of all other NIS hospitalizations during this time period. Since approximately 95% of all HRI hospitalizations occurred in the summer months (May-September), all hospitalizations not occurring during these months were excluded. For chapter 3, the study population consists of patients who had a primary or secondary diagnoses of diabetes (ICD-9 code 250.00), cardiovascular diseases (ICD-9 codes 390-398, 402, 404-448), respiratory illnesses (ICD-9 codes 460-519), nephritic illnesses and acute renal failure (ICD-9 codes 580-589) along with a diagnosis of a heat-related illness (ICD-9 codes 992.0-992.9).

Data on air conditioner use and total cost of electricity use from air conditioning was derived from the Residential Energy Consumption Survey (RECS), a national household survey conducted by the United States Energy Information Administration (EIA) starting in 1978. In 2005 and 2009 surveys were collected from approximately 4,000 and 12,000 households, respectively, which were nationally representative of the 110 million residential U.S. households.[80] The variables from the RECS used in this study include census region, state, air conditioner use, total cost of electricity for air conditioner use and householder age, poverty status and employment status. Chapter 2 focused on the spatial patterns of air conditioner use among households in the United States among 4 U.S. Census regions. Chapter 4 consisted of total costs of electricity for air conditioner use among state and state groupings as defined by the RECS.

Chapter 2. Identifying individual risk factors and documenting the pattern of heat-related illness through hospitalization and spatial patterns of household cooling

2.1. Introduction

Heat from high environmental temperatures is a natural hazard that can adversely affect human health.[1-4] Human populations have acclimatized to a variety of local climates physiologically and behaviorally, though there are limits to the extremes in temperature the human body can tolerate. An individual's ability to thermoregulate protects the body from ambient temperatures by maintaining a core body temperature around 36.0°C to 37.5°C.[5] Body temperatures outside of this range are classified as either hypothermia (body temperature below 35.0°C) or hyperthermia (body temperature above 37.5°C).[6,7] Heat-related illnesses (HRIs) - usually termed heat stress, heat exhaustion and heat stroke - include a range of signs and symptoms within the broader definition of hyperthermia. Heat stress is a perceived discomfort and physiological strain; heat exhaustion, a mild to moderate illness; and heat stroke, a severe illness characterized by a core body temperature above 40.0°C.[7] Clinically, severe heat illness can be seen as a combination of systematic inflammatory response and cytotoxicity, which left untreated results in multiple organ failure.[5,7,8] Infants are at increased risk of heat-related morbidity and mortality as are the elderly, individuals taking medications that interfere with thermoregulation, those with underlying medical conditions such as cardiac, respiratory, renal disease or diabetes.[4,9-11]

Studies of heat mortality during specific events, such as the 1995 Chicago heat wave and the 2003 heat wave that affected much of Europe, highlight characteristics of populations that are at risk of dying during extreme heat events. During the 1995 Chicago heat wave, Semenza et al., described heat mortality among the elderly, those with known medical conditions such as cardiovascular and respiratory disease, individuals confined to bed, unable to care for themselves and with social risk factors such as not leaving the home daily, living alone, and limited social networks.[12] Similar populations were affected in and around Paris, France during the August 2003 heat wave.[13] Regression models of time series data quantifying excess mortality during heat events show that mortality rises as temperature exceeds a certain threshold.[14-16] Study methodologies using mortality end points identify risk factors for heat mortality such as being elderly, of a lower socioeconomic status, or a person of color or having an underlying medical condition (cardiovascular, cerebrovascular, respiratory, renal, neurological diseases, and diabetes).[17-19] However, the diagnosis of a specific heat-related illness is not always confirmed during heat events and diagnoses for cause of death are primarily due to the exacerbated underlying medical condition (e.g. cardiovascular disease, respiratory disease, etc.).[20-23] While relatively few studies have examined heat-related morbidity most heat morbidity studies have used methodologies that incorporate heat-related illness diagnoses and show a stronger relationship between the risk factors and outcomes. These associations also highlight a number of protective factors for HRIs.

Some studies of heat-related morbidity have focused on emergency dispatch data and emergency department visits during individual heat events, with specific HRI diagnoses,[24-27] while others have analyzed excess hospitalizations during specific extreme heat events.[19,28,29] While there has been increased research attention on the health outcomes associated with extreme heat events, few investigations have identified risk factors that lead to HRI hospitalizations, particularly those comparable among different geographic regions mainly due to the difference in the classification of heat events across regions.[30,31] Additionally diagnoses of HRIs are often under-reported as the underlying medical conditions are often considered the primary diagnoses during a hospitalization while the HRI diagnosis may be noted as secondary or not recorded at all limiting our understanding and knowledge of heat-related illnesses.[32,33]

One of the strongest preventive measures to HRIs is ownership and use of an air conditioner during extreme heat events.[34-36] As of 2009, 87% of homes in the United States have air conditioning, although the prevalence of AC is lower (and less efficient cooling systems higher) among apartment dwellers and low income households.[37] A recent Morbidity and Mortality Weekly Report (MMWR) highlighting heat illness and deaths in New York City indicated that a majority of heat illness decedents did not have a working air conditioner, although information on cooling practices of decedents was limited.[38] Research is needed regarding a number of socioeconomic and behavioral issues that might improve access to air conditioning and reduce heat mortality and morbidity.[39,40]

In addition to individual level determinants and behaviors around cooling during extreme heat events, the environment plays a key role in exacerbating or protecting us from extreme heat events. While the urban heat island (UHI) is not a new concept, it has been used to explain higher rates of HRI in urban areas as compared to rural areas, due to the urban landscape, including lack of vegetation and impervious surfaces covering large areas.[41,42] The average ambient urban temperature is increased where vegetation has been replaced by heat-retaining materials such as asphalt and concrete. Recent studies using remote sensing and spatial analysis attempt to create heat vulnerability maps and indexes based on environmental factors.[43-45] An integrated understanding of environmental factors, individual level factors and socio-behavioral determinants is needed to accurately identify populations most vulnerable to extreme events due to climate change.

Climate change has initially affected vulnerable populations, but the increase in frequency and magnitude of climate change associated heat events ultimately disrupt and affect all populations. Using the conceptual framework discussed in chapter one, this chapter will specifically examine the sensitivity of a population and how these factors, both individual and environmental characteristics can help determine at risk populations from exposure to extreme heat events (Figure 2.1). The sociodemographic and environmental characteristics examined have a direct influence on heat-related illness hospitalizations. This research examines specific health outcomes due to climate change, heat waves, by identifying risk factors, discussing preventable measures and informing policy recommendations to prevent HRIs and adapt to extreme heat events. This study examines heat-related morbidity using a large nationally-representative administrative database to identify individual and environmental risk factors for hospitalizations due to HRI and document the pattern of household cooling. This analysis aims to identify public health strategies for reaching populations vulnerable to heat morbidity and preventing illness and death during future heat events.

2.2. Methods

2.2.1. Data sources

The primary source of data for this study was the 2001 to 2010 Healthcare Cost and Utilization Project (HCUP) Nationwide Inpatient Sample (NIS), which was developed by the Agency for Healthcare Research and Quality (AHRQ). The NIS is the largest all-payer care database, with data from approximately 8 million hospitalizations per year (about 20% of all hospital discharges in the United States).[46] The NIS includes data on patient demographics and hospital characteristics, primary and secondary diagnoses coded according to the *International*

Classification of Diseases, Ninth Revision (ICD-9) (with up to 15 diagnoses available for the years 2001-2008 and up to 25 diagnoses for 2009-2010), primary and secondary procedures (ICD-9 coding up to 15 diagnoses available for the years 2001-2008 and up to 25 diagnoses for 2009-2010), type and source of admission, discharge disposition, primary payer type, total hospital charges, and length of stay. Stratification and weighting variables allow calculation of national estimates and account for the complex sampling design.[46,47]

This data includes information on urban vs. rural hospital location. Additional spatial data for geocoded hospital location was obtained from ESRI based on American Hospital Association (AHA) identifiers, and merged to the NIS dataset to create an updated hospital location variable. Using the 2010 Census Urban and Rural classification, geocoded hospitals were mapped and designated as being in urbanized areas of 50,000 or more people, in small urban clusters of 2,500 to 50,000 people or in rural areas which encompassed all populations outside urbanized areas and small urban clusters.[48] This updated definition was created to determine if environmental factors like high and low urban populations and rural populations differed in HRI hospitalizations. All maps were created using ArcGIS (version 10; ESRI, Redlands, CA).

Data on spatial patterns of air conditioner use was derived from the Residential Energy Consumption Survey (RECS), a national household survey conducted by the United States Energy Information Administration (EIA) every three years starting in 1978. In 2005 and 2009 surveys were collected from approximately 4,000 and 12,000 households, respectively, which were nationally representative of the 110 million residential U.S. households. The variables from the RECS used in this study include census region, state and air conditioner use.

2.2.2. Subjects and definitions

The study population for HRI consists of patients in the 2001-2010 NIS with at least one diagnosis of a heat-related illness (ICD-9 codes 992.0 – 992.9) from 2001 to 2010. The control group consisted of all other NIS hospitalizations during this time period. The HRI variable was coded as a binary indicator variable. The initial cohort consisted of 15,885 discharge records for heat-related illness (HRI) and 79,140,110 discharge records for control comparison. Since approximately 95% of all HRI hospitalizations occurred in the summer months (May-September), all hospitalizations not occurring during these months were excluded yielding a final cohort of 14,949 HRI discharge records and 37,019,792 controls.

2.2.3. Statistical analyses

The outcome variable was heat-related illness. First, a descriptive analysis of baseline characteristics was performed for HRI and control populations. Second, multivariable analysis was performed to determine risk factors associated with heat morbidity. A log-binomial model, which directly models risk ratios (RRs), was used. Analyses were weighted for national estimates and to enhance the log-binomial approach for maximum likelihood estimates and likelihood ratios.[49] Risk factors for heat-related illnesses were explored, including patient characteristics (gender, age, race, zip code income quartile, insurance), hospital characteristics (hospital bed size, hospital location, hospital region), and comorbidities. Patient comorbidities were coded and assessed using the AHRQ algorithms based on methods developed by Elixhauser et al.[50] Third, a multilevel model was used to account for clustering of patients within hospitals. Weighted samples were not used for multilevel analysis as recommended by the HCUP hierarchical modeling report.[51] Lastly a spatial analysis was performed to visually represent HRI hospitalizations among hospital clusters. A spatial analysis was also performed with RECS air conditioner data to analyze the use of air conditioning among vulnerable populations and to compare this to findings from the analysis of risk factors for hospitalizations due to HRI.

All statistical analyses were performed using SAS 9.3. This study was approved by the Institutional Review Board of Hunter College, CUNY and conforms to the HCUP data use agreement.

2.3. Results

2.3.1. Demographic and hospital characteristics

The characteristics of patients with HRI and of all hospitalized patients during the five "summer" months from 2001 to 2010 in the NIS data are shown in Tables 2.1 and 2.2. After weighting there were 73,185 patient discharges for HRI and 181,094,795 for all other discharges during this time period. Compared to all non-HRI hospitalizations, more HRI admissions were emergencies. Emergency department (ED) admission (the source) accounted for 59% for HRI hospitalizations and 34% of non-HRI hospitalizations, while emergency admission (as type of admission) accounted for 73% for HRI and 41% of non-HRI hospitalizations The mean age was also higher for HRI than non-HRI hospitalizations, 55 years compared to 48 years. The number of HRI hospitalizations increased faster than non-HRI hospitalizations, albeit with large year to year variation (Figure 2.2).

2.3.2. Multivariable analysis of risk factors for heat-related illness hospitalization

Multivariable analyses identifying risk factors for patients with an HRI diagnosis and any other hospitalization are shown in Table 2.3. The multivariable model included race, age, gender, zip code income quartile, insurance, common comorbidities (congestive heart failure, chronic pulmonary disease, diabetes, hypertension, neurological disorders, renal failure and psychoses), and hospital characteristics including region, bed size, and hospital location (urbanize area, small urban cluster or rural). Blacks, 1.21 (95% CI: 1.19-1.23), males 3.54 (95% CI: 3.49-3.58) and patients above the age of 40 (ages 40-64) 1.34 (95% CI: 1.32-1.37), (ages 65-74) 1.28 (95% CI: 1.25-1.30), (ages 75+) 1.52 (95% CI: 1.47-1.55) had higher risk of HRI hospitalizations. Patients who lived in zip codes with the lowest median income quartile were more likely to be hospitalized for a HRI, 1.19 (95% CI: 1.17-1.21) as were those in the second median income quartile 1.08 (95% CI: 1.07-1.10). Lack of health insurance was a particularly strong predictor of being hospitalized due to HRI, 2.33 (95% CI: 2.29-2.37).

Patients with neurological disorders and psychoses were more likely to be hospitalized with HRI, with a relative risk of 1.79 (95% CI: 1.75-1.82) and 1.83 (95% CI: 1.79-1.87) respectively. Other comorbidities such as diabetes, renal failure and respiratory diseases did not predict HRI relative to non-HRI hospitalizations with risk ratios of 0.80 (95% CI: 0.78-0.82) for congestive heart failure, 0.72 (95% CI: 0.71-0.82) for chronic pulmonary diseases, 0.90 (95% CI: 0.89-0.92) for diabetes, 1.00 (95% CI: 0.99-1.01) for hypertension and 0.61 (95% CI: 0.60-0.63) for renal failure. Examination of hospital characteristics indicate that patients in the Western U.S. region had higher risk of HRI hospitalization, 1.23 (95% CI: 1.20-1.25) as did small, 1.39 (95% CI: 1.37-1.42) and medium sized hospitals, 1.25 (95% CI: 1.23-1.27) and located in rural areas, 1.79 (95% CI: 1.74-1.83) or small urban clusters, 2.09 (95% CI: 2.06-2.12).

2.3.3. Multilevel analysis of risk factors for heat-related illness hospitalization

The multilevel analysis (Table 2.4.), found risk ratios similar to the single-level multivariable analysis. Blacks, (RR 1.17, 95% CI: 1.08-1.27), males (RR 3.55, 95% CI: 3.35-3.77) and patients above the age of 40 (ages 40-64) (RR 1.29, 95% CI: 1.19-1.40), (ages 65-74) (RR 1.15, 95% CI: 1.04-1.27), (ages 75+) (RR 1.40, 95% CI: 1.28-1.53) were at significantly higher risk of HRI hospitalizations after accounting for clustering within hospitals. Being in the lowest zip code income quartile was significantly predicted of HRI at 1.13 (95% CI: 1.03-1.25) as did being uninsured (RR 2.51, 95% CI: 2.31-2.72) in the multilevel analysis. Hospital level characteristics for the multilevel analysis also had similar results with small hospital size having a relative risk of 1.35 (95% CI: 1.19-1.53) and medium hospital size a relative risk of 1.17(95% CI: 1.05-1.30). Both the South and West were associated with an elevated risk of 1.13 (95% CI: 0.96-1.32) and 1.12 (95% CI: 0.94-1.32) respectively for HRI hospitalization. Risk of HRI hospitalization in rural areas and small urban clusters also remained higher than in urban areas.

2.3.4. Spatial analysis of heat-related illness hospitalization and household cooling

The spatial analysis for incidence of HRI hospitalizations from 2001 to 2010 by hospital location is shown in Figure 2.3. Darker shades on the map show a higher incidence of HRI hospitalizations per square mile based on hospital address, with lighter shades indicating lower rates of HRI hospitalization. Figure 2.4. shows air conditioner use among households whose income was 100% below the poverty line for 2005 and 2009. While overall air conditioner use for all households increased from 82% in 2005 to 87% in 2009, households 100% to 150% below the poverty line had 3% to 6% decrease in owning an air conditioner from 2005 to 2009 compared with households above the poverty line. Air conditioner use among householders unemployed, retired or employed part-time (not shown in Figure 2.4.) showed a 25% overall decrease in owning an air conditioner from 2005 to 2009, compared to householders employed full-time (based only on survey results). Additionally, air conditioner use increased among householders of most age groups from 2005 to 2009, but decreased by 13% among householders 75 and older.

2.4. Discussion

Most of the individual risk factors for heat related morbidity that were identified were similar to those previous heat-related morbidity and mortality studies.[32,52,53] For instance individuals identified as African American, the elderly, and those living in zip codes at the lowest income quartile were at a higher risk for hospitalizations due to heat-related illnesses. However, the nationally representative data yielded some surprising findings as well. Males were over 3 times more likely than females to suffer HRI hospitalization, though much of the prior research has found that females were more likely to suffer from heat-related mortality and morbidity. Results also showed that all age groups over the referent group were at an increased risk of heat-related illness as compared to 18-39 year olds. Prior studies have frequently highlighted infants and elderly as being most vulnerable, especially to heat mortality, but I found that all adults 40 years old and over were at somewhat elevated risk for HRI hospitalizations.

This increased risk of hospitalization among middle-aged adults, not just the elderly may signify a lack of risk perception among the population in regards to heat-related illness. Studies have shown that adults and many elderly populations do not perceive themselves as at risk for a HRI. Many of the signs and symptoms of heat stress or heat exhaustion may go unnoticed or be attributed only to a lack of proper hydration. These early signs can quickly advance to a more serious illness without proper medical attention or cooling.

Heat is the number one cause of death from natural disasters in the United States, and is often overlooked due to the limited visibility of heat as a hazard.[54] Tornados, hurricanes, floods and blizzards are more tangible and dramatic than heat. Future intervention strategies and policy should increase awareness of heat as a significant health risk. Public health outreach and education can enhance the response to extreme weather events, such as heat waves, thereby improving potential outcomes both by improving the understanding of heat waves and knowledge concerning the risk perception and behaviors of vulnerable populations.
Environmental factors that increase the risk of heat morbidity (e.g. built environment, geography) should also be identified and where possible ameliorated. Important discussions and decisions will need to center around urban design and land use as potential factors that influence our adaptive capacity and response to extreme heat events. The urban heat-island effect is one such factor influencing the risk of heat morbidity, though other structural changes such as green roofs and increase green space will also have an effect on heat morbidity and mortality.
Much research has been done on the urban heat island effect and its implications on heat-related illness; though this study indicates that heat morbidity is not restricted to urban environments. Risk of hospitalization due to HRI was actually higher in small urban clusters (populations 2,500 to 50,000) and rural areas as compared to urban areas (populations 50,000+). Additional research into heat morbidity is needed to fully understand why risk of hospitalization due to HRI is higher in small urban clusters and rural areas, more so than urban areas, despite the fact that urban areas have higher temperatures than surrounding areas, and hold that heat for longer periods of time. Hospital travel distance, absent heat-health warning systems and lower health literacy outside of urban areas may explain these differences.

Accounting for the hierarchical nature of the data improved the robustness of the analysis allowing consideration of the interacting effects of patient and hospital characteristics. Future analyses might include additional hospital-level and environmental-level variables to determine how factors such as patient or hospital location influence HRI risk. Surprisingly, I found that common serious comorbidities, aside from neurological disorders and psychoses, were not a significant risk factor for being hospitalized for a heat-related illness compared to all other hospitalizations. This is contrary to previous research indicating that these common comorbidities are exacerbated during extreme heat events. This should be interpreted cautiously as it may indicate only that other hospitalizations (i.e. our comparator) are very frequent for persons with "chronic" medical conditions. Additionally artifacts may have been introduced if the severity of the underlying condition led providers to code these conditions and under-diagnose or under-code HRI. Such underreporting can lead to gaps to further understanding of risk factors for heat-related illnesses, especially in vulnerable subpopulations. Current policies regarding diagnostic procedures during heat events should be examined to increase awareness among emergency personal and physicians to improve diagnoses of heat-related illnesses.

Our results also indicate that individuals from poorer neighborhoods and especially persons without insurance are at an increased risk of hospitalizations due to heat-related illnesses. As pervasive as air conditioning use has become in the United States, many among these vulnerable populations still lack access to this protective factor. Our spatial and descriptive analysis of air conditioning data found that poor and elderly individuals as well as those who are unemployed or underemployed have lower rates of air conditioning. These same populations are at the highest risk of being hospitalized for heat-related illnesses. In some communities air conditioning is still thought of as a luxury, but the increase in extreme heat events may make air conditioning a necessity. Steps are needed to improve the availability and affordability of air conditioning and to improve access to cooling centers. Policy surrounding energy consumption during summer months and during heat events will become an important topic as the demand for energy increases and further stresses energy distribution systems around the United States.

Although this study is the first to assess nationally representative data on HRI, there are limitations. Administrative data is not as accurate as clinical data and HRI is almost certainly under-coded. Because the NIS does not capture information regarding hospital readmission, an individual can be counted multiple times if hospitalized for an HRI during different time periods. Because I was unable to account for clustered patient data, this may cause narrower confidence intervals, though given the large data set and rarity of heat-related illness diagnoses I believe it would not make much difference in the overall analysis. Additionally, the RECS data does not link specifically with NIS records due to different levels of measurement (individual versus household) thus comparisons can only be made at an ecological level. Additionally, reporting for some hospital level variables varies from state to state.

In summary, risk factors for heat morbidity differ from those of heat mortality. Using the NIS database, I identified a number of previously unknown risk factors for heat morbidity HRI, including age greater than 40, males and hospitalization in rural areas and small urban clusters. Epidemiological and spatial analytic techniques can help identify targets for policy interventions and future research.

Table 2.1: Demographic characteristics of heat-related illness patients, United States 2001-2010 (Summer)

	HRI (Not weighted), N	HRI (Weighted), %	All Hospitalization (Weighted), %
Total	14,949	73,185 (100%)	181,094,795 (100%)
Age, Mean (±SD)	55 (21.62)	--	48 (27.9)
Gender			
Male	10,998	72.99%	41.33%
Female	3,937	26.91%	58.66%
Missing	14	0.1%	0.01%
Age Categories			
0-17	669	4.45%	16.56%
18-39	3,088	20.54%	21.60%
40-64	5,709	38.17%	27.56%
65-74	1,995	13.41%	13.02%
75+	3,488	23.43%	21.26%
Race/Ethnicity			
White	8,213	54.93%	52.30%
Black	2,089	13.92%	11.20%
Hispanic	1,406	9.35%	10.40%
Other	566	3.77%	4.81%
Missing	2,675	18.02%	21.29%
Median Income Quartile*			
0-25th percentile	4,458	29.92%	22.86%
26th to 50th percentile$^{\#}$	3,210	21.44%	20.87%
51st to 75th percentile	2,345	15.59%	18.68%
76th to 100th percentile	1,716	11.42%	16.13%
Missing	3,200	21.63%	21.45%
Payer – Primary			
Medicare	5,897	39.6%	36.99%
Medicaid	1,365	9.14%	20.83%
Private/HMO	4,161	27.79%	34.83%
Self/Other	3,476	23.14%	9.01%
Missing	50	0.33%	0.16%
Insurance Status			
Insured	11,423	76.52%	90.82%
Uninsured	2,261	15.05%	5.81%
Missing	1,265	8.43%	3.36%
Admin Source			
ED	8,879	58.89%	33.95%
Other Hosp/Facility	280	1.86%	3.51%
Court/Law	7	0.05%	0.09%
Routine/Other	1,719	11.51%	38.89%
Missing	4,064	27.7%	23.56%

Admin Type			
Emergency Department	10,870	72.76%	40.94%
Urgent	2,088	14.13%	17.28%
Elective	784	5.23%	22.18%
Trauma/Other	22	0.15%	9.65%
Missing	1,185	7.74%	9.99%

* based on zip code of patient
# Median zip-code income

Table 2.2: Hospital characteristics of heat-related illness patients, United States 2001-2010 (Summer)

	HRI (Not weighted), N	**HRI (Weighted), %**	**All Hospitalizations (Weighted), %**
Total	14949	72811 (100%)	180042390 (100%)
Hospital Region			
Northeast	1733	11.61%	17.13%
Mid-West	2788	18.75%	19.98%
South	8120	54.43%	45.62%
West	2308	15.22%	17.27%
Hospital Bed size			
Small	2553	17.15%	11.88%
Medium	3980	26.59%	24.45%
Large	8344	55.77%	63.34%
Missing	72	0.48%	0.32%
Hospital Location			
Rural	574	3.81%	2.21%
Small Urban Cluster	1607	10.76%	6.37%
Urbanized Area	7255	48.72%	64.67%
Missing	5513	37.01%	26.75%

Table 2.3. Multivariable model of risk factors of hospitalization for heat-related illnesses, United States 2001-2010 (Summer)

Variables	**Unadjusted**	**Adjusted**#	
	RR (95%CI)†	RR (95%CI)	*p*-Value
Race			
White	1 *ref.*	1 *ref.*	
Black	1.18 (1.17, 1.20)	1.21 (1.19, 1.23)	<0.001
Hispanic	0.86 (0.84, 0.87)	0.88 (0.86, 0.90)	<0.001
Other	0.75 (0.73, 0.76)	0.88 (0.85, 0.90)	<0.001
Gender			
Female	1 *ref.*	1 *ref.*	
Male	3.13 (3.08, 3.18)	3.54 (3.49, 3.58)	<0.001
Age Category			
0-17	0.28 (0.27, 0.29)	0.26 (0.25, 0.27)	<0.001
18-39	1 *ref.*	1 *ref.*	
40-64	1.45 (1.42, 1.47)	1.34 (1.32, 1.37)	<0.001
65-74	1.08 (1.06, 1.09)	1.28 (1.25, 1.30)	<0.001
75+	1.15 (1.14, 1.17)	1.52 (1.49, 1.55)	<0.001
Median Income Quartile			
0-25th percentile	1.85 (1.83, 1.87)	1.19 (1.17, 1.21)	<0.001
26th to 50th percentile**	1.46 (1.44, 1.47)	1.08 (1.07, 1.10)	<0.001
51st to 75th percentile	1.18 (1.17, 1.20)	0.97 (0.95, 0.98)	<0.001
76th to 100th percentile	1 *ref.*	1 *ref.*	
Payer – Primary			
Medicare	1.33 (1.29, 1.39)		
Medicaid	0.60 (0.57, 0.63)		
Private/HMO	1 *ref.*		
Self/Other	3.17 (3.13, 3.21)		
Insurance Status			
Insured	1 *ref.*		
Uninsured	3.09 (3.05, 3.11)	2.33 (2.29, 2.37)	<0.001
Comorbidities			
Congestive Heart Failure	0.80 (0.78, 0.81)	0.80 (0.78, 0.82)	<0.001
Chronic Pulmonary Disease	0.79 (0.78, 0.80)	0.72 (0.71, 0.82)	<0.001
Diabetes (no complications)	1.08 (1.06, 1.09)	0.90 (0.89, 0.92)	<0.001
Diabetes (complications)	0.75 (0.73, 0.78)		
Hypertension	1.30 (1.29, 1.31)	1.00 (0.99, 1.01)	0.8093
Fluid and Electrolyte Disorders*	7.76 (7.70, 7.81)		
Other Neurologic Disorders	1.98 (1.96, 2.00)	1.79 (1.75, 1.82)	<0.001
Obesity	0.79 (0.78, 0.80)		
Peripheral Vascular Disorders	0.66 (0.64, 0.68)		
Pulmonary Circulation Disorders	0.60 (0.57, 0.63)		
Renal Failure	0.77 (0.75, 0.78)	0.61 (0.60, 0.63)	<0.001
Psychoses	1.99 (1.96, 2.02)	1.83 (1.79, 1.87)	<0.001
Hospital Region			

Northeast	0.71 (0.70, 0.72)	0.72 (0.70, 0.73)	<0.001
Mid-West	1 *ref.*	1 *ref.*	
South	1.27 (1.26, 1.29)	0.94 (0.92, 0.95)	<0.001
West	0.94 (0.93, 0.95)	1.23 (1.20, 1.25)	<0.001
Hospital Bed size			
Small	1.68 (1.66, 1.69)	1.39 (1.37, 1.42)	<0.001
Medium	1.24 (1.23, 1.25)	1.25 (1.23, 1.27)	<0.001
Large	1 *ref.*	1 *ref.*	
Hospital Location			
Rural	2.32 (2.28, 2.36)	1.79 (1.74, 1.83)	<0.001
Small Urban Cluster	2.27 (2.24, 2.29)	2.09 (2.06, 2.12)	<0.001
Urbanized Area	1 *ref.*		

† P-values for unadjusted models were <0.001

*We interpret this as part of the HRI rather than comorbidity per se.

**Median zip-code income

[#]Adjusted for race, gender, age, median income zip code quartile, insurance status, comorbidities, hospital-bed size, -region, and -location.

Table 2.4. Multilevel multivariable model of risk factors of hospitalization for heat-related illnesses, United States 2001-2010 (Summer)

Variables			
	RR*	(95%CI)	*p* Value
Race			
White	1 *ref.*		
Black	1.17	1.08 – 1.27	0.002
Hispanic	0.93	0.84 – 1.03	0.148
Other	0.91	0.79 – 1.05	0.186
Gender			
Female	1 *ref.*		
Male	3.55	3.35 – 3.77	<0.001
Age Category			
0-17	0.26	0.22 – 0.30	<0.001
18-39 (Ref)	1 *ref.*		
40-64	1.29	1.19 – 1.40	<0.001
65-74	1.15	1.04 – 1.27	0.007
75+	1.40	1.29 – 1.53	<0.001
Median Income Quartile			
0-25th percentile	1.13	1.03 – 1.25	0.009
26th to 50th percentile (median)	1.05	0.96 – 1.15	0.258
51st to 75th percentile	0.97	0.89 – 1.06	0.463
76th to 100th percentile	1 *ref.*		
Insurance Status			
Insured	1 *ref.*		
Uninsured	2.51	2.31 – 2.72	<0.001
Hospital Region			
Northeast	0.72	0.61 – 0.86	0.002
Mid-West	1 *ref.*		
South	1.13	0.96 – 1.32	0.160
West	1.12	0.94 – 1.32	0.213
Hospital Bed size			
Small	1.35	1.19 – 1.53	<0.001
Medium	1.17	1.05 – 1.30	0.004
Large	1 *ref.*	0.77 – 0.95	
Hospital Location			
Rural	1.93	1.57 – 2.37	<0.001
Small Urban Cluster	2.00	1.75 – 2.29	<0.001
Urbanized Area	1 *ref.*		

*Adjusted for race, gender, age, median income zip code quartile, insurance, hospital-bed size, -region, and -location.

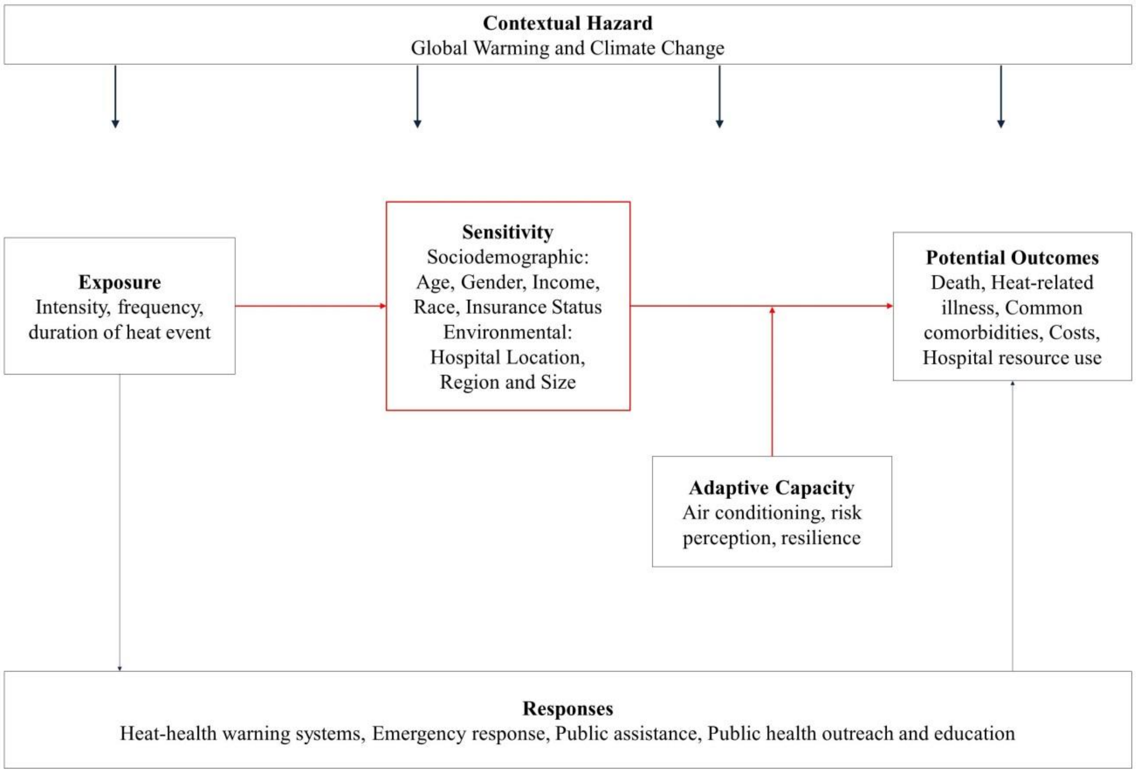


Figure 2.1. Risk factors associated with hospitalizations of heat-related illnesses. Identifying risk factors for hospitalizations of heat-related illness improves understanding of populations vulnerable to heat morbidity. Air conditioning use, a preventative measure, among vulnerable populations is examined as a potential adaptive capacity for influencing potential negative outcomes.

Figure 2.2. Heat-related illness versus all hospitalizations, United States 2001-2010 (Summer)

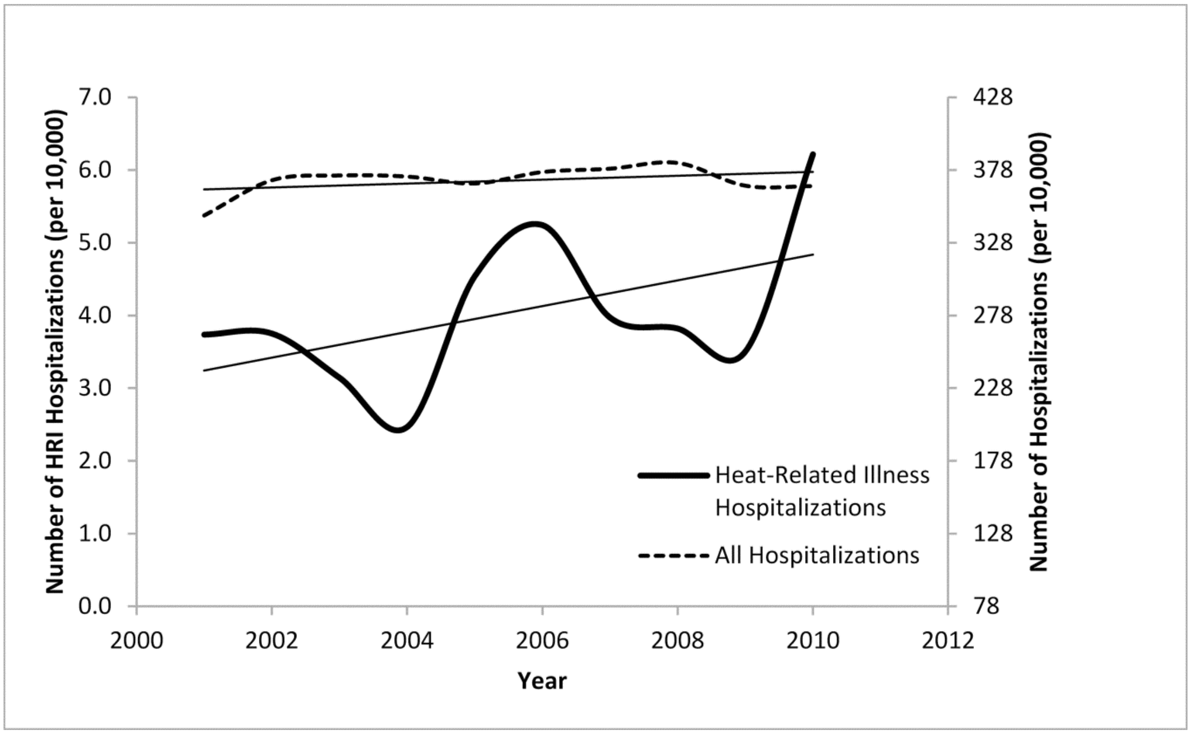


Figure 2.3. Hospitalization of heat-related illness (HRI), United States 2001-2010 (Summer)*

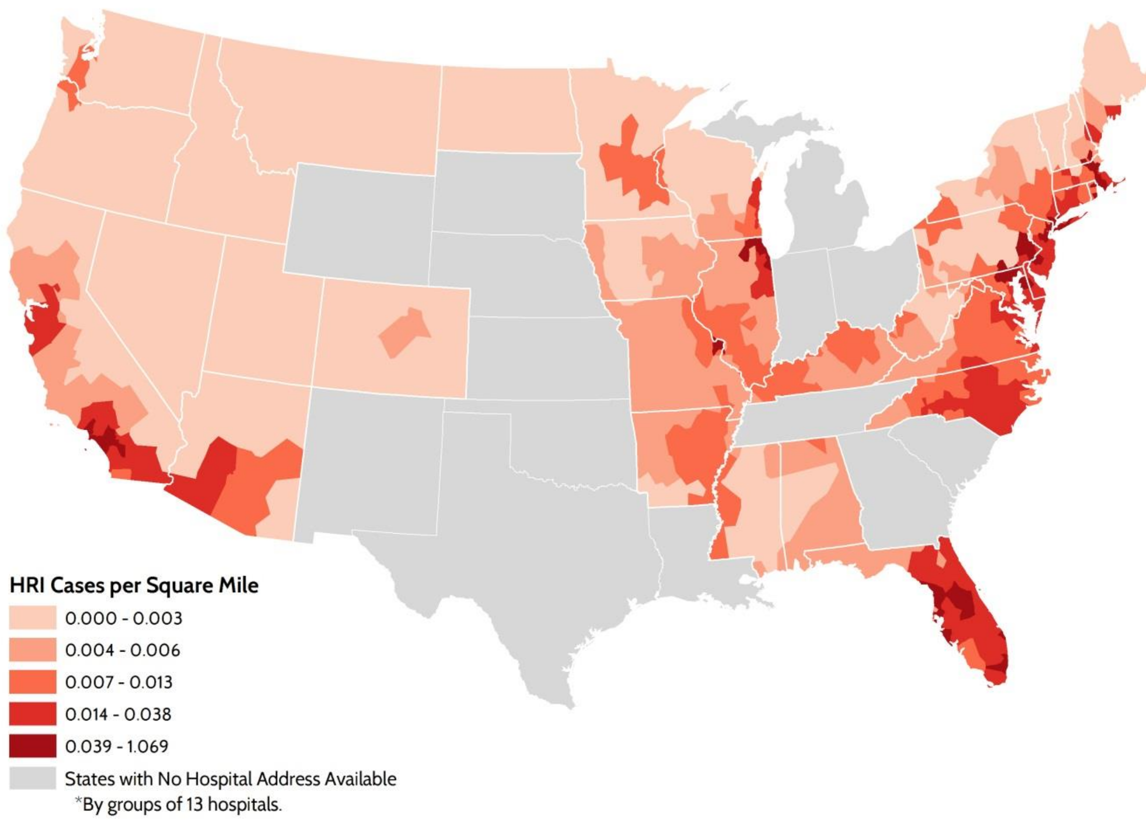
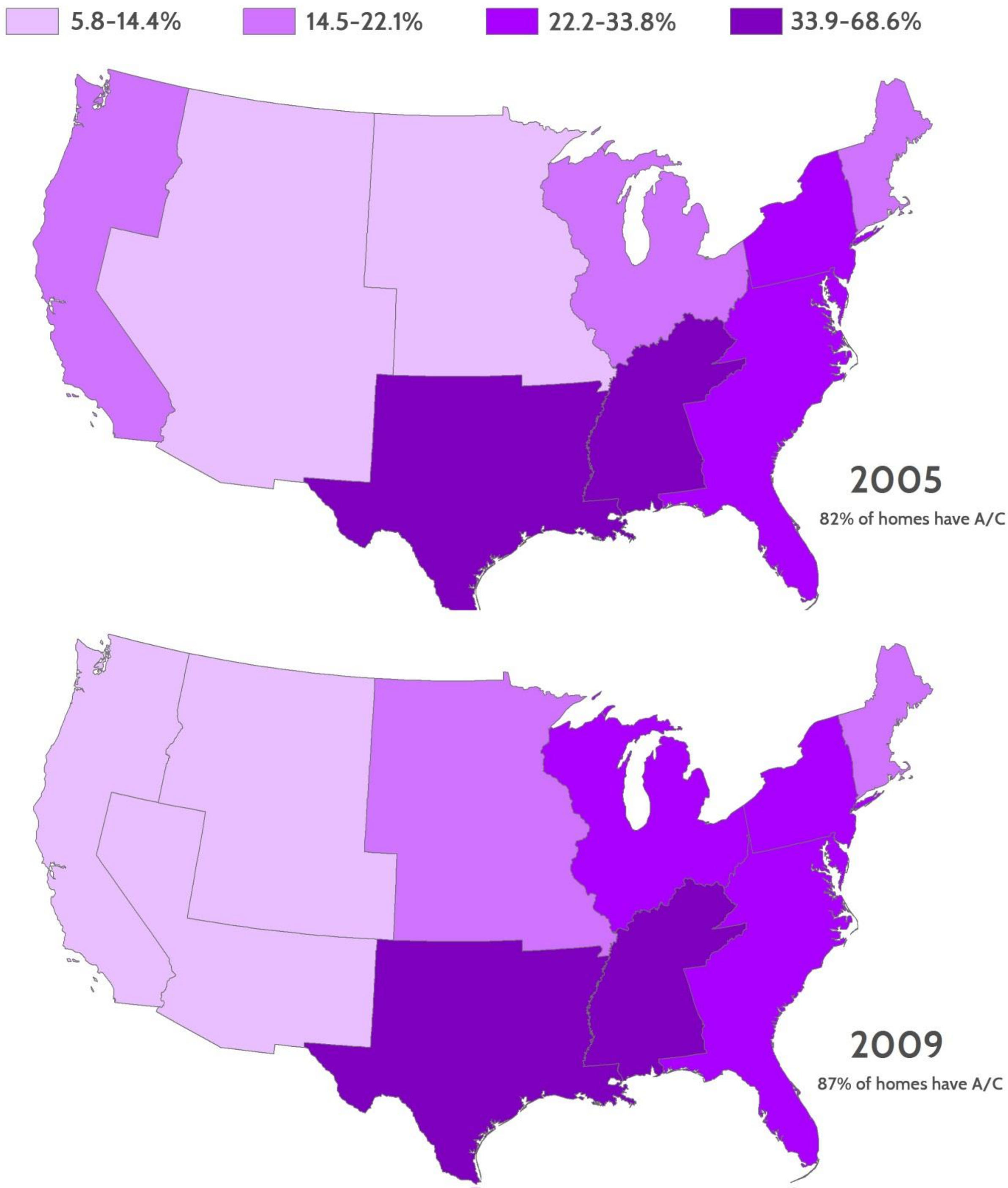


Figure 2.4. Percentage of Households with Incomes At or Below 100% of the Poverty Line without Air Conditioning, by Census Region



Chapter 3. Investigation of outcomes and hospital resource use of heat-related illness hospitalizations

3.1. Introduction

According to the latest Intergovernmental Panel on Climate Change (IPCC) global mean temperature is projected to increase between 1.5 and 2.3°C by mid-century and over 4°C by the end of the century.[1] High ambient temperature and extreme heat events worsen human health and are associated with excess mortality and morbidity through a range of heat-related illnesses (HRI) and exacerbations of underlying medical conditions.[2,3] The

The effect of high temperature on morbidity is a significant public health issue and is associated with a large number of hospitalizations each year.[4,5] Although hospitalizations from direct heat-related illnesses such as heat exhaustion and heat stroke are notable, there are significant hospitalizations due to exacerbated underlying medical conditions such as cardiovascular diseases, respiratory diseases and renal diseases.[6-9] In addition, urban residents may be at higher risk for heat morbidity due to the "urban heat island effect" resulting from higher absorption of heat among dark paved surfaces and buildings and the potential for higher concentrations of air pollutants.[10-12]

The previous chapter spoke at length concerning risk factors for heat-related illness hospitalizations, though the current chapter will now examine what are the potential outcomes related to hospitalizations due to heat-related illnesses. Additionally this study will explore some of the common comorbidities that are exacerbated. While heat-related illness hospitalizations spike during extreme heat events, excess hospitalizations for underlying medical conditions, as mentioned above, increase as well. Researchers in Taiwan showed that hospital admissions for kidney disease increased by 27% among all age-groups for ambient temperatures at or above 30°C.[13] Green et al. estimated relative risks of hospitalizations in California increased for acute renal disease (7.4%) and diabetes (3.1%) per 10°F increase above mean daily ambient temperature.[14] In Melbourne Australia acute myocardial infarction admissions to hospitals increased by 10% for one-day daily average temperatures of 30°C.[15] A recent study in the United States showed that heat-related hospitalizations for respiratory diseases in the Medicare population increased by 4.3% per 10°F increase in mean daily temperature.[7] Similarly a study in New York City showed that when temperatures exceeded 28.9°C hospital admissions for respiratory diseases increased by up to 2.7% per °C above the threshold temperature(28.9°C).[8] Additionally, current research into how heat events affect individuals with Type 2 Diabetes indicate that they are more susceptible to hospitalization during these events due to impaired thermoregulation due to the illness and prescribed medications.[16]

Heat-related illnesses are a significant cause for hospitalizations during heat events though underlying medical conditions may mask the initial heat-induced reason for the hospitalization. Hospitalizations from direct heat illness have deleterious consequences as seen during the 2003 heat wave in France with patients, especially elderly individuals, having reduced survival rates even 1 or 2 years after the initial hospitalization.[17] Patients with underlying medical conditions that are exacerbated by heat may increase the likelihood of greater negative outcomes including permanent disability and death. By using the conceptual framework for vulnerability assessment this chapter will explore potential outcomes and assess whether individuals diagnosed with a heat-related illness and common comorbidity, including diabetes, cardiovascular disease, respiratory disease and renal disease have greater negative outcomes than individuals hospitalized with only the common comorbidity thus improving knowledge concerning heat-related morbidity and providing opportunities for intervention to prevent heat-related illness. Information on the potential outcomes, specifically in identifying patients and populations with underlying medical conditions that are sensitive to extreme heat, will improve our ability to assess and intervene for at risk populations vulnerable to hospitalization due to heat-related illnesses (Figure 3.1).

3.2. Methods

3.2.1. Data Sources

The primary source of data for this analysis was the 2001 to 2010 Healthcare Cost and Utilization Project (HCUP) Nationwide Inpatient Sample (NIS), which was developed by the Agency for Healthcare Research and Quality (AHRQ). The NIS is the largest all-payer care database, with data from approximately 8 million hospitalizations per year, or about 20% of all hospital discharges in the United States.[18] The NIS contains data on patient and hospital demographic characteristics, primary and secondary diagnoses (*International Classification of Diseases, Ninth Revision* [ICD-9-CM] coding up to 25), primary and secondary procedures (ICD-9-CM coding up to 25), type and source of admission, discharge disposition, primary payer type, total hospital charges, and length of stay. Stratification and weighting variables allow calculation of national estimates, accounting for the complex sampling design and the expanded sampling framework over time.

3.2.2. Subjects and Definitions

The study population consists of patients who had a primary or secondary diagnoses of diabetes (ICD-9 code 250.00), cardiovascular diseases (ICD-9 codes 390-398, 402, 404-448), respiratory illnesses (ICD-9 codes 460-519), nephritic illnesses and acute renal failure (ICD-9 codes 580-589) along with a diagnosis of a heat-related illness (ICD-9 codes 992.0-992.9). The major disease groupings chosen were consistent with previous heat wave hospitalization studies, notably Semenza, et al. 1999 and Knowlton, et al. 2009.[4,19] Since approximately 95% of all HRI hospitalizations occurred in the summer months (May-September), all hospitalizations not occurring during these months were excluded. Each disease group (diabetes, cardiac, respiratory and renal diseases) hospitalization was compared to the disease group with a diagnosed heat-related illness.

3.2.3. Statistical Analysis

Outcome and hospital resource use dependent variables analyzed included length of stay, number of procedures, total charges, discharge status and death. Discharge status was categorized as a binary variable for either a routine or non-routine hospital discharge. Analyses for discharge status calculated the risk of having a non-routine discharge, which included transfer to a rehabilitation facility or specialty hospital, discharged with home health care, discharged against medical advice or discharged to court/law enforcement. The first analyses were descriptive statistics of outcomes for heat-related illnesses, disease grouping without a HRI diagnosis, and disease groupings with a HRI diagnosis. Secondly univariate and adjusted multivariable analyses were performed for each dependent variable. Analyses compared disease grouping outcomes versus the outcomes of disease groupings with a heat-related illness. Continuous outcomes, including length of stay, number of procedures and total charges, were analyzed with linear regression models. Binary outcomes, death and discharge status, were analyzed with a log-binomial model, which directly models risk ratios (RRs). Multivariable models included independent variables of sociodemographic characteristics (gender, age, race, zip-code income quartile and insurance status) and hospital characteristics such as geographic region (Northeast, Mid-West, South, West) and hospital location (rural, small urban cluster, and urban area). The final analyses consisted of linear and log-binomial regressions for stratified variables including gender, age category, race, zip-code income quartile, insurance status, hospital location and geographic region. Comparators for analyses were all other hospitalizations without a HRI diagnosis and all other hospitalizations for comorbidities without a co-diagnosis of a HRI and the common comorbidity (e.g. diabetes). For example, males hospitalized with diabetes and a HRI were compared to males who were only hospitalized for diabetes and similarly for each of the stratified analysis.

All statistical analyses were performed using SAS 9.3. This study was approved by the institutional Review Board of Hunter College and conforms to the HCUP data use agreement.

3.3. Results

3.3.1. Discharge Characteristics

Sociodemographic characteristics and hospital characteristics for heat-related illness hospitalizations and disease grouping hospitalizations with and without a HRI diagnoses are found in the Appendix. Compared to hospitalizations of disease groupings (diabetes, cardiac, renal and respiratory diseases) alone, characteristics of hospitalizations of disease groupings with an HRI diagnoses were more similar to those of heat-related illness hospitalizations alone. One difference being that males were more likely to be hospitalized with a HRI compared to all other hospitalizations. There were a large number of cases for each disease grouping without a HRI diagnoses compared to the diseases groupings with a HRI diagnosis. Diabetes with a heat-related illness diagnoses only consisted of 384 cases which limited some analyses. For cardiac diseases with an HRI diagnoses there were 1819 cases. There were also some differences particularly among the youngest age category for cardiac diseases, which include fewer cases than those patients with just a heat-related illnesses diagnosis, 0.78% vs. 4.45% respectively. Respiratory diseases with an HRI diagnosis consisted of 1430 cases and renal diseases with an HRI diagnosis included 2485 cases.

3.3.2. Univariate and multivariable model outcomes: Heat-related illness and common comorbidities

Comparative analysis for unadjusted and adjusted outcomes can be seen in tables 3.1.1., 3.1.2., 3.1.3., 3.1.4. and 3.1.5. for HRIs and disease groups, diabetes, cardiac, renal and respiratory diseases, respectively. The dependent variable for each outcome was modeled for having either a HRI or a disease grouping and a HRI diagnosis compared to not having the diagnosis among hospitalized populations. Multivariable models included independent variables such as age, gender, race, zip code income quartile of patient, insurance status, hospital location and geographic region. Outcomes of heat-related illnesses and all other hospitalizations during the time period showed no increase in length of stay, number of procedures, or total charges. Additionally there was no elevated risk of death or non-routine discharge among heat-related illness hospitalizations compared to all non-heat-related illness hospitalizations. Similar results were seen in the disease groupings, diabetes, cardiac and renal diseases with HRI diagnoses, no increase in length of stay, number of procedures or total charges and no elevated risk of death or non-routine discharges compared to diseases groupings, diabetes, cardiac and renal diseases with no HRI diagnoses.

Respiratory diseases with an HRI diagnoses showed increased number of procedures, 0.29 and increased total charges $5027 in addition to a 21% higher risk of death compared with only a respiratory disease diagnosis in the unadjusted model. When adjusted with independent variables respiratory diseases with an HRI diagnosis still showed an increased number of procedures, 0.19, a 34% increased risk of death and a 7% increased risk of non-routine discharge. Total charges increased by $4378, though this result was not statistically significant.

3.3.3. Stratified Multivariable model outcomes: Heat-related illness and common comorbidities

Stratified multivariable model analysis outcomes are shown in tables 3.2.1., 3.2.2., 3.2.3.. 3.2.4. and 3.2.5. Similar to the above analysis the dependent variable for each outcome was modeled for having either a HRI or a disease grouping and HRI diagnosis compared to not having the diagnosis among hospitalized populations. Heat-related illness diagnoses and each disease grouping with HRI diagnoses were stratified by gender, age category, race, zip code income quartile of patient, insurance status, hospital location and geographic region.

Outcomes for heat-related illness hospitalizations showed increased total charges for age group 0-17 year olds by approximately $7000 compared to non-heat-related illness hospitalizations during this time period. This age group also showed an increased risk of death and non-routine discharge, though not statistically significant. Age groups, 18-39 year olds showed a 2-fold increased risk of dying due to HRI hospitalization and 40-64 year olds showed a 4% increased risk of death due to HRI hospitalization all compared to non-heat-related illness hospitalization. Patients who were uninsured and had a HRI had more than 2 times the risk of dying than those without a heat-related illness diagnosis. Discharge records in the West showed patients have a

16% increased risk of death, though all other hospital locations and regions were at a reduced risk.

Cases with a diagnosis of diabetes and a heat-related illness showed an increase in the number of procedures, 2.72 more, among the youngest age group, 0-17 year olds, while all other outcomes were elevated but not statistically significant. Results from risk of death among patients with a diagnoses of diabetes and HRI were inconclusive due to very few deaths among this population. Females, in addition to 0-17 year olds had an increased risk of death with a renal disease diagnosis and heat-related illness. Increased risk of death was also seen among males, 18-74 year olds, Black, Hispanic, and those identifying as Other (including Asian/Pacific Islander and Native Americans) for diagnoses of cardiac diseases with a heat-related illness, compared to those with only a cardiac disease diagnosis. Additionally, patients in the lowest zip code income quartiles were 60% more likely to die, as were those without insurance, almost 2.5 times the risk. Patients in urban areas had a 12% increased risk and those in the West had a 48% increased risk of death compared to those patients with only a diagnosis of cardiac disease and no heat-related illness.

There were a number of elevated outcomes for patients diagnosed with a respiratory disease and a heat-related illness. A greater number of procedures were shown for females, 0-39 year olds, Black and Hispanics, compared to patients with only a respiratory disease diagnosis. Total charges were also higher among Blacks (> $28,000), and those in the median zip code income quartile (> $28,000) for hospitalizations of a respiratory disease and heat-related illness compared to those hospitalized for just a respiratory disease. Increased risk of death was shown for males and among all racial groups. Age group 0-17 year olds showed a 6.5 times increased risk, 18-39 year olds showed a 5.5 times increased risk and 40-64 year olds showed a 17%

increased risk of death in addition to an increase in non-routine discharges among these age groups for respiratory diseases and HRI diagnosis. The lowest two zip code income quartiles showed a 37% and 36% increase in risk of death and an increased risk of non-routine discharge for those diagnosed with a respiratory disease and HRI compared to those with just a diagnosis of a respiratory disease. Additionally patients hospitalized in urban areas showed an increased risk of death, 26%, and increased risk of non-routine discharge, 6%, for those diagnosed with an HRI and respiratory disease.

3.4. Discussion

This study investigated whether patients hospitalized for HRI and common comorbidities had an increased risk for greater negative outcomes. Although most of the multivariable analyses did not show greater negative outcomes compared to non-HRI hospitalizations the stratified analyses indicated that certain groups had significantly increased negative outcomes for hospitalizations due to HRIs and common comorbidities. The stratified analysis was important because prior research supported conclusions that specific vulnerable groups, such as children, had increased negative health outcomes due to heat-related illnesses.[20,21] By using a stratified analysis population denominators represented populations and were more reflective of previous studies' conclusions identifying vulnerable populations with the identified underlying medical conditions. Children, aged 0-17 years, were particularly vulnerable showing increased risk of death and non-routine discharges for HRIs alone and with additional diagnoses of renal and respiratory diseases. Risk of death among children with a respiratory disease and HRI diagnosis was greater than 6 times that of children with only a respiratory disease diagnosis, without the co-diagnosis of HRI. Children also showed increased number of procedures among diagnoses of diabetes and respiratory diseases with a heat-related illness diagnosis. While children have been noted as particularly vulnerable to high temperatures the current study also highlights a number of significant findings indicating that common comorbidities play a role in further defining which groups of children are at a heightened risk for negative health outcomes due to heat-related illnesses. A recent meta-analysis on the impact of temperature on children's health argued that more research is needed to identify possible modifiers of temperature and its relationship with children's health which is highlighted in the results of this study and asserts the need for further research in this area.[22]

As with children, the elderly are considered at an increased risk of mortality and morbidity due to heat-related illnesses. Though in the current study increased risk of death was seen among age groups 0-64 years old for HRI diagnoses alone and cardiac diseases with a HRI diagnosis as well as with all age groups for respiratory diseases and a HRI diagnosis based on the stratified analyses. The older age groups were not indicative of greater negative outcomes as readily as other age groups in this analysis. This research highlights that underlying medical conditions play a significant role in morbidity and mortality of HRIs among all age groups, not necessarily just children and the elderly. Males also had increased risk of death with diagnosis of cardiac and respiratory diseases with a HRI, though females had a higher risk of non-routine discharge for a diagnosis of respiratory and renal diseases and HRIs.

Overall, in the current study, increased risks of negative health outcomes were more prominent than increased hospital resource use. Increased length of stay was only seen in Black patients diagnosed with a respiratory disease and a HRI while increased costs and number of procedures were also limited to patients with diagnoses of respiratory diseases and a HRI. Although this study did not control for air pollution, previous studies have suggested a synergistic effect between high ambient temperatures and air pollution on morbidity and mortality.[23,24] This can account for the elevated negative outcomes for patients diagnosed with a respiratory diseases and HRIs. Additionally, patients in urban areas had increased risk of death and non-routine discharges for diagnoses of respiratory diseases with an HRI which could also indicate that air pollution in urban areas is a contributing factor to negative health outcomes of hospitalizations due to heat-related illnesses. In conjunction with the known urban heat island effect, individuals in urban areas with underlying medical conditions, particularly respiratory diseases may have compounded risk of hospitalizations for HRIs and more specific interventions will be needed for this vulnerable population compared to smaller urban and rural populations.

Outcomes from heat-related illness diagnoses can range from mild dehydration, due to electrolyte imbalance, to multi-organ failure in patients presenting with heat stroke. Outcomes are directly related to the hospital resource use and costs associated with the diagnoses of heat-related illness, usually increasing the length of stay and number of procedures performed as well as having an elevated risk of disability and death. Studies have shown that those individuals presenting with the more severe cases of heat-related illness have a greater need for hospital resources and are at a higher risk for negative health outcomes.[25,26] Some researchers have indicated that individuals that die in heat waves are part of a "harvesting" effect in which heat deaths occur in frail or sick individuals whose death was only hastened by the heat and would have subsequently died within a short period had the heat wave not occurred.[27,28] Though other studies suggest that assessing a harvesting effect is complicated due to multiple subsequent heat events and instances where no harvesting effect was detected for short-term follow-up of heat waves.[29,30] Further research is needed to understand the degree of mortality displacement during extreme heat events.

As this study has shown, there are a range of outcomes of hospitalizations for heat-related illnesses and common comorbidities. Increased costs, hospital resources and negative health outcomes will continue to rise as the intensity and frequency of extreme heat events increase. Studies have shown that heat-related illnesses can damage organs and potentially increase an individual's chance of being susceptible to additional heat-related illnesses from future events.[31,32] Understanding the interaction of underlying medical conditions such as diabetes, cardiac, renal, and respiratory diseases is an important indication of whether an individual is both at risk for a heat-related illness and at an increased risk for greater negative health outcomes from hospitalizations. In the conceptual framework for vulnerability assessment (Figure 3.1) potential outcomes are influenced by sociodemographic and environmental characteristics. Understanding how underlying medical conditions that are exacerbated by extreme heat events contribute to hospitalizations can help reduce the severity and number of hospitalizations due to heat-related illness.

Heat-illness awareness needs be increased among populations with underlying medical conditions. Informational interventions can be included in preventative care programs similar to that for patients with heart disease and diabetes. Conditions that require consistent monitoring which also put these individuals at increased risk for a heat-related illness can improve outcomes if knowledge and understanding of outcomes is related to these vulnerable populations. In addition, health care professionals need to be further trained to diagnosis and treat patients with medical conditions exacerbated by high ambient temperatures. This includes nurses and physicians, but as more and more people seek information online and at retail pharmacies, information concerning the interaction of extreme heat, underlying medical conditions and heat-related illnesses will need to include secondary and tertiary sources of medical and health information. Heat-related illnesses are potentially greatly underreported and may lead to wrong diagnoses and treatment of illnesses during heat events. Policies regarding educational information for the underlying medical conditions exacerbated by extreme heat will need to increase the level of knowledge among health care professionals in addition to the at risk populations themselves to achieve a broad spectrum of knowledge within society.

Although this study is the first to assess nationally representative data on HRI and common comorbidity outcomes, there are limitations. Administrative data is not as accurate as clinical data and HRIs are almost certainly under-coded and diagnoses of exacerbated medical conditions may take precedence over the underlying HRI. In some instances data analysis was limited due to small sample sizes which reduced statistical significance. Air pollution was discussed as a possible confounder or effect modifier though was not accounted for in the analysis though most studies have found that heat-mortality and morbidity persist even after adjustments. There were a number of strengths to the study as well. Using the NIS as a nationally representative sample of hospitalizations for heat-related illnesses and common comorbidities and applying sample weights allows for the identification of risk factors and outcomes that are generalizable to a much larger population than the sample size. This contributes to the expanding descriptive data and general understanding of heat morbidity and common comorbidities. And while the fully adjusted model analyses for hospitalizations of HRI and common comorbidities did not show increased negative outcomes, stratified analyses showed increased negative outcomes among specific groups hospitalized and indicated which population with underlying medical conditions may be particularly vulnerable to heat events.

In summary, outcomes of individuals hospitalized for heat-related illnesses and common comorbidities differ from those patients with non-HRI hospitalizations. Elevated risk of negative health outcomes and increased hospital resource use was seen in the stratified analysis of patients diagnosed with common comorbidities, in particular those with cardiac and respiratory diseases with HRIs. This study may help increase knowledge among policy makers and clinicians and target interventions among at-risk populations who are vulnerable due to underlying medical conditions.

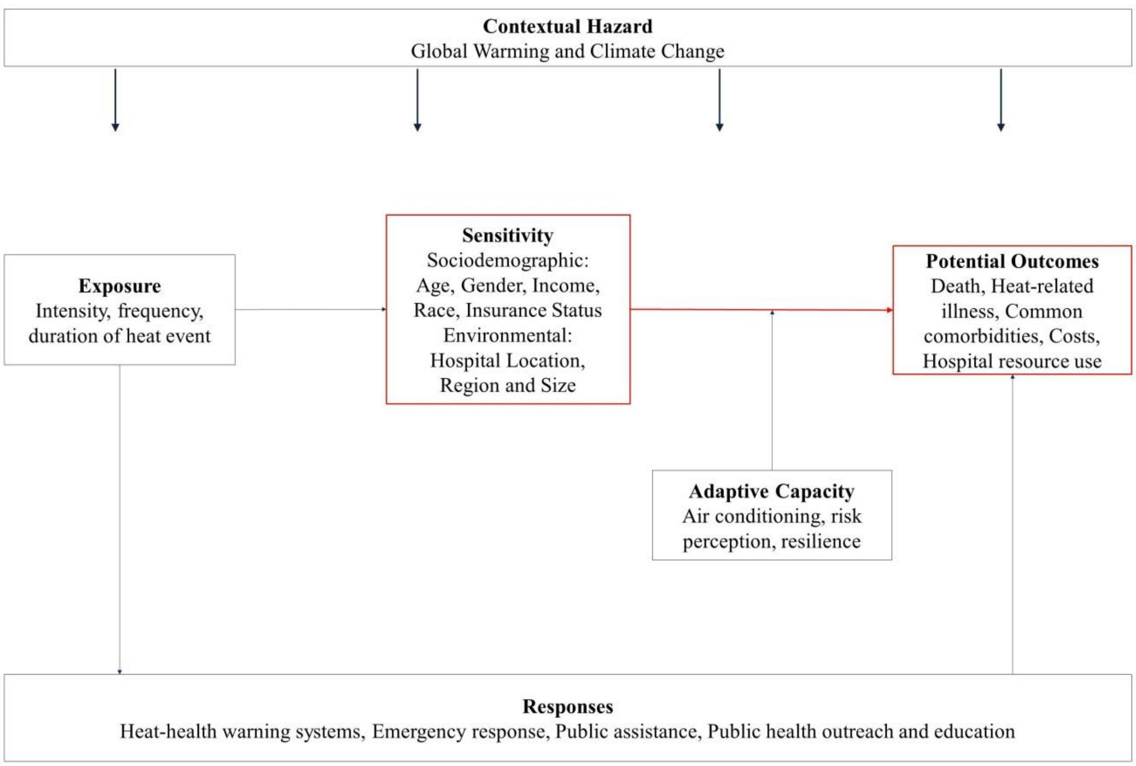


Figure 3.1. Potential outcomes associated with hospitalizations of heat-related illnesses. Common comorbidities along with individual and environmental risk factors associated with heat-related illness diagnoses are analyzed to further elucidate whether populations with underlying medical conditions have greater negative outcomes compared to those without a heat-related illness.

Table 3.1.1. Multivariable model outcomes of hospitalization due to heat-related illnesses, United State 2001-2010 (Summer)

Outcome*	Unadjusted	p-value	Adjusted	p-value
Length of Stay (Days)	-1.54	<0.001	-1.67	<0.001
Number of Procedures	-0.93	<0.001	-0.90	<0.001
Total Charges (US Dollars)	-$7098	<0.001	-$10070	<0.001
Death (RR)	0.94	<0.001	0.85	<0.001
(95% CI)	0.91-0.96		0.82-0.88	
Non-Routine Discharge (RR)	0.72	<0.001	0.83	<0.001
(95% CI)	0.71-0.73		0.82-0.84	

*Outcomes are compared to all hospitalizations without a heat-related illness diagnosis

Table 3.1.2. Multivariable model of outcomes from hospitalization due to diabetes with a heat-related illness diagnosis, United State 2001-2010 (Summer)

Outcome*	Unadjusted	p-value	Adjusted	p-value
Length of Stay (Days)	-1.86	<0.001	-1.7	0.001
Number of Procedures	-0.83	<0.001	-0.72	<0.001
Total Charges (US Dollars)	-$10621	<0.001	-$10539	0.001
Death (RR)	-	-	0.84	<0.001
(95% CI)			0.83-0.86	
Non-Routine Discharge (RR)	0.52	<0.001	0.74	<0.001
(95% CI)	0.50-0.55		0.71-0.76	

*Outcomes are compared to all hospitalizations due to diabetes without a heat-related illness diagnosis

Table 3.1.3. Multivariable model of outcomes from hospitalization due to cardiac disease with a heat-related illness diagnosis, United State 2001-2010 (Summer)

Outcome*	Unadjusted	p-value	Adjusted	p-value
Length of Stay (Days)	-1.36	<0.001	-1.21	<0.001
Number of Procedures	-1.03	<0.001	-1.02	<0.001
Total Charges (US Dollars)	-$12736	<0.001	-$13278	<0.001
Death (RR)	0.90	<0.001	0.98	0.05
(95% CI)	0.85-0.95		0.89-1.06	
Non-Routine Discharge (RR)	0.73	<0.001	0.84	<0.001
(95% CI)	0.72-0.74		0.83-0.86	

*Outcomes are compared to all hospitalizations due to cardiac disease without a heat-related illness diagnosis

Table 3.1.4. Multivariable model of outcomes from hospitalization due to renal disease with a heat-related illness diagnosis, United State 2001-2010 (Summer)

Outcome*	Unadjusted	p-value	Adjusted	p-value
Length of Stay (Days)	-3.84	<0.001	-3.16	<0.001
Number of Procedures	-1.35	<0.001	-1.12	<0.001
Total Charges (US Dollars)	-$24155	<0.001	-$23434	<0.001
Death (RR)	0.27	<0.001	0.39	<0.001
(95% CI)	0.25-0.29		0.34-0.42	
Non-Routine Discharge (RR)	0.28	<0.001	0.53	<0.001
(95% CI)	0.27-0.29		0.52-0.54	

*Outcomes are compared to all hospitalizations due to renal disease without a heat-related illness diagnosis

Table 3.1.5. Multivariable model of outcomes from hospitalization due to respiratory disease with a heat-related illness diagnosis, United State 2001-2010 (Summer)

Outcome*	Unadjusted	p-value	Adjusted	p-value
Length of Stay (Days)	-0.47	<0.001	-0.27	0.43
Number of Procedures	0.29	<0.001	**0.19**	0.04
Total Charges (US Dollars)	$5027	<0.001	$4378	0.10
Death (RR)	1.21	<0.001	**1.34**	<0.001
(95% CI)	1.15-1.25		1.32-1.36	
Non-Routine Discharge (RR)	0.90	<0.001	**1.07**	<0.001
(95% CI)	0.87-0.93		1.06-1.08	

*Outcomes are compared to all hospitalizations due to respiratory disease without a heat-related illness diagnosis

Table 3.2.1. Stratified multivariable model of outcomes from hospitalization due to heat-related illnesses, United State 2001-2010 (Summer)

	Outcome						
Stratified Variable[#]	**Length of Stay (days)**	**Number of Procedures**	**Total Charges (US Dollars)**	**Death**		**Non-Routine Discharge**	
				RR	**(95%CI)**	**RR**	**(95%CI)**
Gender							
Male	-1.77	-0.69	-$8110	0.76	0.76-0.77	0.62	0.62-0.62
Female	-1.40	-0.91	-$11291	0.83	0.83-0.84	0.84	0.83-0.85
Age Categories							
0-17	-1.04	-0.42	**$7027**	2.41†	-	1.00†	0.95-1.05
18-39	-1.71	-0.77	-$6768	**2.08**	1.83-2.33	0.72	0.72-0.73
40-64	-1.60	-0.96	-$11245	**1.04**	1.00-1.08	0.71	0.69-0.72
65-74	-1.90	-1.11	-$16703	0.92†	0.91-1.03	0.78	0.78-0.79
75+	-1.84	-0.82	-$12615	0.77	0.74-0.80	0.77	0.76-0.78
Race/Ethnicity							
Black	-1.53	-0.63	-$5546	0.41†	0.36-0.46	0.79	0.79-0.81
White	-1.64	-1.01	-$10914	0.98	0.84-1.14	0.79	0.78-0.80
Hispanic	-1.31	-0.85	-$7782	1.05	0.96-1.14	0.80	0.79-0.81
Other	-1.63	-0.96	-$17486	1.57†	1.43-1.74	0.68	0.67-0.99
Median Income Quartile*							
0-25th percentile	-1.48	-0.78	-$7425	1.01†	1.00-1.02	0.78	0.77-0.79
26th to 50th percentile	-1.46	-0.95	-$8728	0.89	0.83-0.96	0.66	0.65-0.67
51st to 75th percentile	-1.71	-1.05	-$12648	0.60	0.64-0.66	0.66	0.65-0.68
76th to 100th percentile	-1.80	-0.97	-$12134	0.89	0.82-0.97	0.77	0.77-0.79
Insurance Status							
Insured	-1.63	-0.95	-$10645	0.73	0.70-0.76	0.81	0.80-0.82
Uninsured	-1.39	-0.74	-$6749	**2.30**	2.12-2.49	0.79†	-
Hospital Location							
Rural	-1.51	-0.80	-$7825	0.44	0.36-0.56	0.74	0.72-0.75
Small Urban Cluster	-1.45	-0.70	-$6120	0.56	0.49-0.64	0.61	0.60-0.62
Urban Area	-1.60	-0.96	-$10661	1.01†	0.97-1.04	0.77	0.77-0.78
Hospital Region							

Northeast	-1.95	-0.88	-$10539	0.94†	0.87-1.02	0.83	0.82-0.83
Mid-West	-1.41	-0.97	-$6879	0.87	0.83-0.92	0.83	0.82-0.83
South	-1.78	-1.01	-$11607	0.72	0.67-0.76	0.71	0.70-0.72
West	-0.96	-0.84	-$8700	**1.16**	1.10-1.24	0.98†	-

*zip code of patient, †p-value > 0.05, #Reference group for all stratified variables are those hospitalized without a heat-related illness

Table 3.2.2. Stratified multivariable model of outcomes from hospitalization due to diabetes with a heat-related illness diagnosis, United State 2001-2010 (Summer)

	Outcome						
Stratified Variable#	**Length of Stay (days)**	**Number of Procedures**	**Total Charges (US Dollars)**	**Death**		**Non-Routine Discharge**	
				RR	**(95%CI)**	**RR**	**(95%CI)**
Gender							
Male	-1.68	-0.32	-$10051	-		0.67	0.64-0.71
Female	-1.69†	-0.73†	-$11133†	-		0.62	0.57-0.68
Age Categories							
0-17	1.02†	**2.72**	$28901†	-		-	
18-39	-1.51	-0.27†	-$7513†	-		1.04†	0.89-1.21
40-64	-1.79	-0.78	-$11911	-		0.58	0.51-0.66
65-74	-1.23†	-0.65†	-$12299†	-		0.98	0.97-0.99
75+	-2.01	-1.08	-$13436	-		0.57	0.53-0.62
Race/Ethnicity							
Black	-2.22†	-0.35†	-$12560†	-		0.53	0.46-0.62
White	-1.61	-0.91	-$9312	-		0.66	0.62-0.69
Hispanic	-1.75†	-0.25†	-$9378†	-		0.58	0.51-0.66
Other	-0.74†	-1.45†	-$23225†	-		**1.72**	1.68-1.76
Median Income Quartile*							
0-25th percentile	-1.71†	-0.42†	-$6689†	-		0.75	0.70-0.81
26th to 50th percentile	-1.48†	-0.62	-$12581	-		0.91	0.89-0.92
51st to 75th percentile	-2.24	-0.96	-$11705†	-		0.54	0.49-0.61
76th to 100th percentile	-1.36†	-1.24	-$14026†	-		0.48	0.73-0.55
Insurance Status							
Insured	-1.74	-0.71	-$11007	-		0.67	0.65-0.70
Uninsured	-1.69†	-0.78	-$8754†	-		0.43	0.33-0.55
Hospital Location							
Rural	-1.26†	-0.26†	-$2474†	-		0.95†	0.77-1.17
Small Urban Cluster	-1.54†	-0.56†	-$6572†	-		0.29	0.25-0.36
Urban Area	-1.78	-0.79	-$12043	-		0.71	0.68-0.74

Hospital Region						
Northeast	-1.63†	-0.51†	-$7090†	-	0.76	0.70-0.83
Mid-West	-1.40†	-0.79†	-$4089†	-	0.56	0.48-0.65
South	-1.70	-0.69	-$10211	-	0.71	0.67-0.77
West	-1.83†	-0.90	-$16738	-	0.50	0.46-0.55

*zip code of patient, †p-value > 0.05, #Reference group for all stratified variables are those hospitalized for diabetes without a heat-related illness

Table 3.2.3. Stratified multivariable model of outcomes from hospitalization due to cardiac disease with a heat-related illness diagnosis, United State 2001-2010(Summer)

	Outcome						
Stratified Variable[#]	**Length of Stay (days)**	**Number of Procedures**	**Total Charges (US Dollars)**	**Death**		**Non-Routine Discharge**	
				RR	**(95%CI)**	**RR**	**(95%CI)**
Gender							
Male	-1.17	-1.17	-14983	**1.08**	1.04-1.12	0.90	0.89-0.91
Female	-1.30	-0.74	-11482	0.95†	-	0.89	0.89-0.90
Age Categories							
0-17	-5.26†	-2.23†	-46823†	-		-	
18-39	0.67†	-0.41†	3126†	**3.11**	2.39-4.06	1.04†	0.98-1.10
40-64	-1.21	-1.19	-15416	**1.66**	1.42-1.95	0.94	0.92-0.98
65-74	-1.33	-1.28	-18848	**1.46**	1.22-1.75	0.95	0.93-0.96
75+	-1.48	-0.87	-11989	0.80	0.76-0.85	0.85	0.85-0.87
Race/Ethnicity							
Black	-1.71	-0.53	-10470†	**1.56**	1.29-1.89	0.89	0.86-0.91
White	-1.21	-1.11	-14479	0.90	0.86-0.94	0.83	0.82-0.84
Hispanic	-0.28†	-1.04	-7151†	**1.04**	1.03-1.05	0.95	0.92-0.98
Other	-1.56†	-0.87†	-24920†	**1.88**	1.43-2.46	0.85	0.80-0.91
Median Income Quartile*							
0-25th percentile	-0.75†	-0.70	-6555†	**1.60**	1.43-1.79	0.93	0.92-0.95
26th to 50th percentile	-1.19	-1.14	-12939	0.85†	0.71-1.01	0.73†	-
51st to 75th percentile	-1.65	-1.26	-17366	0.40	0.30-0.54	0.80	0.77-0.82
76th to 100th percentile	-1.46	-1.08	-20353	0.75	0.61-0.91	0.89	0.87-0.91
Insurance Status							
Insured	-1.25	-1.05	-14204	0.89	0.81-0.97	0.82	0.81-0.83
Uninsured	-0.54†	-0.62†	-8187†	**2.47**	1.99-3.06	**1.29**	1.22-1.36
Hospital Location							
Rural	-1.41†	-0.56†	-9600†	0.54	0.52-0.57	0.84	0.80-0.88
Small Urban Cluster	-1.57	-0.66	-9250	0.52	0.39-0.70	0.65	0.62-0.67
Urban Area	-1.14	-1.09	-14913	**1.12**	1.09-1.14	0.88	0.87-0.89

Hospital Region							
Northeast	-1.39	-1.00	-13716	0.93†	0.76-1.12	0.97†	-
Mid-West	-0.82†	-0.88	-2715†	0.79†	0.60-1.04	0.93†	-
South	-1.44	-1.04	-15583	0.67	0.57-0.79	0.70	0.70-0.71
West	-0.87†	-1.06	-15164	**1.48**	1.30-1.67	0.98†	-

*zip code of patient, †p-value > 0.05, #Reference group for all stratified variables are those hospitalized for cardiac disease without a heat-related illness

Table 3.2.4. Stratified multivariable model of outcomes from hospitalization due to renal disease with a heat-related illness diagnosis, United State 2001-2010(Summer)

	Outcome						
Stratified Variable#	**Length of Stay (days)**	**Number of Procedures**	**Total Charges (US Dollars)**	**Death**		**Non-Routine Discharge**	
				RR	**(95%CI)**	**RR**	**(95%CI)**
Gender							
Male	-3.26	-1.32	-24631	0.13	0.11-0.16	0.46	0.45-0.48
Female	-2.06	-0.77	-11621	**1.28**	1.20-1.36	0.82	0.80-0.84
Age Categories							
0-17	-3.68†	-0.55†	-13010†	**3.46**	2.37-5.06	0.54	0.42-0.70
18-39	-2.84	-1.19	-21150	0.22	0.15-0.34	0.34	0.31-0.37
40-64	-3.63	-1.49	-26163	0.13	0.10-0.17	0.36	0.35-0.39
65-74	-2.95	-1.02	-21079	-	-	0.61	0.61-0.62
75+	-2.08	-0.81	-17371	0.96†	0.86-1.09	0.82	0.81-0.83
Race/Ethnicity							
Black	-2.60	-1.10	-14958	0.15	0.11-0.23	0.67	-
White	-3.38	-1.34	-25123	0.49	0.44-0.55	0.53	0.51-0.54
Hispanic	-3.32	-1.46	-29273	0.24	0.16-0.37	0.53	0.51-0.57
Other	-3.08	-0.88	-24112†	-	-	0.19	0.16-0.24
Median Income Quartile*							
0-25th percentile	-2.94	-1.12	-19724	0.23	0.18-0.29	0.55	0.45-0.57
26th to 50th percentile	-3.38	-1.40	-24263	0.46	0.38-0.55	0.50	0.49-0.52
51st to 75th percentile	-3.33	-1.34	-27045	0.32	0.24-0.41	0.49†	-
76th to 100th percentile	-2.99	-1.32	-24954	0.65	0.54-0.78	0.68	0.66-0.70
Insurance Status							
Insured	-3.16	-1.30	-24247	0.49	0.44-0.55	0.56	0.55-0.57
Uninsured	-2.85	-1.09	-18417	-	-	0.40	0.38-0.99
Hospital Location							
Rural	-1.63†	-0.76	-12310†	-	-	0.48	0.44-0.53
Small Urban Cluster	-2.07	-0.88	-10181	0.51	0.38-0.68	0.40	0.37-0.43
Urban Area	-3.34	-1.35	-25642	0.40	0.35-0.45	0.55	0.54-0.56

Hospital Region							
Northeast	-3.43	-0.99	-23275	0.48	0.39-0.60	0.60†	-
Mid-West	-2.92	-1.44	-21981	-	-	0.45	0.42-0.48
South	-3.33	-1.40	-22970	0.50	0.44-0.57	0.45	0.44-0.47
West	-2.65	-1.13	-26329	0.24	0.18-0.32	**3.89**	3.82-3.95

*zip code of patient, †p-value > 0.05, #Reference group for all stratified variables are those hospitalized for renal disease without a heat-related illness

Table 3.2.5. Stratified multivariable model of outcomes from hospitalization due to respiratory disease with a heat-related illness diagnosis, United State 2001-2010(Summer)

Stratified Variable[#]	Length of Stay (days)	Number of Procedures	Total Charges (US Dollars)	Death RR	Death (95%CI)	Non-Routine Discharge RR	Non-Routine Discharge (95%CI)
Gender							
Male	-0.42	0.09†	2651†	**1.22**	1.18-1.26	1.03†	-
Female	-0.06†	**0.37**	7362†	1.08†	1.06-1.11	**1.07**	1.07-1.09
Age Categories							
0-17	-0.27†	**1.95**	17637†	**6.53**	5.39-7.91	**3.32**	3.19-3.45
18-39	0.73†	**0.97**	**28689**	**5.57**	4.83-6.42	**1.27**	1.20-1.35
40-64	-0.10†	0.29†	4522†	**1.17**	1.03-1.33	**1.06**	1.04-1.08
65-74	-0.34†	0.07†	1792†	0.81	0.68-0.96	1.00†	0.98-1.02
75+	-1.16	-0.26†	-4158†	0.89	0.83-0.97	0.89†	-
Race/Ethnicity							
Black	**2.43**	**1.33**	**28372**	**1.73**	1.51-1.97	**1.45**	1.42-1.48
White	0.66†	0.10†	538†	**1.07**	1.03-1.11	0.96	0.95-0.97
Hispanic	-0.34†	**0.85**	11407†	**1.38**	1.24-1.54	1.02†	0.97-1.07
Other	-3.30†	-0.05†	-28302†	**2.52**	2.16-2.94	**1.46**	1.41-1.50
Median Income Quartile*							
0-25th percentile	-0.71†	0.22†	2876†	**1.37**	1.23-1.52	**1.05**	1.04-1.05
26th to 50th percentile	1.02†	0.23†	**18829**	**1.36**	1.22-1.52	1.09†	-
51st to 75th percentile	-0.79†	0.08†	-8333†	0.86†	0.73-1.02	**1.04**	1.03-1.05
76th to 100th percentile	-0.85†	0.31†	898†	1.12†	0.97-1.30	1.02†	1.00-1.04
Insurance Status							
Insured	-0.28†	0.11†	4358†	1.01†	0.78-1.29	1.02	1.01-1.02
Uninsured	-0.25†	**0.79**	5026†	**3.43**	3.28-3.59	**1.32**	1.26-1.38
Hospital Location							
Rural	-2.02†	-0.24†	-8929†	-	-	0.68	0.63-0.73
Small Urban Cluster	-0.38†	0.34†	828†	1.07†	0.88-1.31	1.00†	-
Urban Area	-0.12†	0.20†	5906†	**1.26**	1.20-1.31	**1.06**	1.05-1.06

Hospital Region							
Northeast	-1.08†	0.12†	-2189†	**1.54**	1.39-1.73	0.98	0.98-0.99
Mid-West	0.57†	0.10†	8371†	1.10†	0.91-1.34	**1.18**	1.17-1.20
South	-0.35†	0.19†	1250†	**1.37**	1.24-1.51	0.90	0.93-0.94
West	0.10†	0.29†	12122†	0.92	0.88-0.95	**1.10**	1.09-1.10

*zip code of patient, †p-value > 0.05, #Reference group for all stratified variables are those hospitalized for respiratory disease without a heat-related illness

Chapter 4. Association of heat-related illness morbidity patterns and costs related to heat-related illness hospitalizations

4.1. Introduction

Assessing the impact of climate change on human health and the economy is an enormous task.[1,2] These health impacts will greatly increase economic costs, such as health care expenditures and implementation of adaptive measures, both in preparing for and recovering from hazards related to climate change.[3] Recent studies on the economic cost of climate change have focused on emission rates of greenhouse gases, particularly carbon dioxide, and the impact they will have on global warming. Such studies have been on the estimated cost of reducing our use of fossil fuels and on the implementing carbon taxes but there have been few estimates on the actual economic burden to public health attributed to climate change.[4-6] Previous studies on climate change and health have estimated costs associated for malnutrition, waterborne disease, and malaria[7-9] though little research has been done to estimate the costs of heat morbidity and mortality.

Understanding how heat waves affect morbidity and mortality will be an important factor in how climate change will impact human health in future heat events. Current research has already shown that mortality and morbidity increase during extreme heat events.[10-12] For example, Basu et al. (2012), observed a 393% increase in heat illness hospitalizations, a 3% increase in ischemic stroke hospitalizations and a 15% increase in acute renal failure hospitalizations for every 10F increase in temperature above the mean ambient temperature in a study from California.[13] Studies also predict that there will be an increase in mortality and morbidity from heat-related illnesses from future extreme heat events. Knowlton et al. estimated premature mortality from extreme heat events in the New York City region to increase by 47% to 95% by mid-21st century compared with the 1990's.[14] As heat events increase, deaths and hospitalizations due to heat-related illnesses will continue to incur greater economic costs.

Only a handful of studies have either identified or estimated costs associated with high ambient temperatures and extreme heat events.[15-17] Knowlton et al. identified total health costs associated with a 2006 California heat wave to be $5.4 billion, though a significant portion of the estimated case was due to premature death ($5.1 billion).[16] Interventions such as heat-health warning systems (HHWS) and air conditioner use have proven effective in reducing heat morbidity and mortality though there is a gap in the research providing cost-effective and cost benefit analyses for policymakers to implement strategies for reducing heat mortality and morbidity.[18]

By examining the conceptual framework (Figure 4.1), hospitalization costs are indirectly influenced by society's adaptive capacities. Responses to an extreme heat events and how those responses directly relate to potential outcomes provide information on cost benefit analyses of interventions used to prevent heat-related illness hospitalizations. By exploring these two facets within the vulnerability assessment framework and examining how adaptive capacities and responses impact heat-related illness hospitalization costs, this research will yield additional information to on the economic burden of heat morbidity. The goal of the current study then is to calculate the cost of hospitalizations due to heat-related illnesses in the United States from 2001 to 2010. Although there are a number of different projections and scenarios for the future climate, all estimate an increase in ambient temperatures and extreme heat events. This study will also aim to estimate the future cost of hospitalizations due to heat-related illnesses based on projections from a number of these studies. Additionally this study will briefly look at air conditioning use and cost in 2009 as a potential cost-effective strategy to combat heat morbidity. Because there is a limited amount of information regarding the economic cost of heat-related morbidity and mortality, this study will be important for examining the costs of public health preparedness and responses to climate change and extreme heat events.

4.2. Methods

4.2.1. Data Sources

The primary source of data for this study was the 2001 to 2010 Healthcare Cost and Utilization Project (HCUP) Nationwide Inpatient Sample (NIS), which was developed by the Agency for Healthcare Research and Quality (AHRQ). The NIS is the largest all-payer care database, with data from approximately 8 million hospitalizations per year (about 20% of all hospital discharges in the United States). (HCUP) The NIS includes data on patient demographics and hospital characteristics, primary and secondary diagnoses coded according to the *International Classification of Diseases, Ninth Revision* (ICD-9) (with up to 15 diagnoses available for the years 2001-2008 and up to 25 diagnoses for 2009-2010), primary and secondary procedures (ICD-9 coding up to 15 diagnoses available for the years 2001-2008 and up to 25 diagnoses for 2009-2010), type and source of admission, discharge disposition, primary payer type, total hospital charges, and length of stay. Stratification and weighting variables allow calculation of national estimates and account for the complex sampling design.[19,20]

Data on air conditioner use and cost was derived from the Residential Energy Consumption Survey (RECS), a national household survey conducted by the United States Energy Information Administration (EIA). In 2009 surveys were collected from approximately 12,000 households, which were nationally representative of the 110 million residential U.S. households. The variables from the RECS used in this study include census region, state and average air conditioner cost per household.[21]

4.2.2. Subjects and Definitions

The study population for HRI consists of patients in the 2001-2010 NIS with at least one diagnosis of a heat-related illness (ICD-9 codes 992.0 – 992.9) from 2001 to 2010. The main outcome assessed in this study was total billed charges for hospitalization. Total billed charges were converted to individual hospital all-payer inpatient costs by applying the AHRQ hospital-specific cost-to-charge ratios to total charges within the NIS dataset. Individual patient records were matched by hospital identification numbers and linked to AHRQ hospital-specific cost-to-charge ratios. For hospitals without a listed all-payer inpatient cost-to-charge ratio a group average all payer-inpatient cost was used. Some years, records for hospitals in Texas, Pennsylvania and Hawaii did not include either cost-to-charge ratios. For these hospitals the group average all payer-inpatient cost was substituted with a cost-to-charge ratio from hospitals in the same census region matched on hospital location and bed size.

4.2.3. Statistical Analysis

Descriptive statistics were used to report hospitalization numbers, aggregate costs, mean costs, standard deviations (SD±) and median costs. All analyses were weighted to obtain national estimates and yearly costs were adjusted to 2013 US dollars accounting for inflation, using the medical consumer price index. Estimated costs of hospitalizations due to heat-related illnesses of future events were based on analyses of studies using climatic models predicting an increase in the intensity and frequency of extreme heat events. Studies by Wu, et al., Gao, et al., and Lau, et al. indicate at least a 2-fold increase but possibly as high as a 7-fold increase by mid-to-late century for the number of extreme heat events per year compared to recent years.[22-24] The current analysis includes a 50%, 2-fold, 5-fold and 7-fold increase to the 2010 aggregate costs of heat-related illness hospitalizations which represents estimated costs of hospitalization for predicted events occurring mid-21st century.

All statistical analyses were performed using SAS 9.3. This study was approved by the Institutional Review Board of Hunter College and conforms to the HCUP data use agreement.

4.3. Results

4.3.1. Costs of heat-related illness hospitalizations

Table 4.1. shows the actual aggregated, mean and median costs of hospitalizations due to heat-related illnesses from 2001 to 2010. As the number of cases increase over the time period, the inpatient costs also increase (all costs in US Dollars). A low of $30.1 million is seen in 2004 and a high of $81.5 million in 2010. The average cost for the ten year period is about $52.7 million while the total aggregate cost for the time period is just over half a billion dollars ($542.7 million). Mean and median adjusted costs remain similar over the 10 year period, though both increase in 2010, due to the high number of total cases in that year compared to previous years.

4.3.1. Estimated costs of heat-related illness hospitalizations

Estimated costs for future heat events were based on the 2010 aggregated costs of heat-related illness hospitalizations and are shown in table 4. 2. A 50%, 2-fold, 5-fold and 7-fold increase in the number of heat-related illness hospitalization costs was calculated. These resulted in estimates close to and above half a billion US dollars for a 5-fold ($407.5 million) and 7-fold ($570.5 million) increase based on current costs of hospitalizations for heat-related illnesses annually. Moderate increases were seen in the 50% and 2-fold estimated costs, at $122.3 million and $163 million per year.

4.3.1. Costs of air conditioner use in the United States, 2009

Table 4.3. gives the total and air conditioning energy expenditures for all homes in the United States in 2009 as well as the total average energy cost and average energy cost of air conditioning. Average energy cost for air conditioning in the United States in 2009 was $196 per household. Higher averages were seen in new homes in the South and West, while older homes in the Northeast and Mid-West had below average costs for air conditioning.

4.4. Discussion

According to the results, hospital all-payer inpatient costs due to HRI have risen over the time period 2001-2010. Additionally, estimates show that based on projections from climate scenarios where global temperature continue to rise and heat waves become more frequent and intense, the economic cost from hospitalizations due to heat-related illness will also increase by mid-century. The estimated costs which are based on a number of studies that take into account various climate models and a range of possible scenarios.[22-24] These scenarios include the Special Report on Emission Scenarios (SRES) which is used by the Intergovernmental Panel on Climate Change (IPCC) to describe greenhouse gas emission projections of possible future climate change and the Representative Concentration Pathways (RCPs) which greenhouse gas concentration trajectories used to model possible climate futures.[25] In some cases adaptation and low carbon emission rates account for the lower end estimates while the upper end estimates are largely due to carbon emission rates that will remain similar to today's rates or increase in greenhouse gas emissions, allowing for greater warming of the climate.

Climate models have relied on these projections of greenhouse gas emissions and concentration trajectories to determine rates of global warming and predictions on what temperatures will be in our future climate.[26] Because of this most of the cost analyses concerning global warming and climate change have been on how to mitigate or reduce greenhouse gas emissions.[5,27] Additionally, even if all greenhouse gas emissions were stopped, these gases tend to stay in the atmosphere for long periods of time and concentrations would continue to rise and stay elevated for hundreds of years.[28] Little is known on the economic costs and the costs and benefits of adaptive measures to protect human health from climate change outside of reducing greenhouse gas emissions. Current global knowledge on these economic impacts is generally of low quality and of limited relevance to policy makers concerned with protecting health.[29] Because there is limited quality information available on costs associated with climate change and health, health will need to be an important component in current and future climate change adaptation, especially those related to economic impacts.

The recent United States National Climate Assessment (NCA) included key messages concerning climate change and health; *a*) Climate change threatens human health, and those impacts are already underway in the United States; *b*) climate change will amplify existing nationwide health threats, especially for vulnerable communities; and *c*) preparedness and prevention can protect people from some of these threats, but given that national capacity to adapt to increasing threats may be limited in the future, early, preemptive action has the most impact potential.[30] Despite the risks and recent priorities to include the impact of climate change on health as a focus for research and policy, funding has been insufficient.[31] It has also been stated that the effects of climate change will be felt greatest in populations already at a disadvantage and hence are most vulnerable, including residents of developing countries, elderly, minorities and those of lower socioeconomic status. Climate change has the potential to exacerbate the cycle of poverty and vulnerability if improvements to adaptation methods are not undertaken among these at risk population. Investment in preparedness, awareness and mitigation can help in terms of both inequality and health.[32]

However, studies that assess the effectiveness and cost-effectiveness of interventions to protect health from climate change have also been limited.[33] Heat-health warning systems (HHWS), which are plans that alert and advise populations to mitigate the dangers of heat from high ambient temperatures and heat waves, have been established to some degree though only a small number of studies provide the evaluation needed to prove effectiveness in terms of reaching target populations and reducing adverse health effects.[34] While some studies provide evidence that HHWS are effective[35,36] there has only been one peer-reviewed article to date that has evaluated the cost-effectiveness of such a system.[37] Ebi et al. estimated that the cost of a HHWS in Philadelphia at approximately $210,000 over a 3-year period while the net benefits were around $486 million for 112 lives saved (benefits were calculated using the Environmental Protection Agency's value of a statistical life).[37] Additional cost estimates for HHWS have come from state or municipal reports; one from California indicates that it would cost around $570,000 to develop a statewide warning system and a similar estimate for intervention during excessive heat warnings annually.[38] In comparison, hospitalizations for heat-related illnesses in 2010 cost $3.1 million in California and $4.2 million Pennsylvania, according to the data from this study. Additionally, a report on the potential economic cost to the state of New Mexico from climate change indicated that medical care costs of $7 to $45 million would be needed for 'heat wave-related illnesses'.[39] Heat-health warning systems include meteorological data combined with a variety of intervention strategies. Heat health warning systems may appear costly due to the logistics of setting up the system, though medical care and hospitalization costs as shown in this study are greater than the cost of the HHWSs mentioned above. These efforts are a cost effective way for public health officials and municipalities to reduce heat-related illness morbidity and mortality.

In addition, educating the public on personal health protection measures, such as air conditioner use, will be a necessary part of HHWSs. However, even though the use of air conditioning as a protective measure against heat-related illness has proven to be highly beneficial, the increased energy demand during summer months is both a strain on electrical grids and a contributor to increased greenhouse gas emissions.[40,41] When looking at household level air conditioning it can be a cost effective way of reducing heat-related illness hospitalizations, with householders in the United States spending, on average, $196 per year on electrical costs for cooling their homes. Overall cost of energy consumption for air conditioning by state though is in the hundreds of millions of dollars. Problems with electrical infrastructure and resource use argue against the expanding use of air conditioning on the larger scale now and in the future. Though public health officials will need to make difficult decisions about promoting the use of air conditioning among vulnerable populations in the short-term and sustainability of air conditioning use in the long term using fuel efficient methods with reduced greenhouse gas emissions.

The primary aim of public health is to promptly detect health threats and intervene in a timely manner. Given the multi-disciplinary nature of climate change and the complexity of activities needed to achieve timely interventions, implementation has been difficult. Additionally, funding for research on the health impacts of climate change has been inadequate and remains focused on carbon emissions and the economic impact carbon taxes and caps on carbon emissions will have on society.[33] Climate change and health is a rapidly growing area of research that will benefit from including studies of the economic costs, cost-effectiveness and cost benefits of the public health burden due to climate change. Cost-effectiveness and cost benefits of interventions to protect health from climate change may also improve responses from policy-makers and politicians in directing funds for further research.

In summary, these data show the substantial cost associated with hospitalizations due to heat-related illnesses and projected estimates for the cost of these hospitalizations in the future climate. The estimates are conservative and represent the absolute minimum cost associated with hospitalizations due to heat-related illnesses, because HRIs themselves are largely underreported with underlying medical conditions, such as cardiac and respiratory diseases, taking precedence as the primary diagnosis for hospitalizations during heat events. While known interventions such as air conditioner use may be beneficial in the short term, more information regarding the cost benefits of additional interventions are needed. Heat-health warning systems have been shown to be a cost-effective intervention, though little evaluation has been done both in terms of economic and health benefits. These intervention strategies are needed to substantiate the evidence needed to both show economic effectiveness and secure funding and research focus on climate change and health. By examining the costs associated with hospitalizations of heat-related illnesses we have initiated some of the first steps in identifying economic factors that influence the impact of climate change on health.

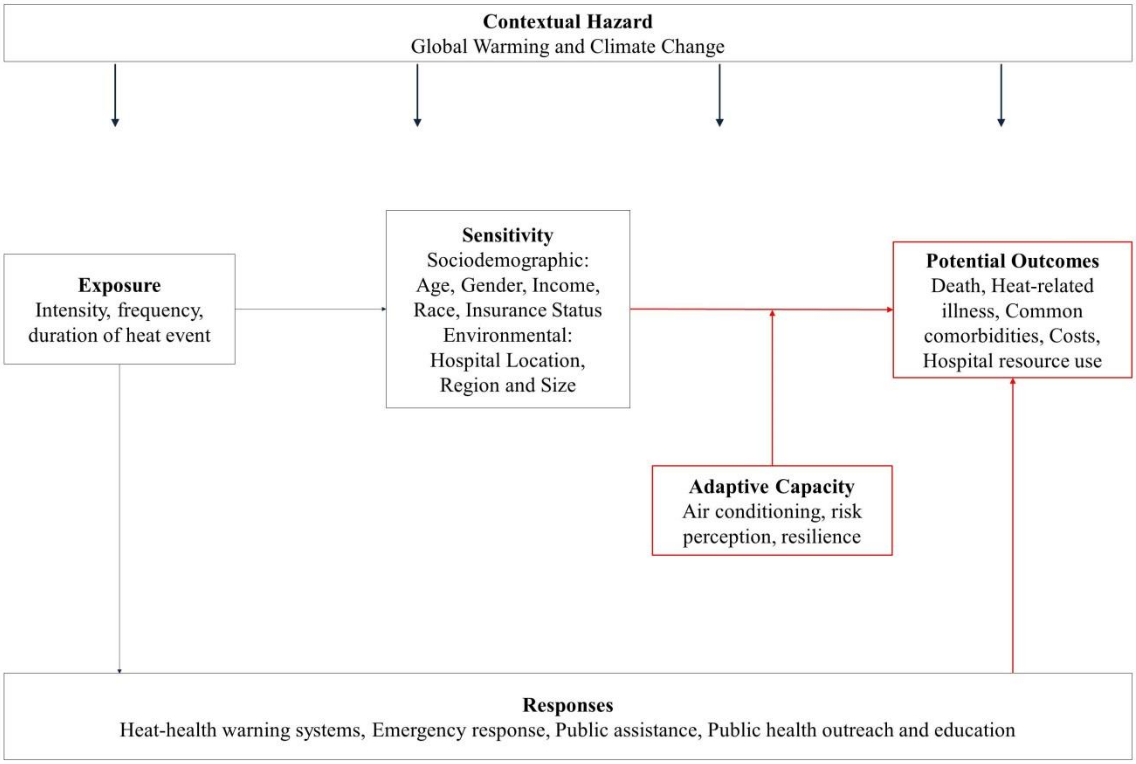


Figure 4.1. Explores costs associated with hospitalizations of heat-related illnesses. As heat-related illness hospitalizations increase with increasing frequency of extreme heat events, costs will continue to rise. Hospitalization costs are compared to the costs of air conditioning and established heat-health warning systems to determine cost-effectiveness of current intervention strategies.

Table 4.1. Hospitalization costs due to heat-related illnesses, United States, 2001-2010 (Summer)

	N (weighted)	**Aggregate Costs (millions)**	**2013***	**Mean (±SD) Costs**	**2013***	**Median Costs**	**2013***
HRI (overall)	72284	$416.2	$542.5	$5,758(±24,790)	$7,505(±32,310)	$3,295	$4,295
2001	6443	$26.6	$41.5	$4,124(±12,768)	$6,427(±19,898)	$2,430	$3,787
2002	6654	$33.1	$49.3	$4,968(±21,327)	$7,395(±31,747)	$2,772	$4,126
2003	5589	$28.9	$41.4	$5,171(±19,921)	$7,399(±28,506)	$2,890	$4,135
2004	4346	$22.3	$30.6	$5,135(±15,358)	$7,040(±21,055)	$3,071	$4,210
2005	8090	$48.9	$64.3	$6,043(±32,592)	$7,950(±42,871)	$3,224	$4,241
2006	9479	$57.6	$72.8	$6,077(±24,348)	$7,654(±30,789)	$3,439	$4,349
2007	7189	$39.2	$47.5	$5,457(±22,889)	$6,609(±27,719)	$3,371	$4,082
2008	6988	$46.8	$54.7	$6,691(±29,343)	$7,813(±34,265)	$3,883	$4,532
2009	6433	$38.4	$43.5	$5,975(±18,987)	$6,763(±21,490)	$3,622	$4,100
2010	11074	$74.5	$81.5	$6,723(±30,929)	$7,358(±33,851)	$7,871	$7,615

*Costs adjusted to 2013 US dollars, accounting for inflation

Table 4.2. Estimated hospitalization costs due to heat-related illnesses

	2010	**50% Estimated Increase***	**2-fold Estimated Increase***	**5-fold Estimated Increase***	**7-fold Estimated Increase***
Aggregate Costs of Heat-related Illness Hospitalizations	$81.5 million	$122.3 million	$163 million	$407.5 million	$570.5 million

*Estimated increases in 2013 US dollars, accounting for inflation

Table 4.3. Total energy and air conditioning costs in households in the United States, 2009

States and State Grouping[#]	Total Energy Expenditures (billion Dollars)		Average Energy Expenditures (dollars per household)	
	Total	**Air Conditioning**	**Total**	**Air Conditioning**
Total U.S.	**229.95**	**22.27**	**2024**	**196**
Connecticut, Maine, New Hampshire, Rhode Island, Vermont	8.95	0.13	2949	43
Massachusetts	6.13	0.1	2478	40
New York	17.58	0.55	2446	77
New Jersey	9.67	0.57	3065	181
Pennsylvania	11.57	0.49	2353	100
Illinois	9.84	0.5	2067	105
Indiana, Ohio	13.64	0.53	1948	76
Michigan	8.21	0.13	2148	35
Wisconsin	4.38	0.06	1926	29
Iowa, Minnesota, North Dakota, South Dakota	7.61	0.21	1947	53
Kansas, Nebraska	3.24	0.23	1786	129
Missouri	4.43	0.35	1892	149
Virginia	6.42	0.7	2162	237
Delaware, Washington DC, Maryland, West Virginia	7.91	0.56	2313	165
Georgia	7.17	1.09	2067	315
North Carolina, South Carolina	10.1	1.26	1878	234
Florida	14.12	3.92	2020	561
Alabama, Kentucky, Mississippi	9.5	1.41	2048	304
Tennessee	4.34	0.51	1774	209
Arkansas, Louisiana, Oklahoma	7.78	1.12	1833	264
Texas	18.42	4.45	2160	521
Colorado	2.96	0.05	1551	25
Idaho, Montana, Utah, Wyoming	3.32	0.11	1650	54
Arizona	4.46	1.28	1959	561
Nevada, New Mexico	3.08	0.46	1802	268
California	17.36	1.34	1422	109
Alaska, Hawaii, Oregon, Washington	7.78	0.15	1646	32

#States and state groupings categorized by US EIA, 2009

Chapter 5. Discussion

5.1. Overview of the dissertation

This cross-sectional study of hospitalizations in the United States due to heat-related illnesses aimed to expand the limited knowledge of the risk factors, outcomes and costs associated with heat morbidity. First, risk factors were identified by comparing all heat-related illness (HRI) hospitalizations over a 10-year time period during the summer months with all other causes of hospitalizations to highlight demographic and environmental characteristics associated with hospitalizations due to HRIs. The study then examined outcomes among common comorbidities (diabetes, cardiac, respiratory and renal diseases) with and without HRI diagnoses to understand how HRIs may increase the risk of death, discharge status, hospital resource use and costs among these exacerbated medical conditions commonly associated with high ambient temperatures and extreme heat events. The study further focused on the direct costs associated with hospitalizations due to HRI and estimated future costs by examining climate models projecting an increase in ambient temperatures as well as an increase in the frequency and intensity of extreme heat events. The three aims of the study fit within the conceptual framework of a vulnerability assessment diagramed in figure 1.1 examining how exposure to heat events, sensitivity of the populations, outcomes and adaptive capacities are related in identifying risk factors and patterns for hospitalizations of heat-related illnesses. The framework exemplifies the connection of how heat events are associated with heat-related illnesses, but this study then examines aspects of the framework, as highlighted in figures 2.1, 3.1 and 4.1, identifying individual and environmental characteristics and examining adaptive capacities that influence the potential outcomes of these hospitalizations. Additionally, by examining the costs associated with hospitalizations the study explored the adaptive capacities and responses that may affect these healthcare costs. In the following section, the main findings and interpretations are summarized.

5.2. Summary of the findings

5.2.1. Chapter 2

Analyses of hospitalizations due to heat-related illnesses in the United States, 2001-2010 highlighted a number of risk factors. It is important to distinguish between heat morbidity and heat mortality since risk factors can be significantly different. This study has found that individuals over 40 years old and males were more likely than females to be hospitalized for a HRI. Prior research in heat mortality had indicated that children and the elderly were most at risk. The current research shows that many age groups are at risk for heat-related illnesses and the perception of who is vulnerable may not be well understood by the general population. As global warming increases average ambient temperatures and extreme heat events become more common, populations that were previously thought to not be at risk for HRI may now be included as vulnerable groups.

Another important finding indicated that people in rural areas and small urban clusters were more likely to be hospitalized for HRIs compared to people in urban areas. The urban heat island effect has shown us that higher ambient temperatures are more likely to occur in urban centers due to heat-retaining properties of building and roads; thus, it is assumed that due to these higher temperatures in urban areas there would be more heat morbidity and mortality. This finding requires additional research as the variables contained in the NIS cannot answer exactly why the risk of hospitalization for HRI is greater in rural and small urban clusters, but highlights the need to understand environmental factors such as geographic location and the built environment which may lead to an increased risk for HRIs. While these results are contrary the above mentioned concept the “urban heat island” differences in occupational exposures and air conditioning availability may reflect these differences though the lack of exposure data complicate the interpretation of these results.

Similar to heat mortality, the current research found that poor populations and those identified as Black, Hispanic, Asian/Pacific Islander and Native Americans were also at an increased risk of hospitalization due to HRIs. This compliments the spatial analysis conducted for air conditioner use, a significant protective factor against HRI, showing that as air conditioner use in the United States grew from 2005-2009, populations at greatest risk, elderly and low-income families had a decrease use of air conditioners. While air conditioner use may not be the best alternative due to its increased energy demand in summer months, it is an option public health officials must consider when trying to protect vulnerable populations from HRIs.

Overall identification of heat-related illnesses is important in understanding who is most at risk and informs our ability to target these populations for protective interventions. In this analysis a decreased risk of diagnosed common comorbidities with heat-related illnesses was contrary to previous research indicating that these common comorbidities are exacerbated during extreme heat events. This is interpreted cautiously as the severity of the underlying condition may have led providers to code these conditions and under-diagnose or under-code HRI. Underreporting of HRI has been noted in past studies as well as the current study and may indicate that greater knowledge is required among health care professionals in recognizing and diagnosing heat-related illnesses especially when common comorbidities are presented.[1,2]

5.2.2. Chapter 3

In addition to the risk factors for hospitalization of HRI, outcomes for these hospitalizations can also help us to better understand vulnerable populations to extreme heat events. As noted in Chapter 3, hospitalizations for heat-related illnesses also include common comorbidities such as diabetes, cardiac, renal and respiratory diseases. These underlying medical conditions may be exacerbated due to heat events and subsequent heat-illnesses triggering a hospitalization.

The current research did not see any increased negative health outcomes (death or non-routine discharge) or increased hospital resource use (length of stay, number of procedures or total charges) among those hospitalized with a heat-related illness and those hospitalized with diabetes, cardiac or renal disease and a concurrent HRI diagnosis. Although those hospitalized with respiratory diseases and a HRI diagnosis did show increased number of procedures as well as increased risk of death and non-routine discharges compared to populations hospitalized with only a respiratory disease.

While multivariable adjusted regressions did not show increased risk of negative health outcomes or increased hospital resource use among those hospitalized for heat-related illness or diabetes, cardiac and renal diseases with a HRI, stratified analysis of sociodemographic and environmental characteristics showed an increase in negative outcomes among certain populations. By changing the population denominator, for example, examining males diagnosed with a respiratory disease compared that to males diagnosed with a respiratory disease and heat-related illness, the analysis was able to isolate the population of males with a diagnosis of respiratory disease in examining how the effect of a diagnosed heat-related illness impacted outcomes among that population. For heat-related illnesses alone, increase risk of death was seen among 18-64 year olds, the uninsured and those hospitalized in the Western United States.

Diagnoses of diabetes with a HRI showed increased number of procedures among infants and children as well as an increased risk of non-routine discharges identifying as Asian/Pacific Islander, Native American or Other.

Discharges with a co-diagnosis of a cardiac disease and a heat-related illness showed increased risk of death among many different groups. These include males, persons 18-74 years old, Blacks, Hispanics, hospitalizations in the lowest zip-code income quartile and those who were uninsured. Additionally, those hospitalizations in urban areas and those in the West were also at an increased risk of death from cardiac disease and a HRI diagnosis as compared to those with just a diagnosis of cardiac disease. Limited negative outcomes were seen in those diagnosed with renal diseases and a heat-related illness though increased risk of death was seen among females, infants and children (0-17 years old).

Similar to the multi-variable analysis of respiratory diseases with a HRI diagnosis, the stratified analyses showed a number of increased negative outcomes. Almost all sociodemographic and environmental characteristics showed increased risk of death and non-routine discharges, with infants and children (0-17 years old) having the highest risk (6.5 increased risk of death and 3.3 increased risk of non-routine discharge). Blacks and those aged 18-39 years old showed an increase in negative outcomes for each category analyzed while the uninsured showed significant results for increased negative outcomes in all but two categories (length of stay and total charges). These results give a clear indication that respiratory diseases with a heat-related illness diagnosis play a significant role in the outcomes for hospitalized individuals. Heat-related illnesses may exacerbate other common comorbidities and can significantly impair health outcomes. The study results from Chapter 3 highlight increased negative outcomes for heat-related illness in addition to the risk factors described in Chapter 2; combined these indicators can help researchers better understand the HRI vulnerabilities among specific high risk populations.

5.2.3. Chapter 4

During the study period, 2001 to 2010, hospitalizations of heat-related illnesses increased at a higher rate than all other hospitalizations. Although comparatively costs for heat-related illness hospitalizations were lower than all hospitalizations during this time period, the average inflation-adjusted hospital stay cost in the United States has remained stable over the years, while costs for heat-related illnesses have increased as much as 18% in years corresponding with increased number of heat events.[3]

From 2001 to 2010 the average inflation-adjusted cost for a heat-related illness was $7,505 (all costs represent inflation-adjusted 2013 US Dollars) and total aggregate costs for all hospitalizations were $542.5 million. Aggregate costs of heat-related illness hospitalizations went from $41.5 million in 2001 to $81.5 million in 2010.

Studies using climatic models predict that there will be an increase in frequency and intensity of heat events corresponding to a 2-fold to 7-fold increase by mid-century, the estimates vary due to the modeling of low emission and high emission scenarios.[4,5] The predicted increases in extreme heat events were then used to estimate the potential for costs associated with heat-related illness hospitalizations by mid-century. A 7-fold increase in costs of hospitalizations for heat-related illness (based on 2013 inflation-adjusted costs from 2010 HRI hospitalizations) would be approximately $570.5 million per year. These estimates indicate that over half a billion dollars per year would be needed to cover costs of heat-related illness hospitalizations by the mid-21st century. The estimates are conservative and represent the absolute minimum cost associated with hospitalizations of heat-related illnesses, due to the conclusions that HRIs themselves are largely underreported as indicated in Chapter 2.

Protective measures such as heat-health warning systems (HHWS) and air conditioning use were examined as cost-effective strategies in reducing heat-related illness hospitalizations. Studies show that HHWSs would cost considerably less to implement and run compared to the cost of individuals hospitalized for HRIs. While there is still some debate about the functionality of these systems, heat health warning systems may be a cost-effective measure to prevent heat-related illness.[6,7]

Additionally, air conditioning use in either residential homes or public cooling centers provides significant protection against HRIs.[8] Analysis of data from the Residential Energy Consumption Survey (2009) estimated that householders in the United States spent $196 annually to cool their homes. This cost is also significantly less than the average cost of a hospitalization due to HRI. While air conditioning may be a protective factor, the demand on energy infrastructure and emissions related to energy use for cooling may be contrary to the concepts of global warming and climate change. Alternative methods to reduce costs for HRI hospitalizations will need to be explored if we continue to see that climatic models and estimated costs increase significantly in the future.

5.3. Limitations

This study has several limitations other than the constraints of a cross-sectional analysis. First, the Nationwide Inpatient Sample (NIS) is an administrative database which limits analyses based on available variables in addition to not being as accurate as clinical data. Additionally ICD-9 codes are prone to coding error and reporting of some variables varies state by state, depending on the reporting requirements for that state.[9] The data in the NIS is based on coding by healthcare providers and confers the prevalence of heat-related illnesses based on their diagnostics criteria; research was not the intended use for this data. Because coding is to facilitate reimbursement and not for epidemiological studies this may introduce selection bias into coding within the heat-related illness spectrum towards that of the more severe cases such as heat stroke. Also, only variables that were included in the NIS dataset were used to control for confounding thus not accounting for variables such as air pollution, which may have an effect on hospitalizations of heat-related illnesses. Second, due to the nature of how data is collected by the NIS, date and time of hospitalization cannot be determined and thus, cannot be linked to a specific heat event. Because of this cases of heat-related illness hospitalizations include both classic non-exertional HRIs and exertional HRIs. This bias, however, may be counterbalanced by controlling for age as most exertional heat-illnesses are seen in healthy and young individuals active primarily outdoors during the summer months. Third, research involving administrative databases may be underreporting chronic comorbidities.[10] Underreporting of heat-related illnesses is also occurring due to underlying medical conditions such as cardiac and respiratory diseases being exacerbated during heat events which in turn may be diagnosed as the primary cause of hospitalization even if exposure to heat was the initial cause. Additionally, due to underreporting of heat-related illnesses, estimations of costs and future costs are conservative and represent the absolute minimum costs associated with hospitalizations of heat-related illnesses. Fourth, data from the Residential Energy Consumption Survey were not linked to the NIS data due to the different levels of measurement (individual discharge record versus household) thus spatial analysis of air conditioning data can only be made at the ecological level, limiting generalizability due to the ecological fallacy.

5.4. Strengths and public health significance

There are a number of strengths in this study. First, by studying heat morbidity, this research adds significantly to the limited knowledge on heat-related illnesses and outcomes that do not relate specifically to heat mortality. By understanding that there are differences in risk factors and outcomes between heat morbidity and heat mortality public health officials can tailor interventions to a broad range of vulnerable populations. Second, using the NIS as a nationally representative sample of hospitalizations for heat-related illnesses and applying sample weights allows for the identification of risk factors and outcomes that are generalizable to a much larger population than the sample size. This contributes to the expanding descriptive data and general understanding of heat-related morbidity in a public health context. In particular, the use of hierarchical modeling in identifying risk factors through hospitalizations accounts for the interacting effects of patient and hospital characteristics. This information will improve the overall knowledge of public health researchers using vulnerability assessments in understanding both individual and environmental characteristics that influence risk factors for heat-related illnesses. Third, while regression analysis on all hospitalizations did not show increased negative outcomes, stratified analyses showed increased negative outcomes among specific groups hospitalized with a HRI and common comorbidity. Methodologically, the use of stratified analyses on outcomes of hospitalizations with a diagnosed HRI and common comorbidity provide a more in-depth view of vulnerable populations to HRIs. Since most pathways from climate change to health are complex, this research highlights potential exposure-response associations in the causal paths which can inform future epidemiological models and studies to further analyze risk factors and outcomes associated with HRIs.[11] Lastly, analyzing costs of hospitalizations from HRIs and estimated future costs provide information on the economic outcomes climate change is has on health. Prior analyses have been limited to economic costs associated with emission though as climate change continues to impact health, costs associated with the disease burden will help garner funding for research to understand the links between climate change and adverse health effects as well as improve adaptation and resiliency strategies to protect vulnerable populations. The negative health effects associated with heat events can be reduced by adequately planned and funded public health responses, this research will assist in improving the cost-effective and cost benefit analyses needed by policymakers and stakeholders to sufficiently allocate resources.[12]

5.5. Policy recommendations and future research directions

This study provides important evidence on risk factors and outcomes associated with hospitalizations due to heat-related illnesses. In general, individuals hospitalized for heat-related illnesses had risk factors that include minorities and persons of lower socioeconomic status, males, most age groups, rural and small urban populations and diagnoses of common comorbidities such as diabetes, cardiac, renal and respiratory diseases. Outcomes of hospitalizations also indicated that as heat events increase the number and cost of hospitalizations will also increase. These study findings justify allocating more resources to target populations at risk for hospitalization due to heat-related illnesses. To achieve this, it will be important to clearly define heat waves, warnings and watches. Currently the National Weather Service (NWS) provides national general heat alert criteria and encourages local NWS Forecast Offices to develop local criteria in cooperation with local emergency and health officials, and/or utilize detailed heat/health warning systems based on scientific research (JG Ferrell – NWS, personal communication, March 20, 2013). This allows for a wide variety of definitions by local areas which may not be consistent with current scientific research. Implementing more structured protocols for identifying a heat event allows national and local weather services to potentially alert vulnerable populations more rapidly and allows researchers to compare regions of similar climates to further understand heat morbidity and heat mortality patterns.

Along with definitions of heat waves and warnings, definitions of heat morbidity and heat mortality have been imprecise and underdiagnosed.[13] The most recent example of improvements to heat mortality definitions came after the 1995 heat wave in Chicago after many deceased were found at home.[14] As noted in this study, common comorbidities may take precedence over the diagnosis of heat-related illnesses, especially in cases of cardiac or respiratory distress. Educating healthcare professionals and improving the diagnostic procedures for identifying a heat-related illness will improve reporting and further our understanding of heat morbidity. Educating the public will also be an important step in reducing the number of hospitalizations of heat-related illnesses. While many individuals understand broad concepts concerning climate change, consequences of climate change in the general population are less well established.[15] Promoting policies of education and information when experiences of heat waves and heat-related illnesses are more prevalent, right before summer and during the summer months may garner increased understanding of the impact of climate change on public health, particularly heat wave awareness and improved health outcomes and reduced hospitalizations of heat-related illnesses. The findings in this study indicate a large burden of heat-related illness on working-age populations may be related to occupational exposures. While the Occupational Safety and Health Administration (OSHA) does not have a regulation specifically for heat stress, they have guidelines that address issues of environmental and occupational exposure to high heat for the workplace. Preventative measures should continue to target at risk workers.

These interventions and adaptations can be leveraged by already existing public health programs.[16] People with chronic medical conditions who regularly receive care can receive additional information about their risk for HRIs during doctor or hospital visits. Also programs that target lower socioeconomic populations can also be used to disseminate information about the risks associated with heat-related illnesses and protective factors such as using air conditioning or visiting a public cooling center. Financial constraints can limit the development and implementation of preventative measures for improving health outcomes associated with extreme heat events. Providing adequate funding in addition to designating project leaders and long term goals to improve heat health awareness will be needed at multiple levels of government and buy-in from stakeholders in the community. Establishing these systems can help plan for and maintain adequate heat-health prevention programs.

As highlighted in this study, the analysis of large administrative data can be useful in further identifying potential risk factors and vulnerabilities for heat-related illnesses. The use of epidemiological methods and data collection from a variety of sources can link known vulnerabilities and protective factors to individual health outcomes to obtain a better understanding of populations most effected by climate change.[11] The lack of high quality long-term data sets reduces our ability to respond effectively to public health emergencies. Improved data collection and analyses in this way will help researchers and public health officials collect relevant and useful information to target interventions towards these vulnerable populations and improve the adaptive capacity and response to extreme heat events.

In conclusion, the study revealed a number of risk factors and negative health outcomes associated with hospitalizations of heat-related illnesses. This study also highlights some of the economic costs of climate change and provides information on the cost-effectiveness and cost-benefit to implementing adaptive measures to prevent hospitalizations of HRIs. These findings provide additional scientific evidence that heat-related illnesses will continue to rise and will continue to be a public health burden as climate changes increase in frequency and intensity of extreme weather events. Along with educational interventions, efforts to understand patterns of hospitalizations of heat-related illnesses will be important to reduce the risk of adverse health conditions and negative health outcomes. This study calls for further research efforts that should focus on improving syndromic surveillance during heat events, clarifying appropriate heat health warning messages and providing stronger theoretical frameworks for projecting heat-related morbidity and mortality.

Appendix I. Demographic Characteristics: Heat-Related Illness (HRI), Diabetes, Cardiac disease Patients, with and w/o HRI diagnosis, 2001-2010 (Summer)

	HRI Hospitalization	Diabetes Hospitalization	HRI + Diabetes Hospitalization	Cardiac Disease Hospitalization	HRI + Cardiac Disease Hospitalization
N	14949	1271472	384	7375754	1819
Age, Mean (SD)	55 (21.8)	57(18.3)	58(18.2)	69(15.3)	69(16.7)
Age Categories					
0-17	4.45%	2.57%	1.56%	0.55%	0.78%
18-39	20.54%	14.15%	16.67%	3.18%	4.71%
40-64	38.17%	45.15%	45.05%	30.15%	31.12%
65-74	13.41%	19.91%	15.53%	23.2%	19.74%
75+	23.43%	19.22%	21.1%	42.92%	43.66%
Gender					
Male	72.99%	47.18%	71.35%	50.78%	68.15%
Female	26.91%	52.82%	25.65%	49.22%	31.85%
Missing	0.19%	0	0	0	0
Race/Ethnicity					
White	54.93%	45.98%	46.99%	59.92%	60.46%
Black	13.92%	17.54%	17.31%	9.6%	11.19%
Hispanic	9.35%	11.75%	11.99%	5.81%	6.32%
Other	3.77%	4.46%	3.09%	3.4%	2.69%
Missing	18.02%	20.27%	20.62%	21.27%	19.34%
Median Income Quartile*					
0-25th percentile	29.92%	27.19%	32.98%	22.19%	27.51%
26th to 50th percentile	21.44%	20.92%	20.62%	21.01%	20.14%
51st to 75th percentile	15.59%	16.82%	13.16%	18.27%	15.34%
76th to 100th percentile	11.42%	12.22%	8.31%	15.36%	13%
Missing	21.63%	22.84%	24.93%	23.17%	24.01%
Payer – Primary, %					
Medicare	39.6%	46.03%	42.94%	66.14%	64.07%

Medicaid	9.14%	14.88%	7.83%	6.06%	5.2%
Private/HMO	27.79%	27.62%	31.38%	22.07%	20.99%
Self/Other	23.14%	11.30%	17.79%	5.61%	9.41%
Missing	0.33%	0.17%	0	0.12%	0.34%
Insured	76.52%	88.53%	82.21%	94.27%	90.25%
Uninsured	15.05%	7.94%	11.35%	3.54%	5.63%
Missing	8.43%	3.53%	6.45%	2.19%	4.12%
Admin Source					
ED	58.89%	48.68%	61.48%	46.54%	60.71%
Other Hosp/Facility	1.86%	3.05%	0.96%	5.92%	2.19%
Court/Law	0.05%	0.07%	0.80%	0.03%	0
Routine/Other	11.51%	27.34%	12.04%	26.65%	12.08%
Missing	27.7%	20.87%	24.72%	20.85%	25.02%
Admin Type					
Emergency	72.76%	55.27%	68.99%	54.32%	71.76%
Department					
Urgent	14.13%	16.33%	15.88%	18.19%	14.24%
Elective	5.23%	18.1%	5.91%	19.41%	5.54%
Trauma/Other	0.15%	0.13%	0	0.15%	0.17%
Missing	7.74%	10.17%	9.22%	7.93%	8.25%

*zip code of patient

Appendix II. Demographic Characteristics: Renal and Respiratory disease patients, with and w/o HRI diagnosis, 2001-2010 (Summer)

	Renal Disease Hospitalization	HRI + Renal Disease Hospitalization	Respiratory Disease Hospitalization	HRI + Respiratory Disease Hospitalization
N	1177189	2485	4776386	1430
Age, Mean (SD)	67(17.6)	48(18.9)	60(24.2)	60(20.3)
Age Categories				
0-17	1.10%	1.70%	8.97%	3.28%
18-39	6.53%	35.13%	7.85%	11.82%
40-64	31.39%	43.64%	29.30%	39.19%
65-74	20.96%	8.20%	19.69%	17.74%
75+	40.02%	11.32%	34.19%	27.97%
Gender				
Male	51.94%	89.7%	47.1%	68.43%
Female	48.06%	10.3%	52.9%	31.57%
Missing	0	0	0	0
Race/Ethnicity				
White	52.3%	51.13%	57.42%	59.71%
Black	18.04%	18.99%	10.77%	12.25%
Hispanic	7.68%	13.38%	7.29%	7.13%
Other	4.01%	3.69%	3.55%	4.21%
Missing	17.96%	12.81%	20.97%	16.70%
Median Income Quartile*				
0-25th percentile	29.03%	34.08%	25.62%	31.49%
26th to 50th percentile	24.45%	25.54%	21.91%	21.61%
51st to 75th percentile	20.87%	17.90%	17.97%	15.12%
76th to 100th percentile	16.43%	12.33%	13.67%	10.97%
Missing	9.22%	10.15%	20.83%	20.82%
Payer – Primary, %				

Medicare	68.78%	23.15%	57.30%	51.35%
Medicaid	8.68%	8.17%	13.70%	11.82%
Private/HMO	16.64%	30.25%	21.84%	18.68%
Self/Other	5.76%	37.91%	7.01%	17.90%
Missing	0.13%	0.52%	0.14%	0.24%
Insured	94.10%	61.57%	92.84%	81.85%
Uninsured	3.68%	26.79%	4.51%	10.33%
Missing	2.22%	11.64%	2.65%	7.83%
Admin Source				
ED	34.69%	39.52%	49.91%	59.18%
Other Hosp/Facility	3.32%	1.42%	4.00%	1.98%
Court/Law	0.03%	0	0.04%	0
Routine/Other	14.88%	6.62%	22.29%	11.44%
Missing	47.08%	52.44%	23.76%	27.40%
Admin Type				
Emergency	65.33%	81.36%	60.29%	72.01%
Department				
Urgent	16.70%	11.86%	17.55%	12.66%
Elective	11.60%	3.47%	14.44%	5.72%
Trauma/Other	0.18%	0	0.29%	0.30%
Missing	6.20%	3.31%	7.43%	9.31%

*zip code of patient

Appendix III. Hospital Characteristics: Heat-Related Illness (HRI), Diabetes, Cardiac disease Patients, with and w/o HRI diagnosis, 2001-2010 (Summer)

	HRI Hospitalization	Diabetes Hospitalization	HRI + Diabetes Hospitalization	Cardiac Disease Hospitalization	HRI + Cardiac Disease Hospitalization
N	14949	1271472	384	7375754	1819
Hospital Region					
Northeast	11.61%	17.78%	10.44%	17.65%	12.43%
Mid-West	18.75%	18.97%	22.51%	20.52%	22.62%
South	54.43%	47.35%	53.38%	47.88%	49.80%
West	15.22%	15.90%	13.38%	13.96%	15.14%
Hospital Bed size					
Small	17.15%	12.69%	17.45%	11.07%	16.00%
Medium	26.59%	25.30%	30.21%	23.11%	26.94%
Large	55.77%	61.71%	52.08%	65.54%	56.73%
Missing	0.48%	0.30%	0.26%	0.29%	0.33%
Hospital Location					
Rural	3.81%	2.40%	3.13%	2.37%	3.90%
Small Urban	10.76%	6.91%	13.02%	6.44%	10.67%
Cluster					
Urban Area	48.72%	62.86%	43.75%	64.93%	50.47%
Missing	37.01%	27.83%	40.10%	26.26%	34.96%

Appendix IV. Hospital Characteristics: Heat-Related Illness (HRI), Renal, and Respiratory disease Patients, with and w/o HRI diagnosis, 2001-2010 (Summer)

	Renal Disease Hospitalization	HRI + Renal Disease Hospitalization	Respiratory Disease Hospitalization	HRI + Respiratory Disease Hospitalization
N	1177189	2485	4776386	1430
Hospital Region				
Northeast	17.71%	7.58%	16.88%	13.71%
Mid-West	20.23%	14.52%	19.93%	18.29%
South	48.72%	65.15%	49.60%	48.58%
West	13.35%	12.75%	13.59%	19.43%
Hospital Bed size				
Small	10.53%	14.25%	13.65%	16.71%
Medium	22.42%	25.67%	25.00%	25.80%
Large	66.40%	59.15%	61.04%	56.78%
Missing	0.65%	0.93%	0.31%	0.70%
Hospital Location				
Rural	1.91%	1.89%	2.96%	3.29%
Small Urban	5.06%	7.08%	8.22%	10.56%
Cluster				
Urban Area	64.69%	48.29%	62.06%	53.85%
Missing	28.34%	42.74%	26.75%	32.31%

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