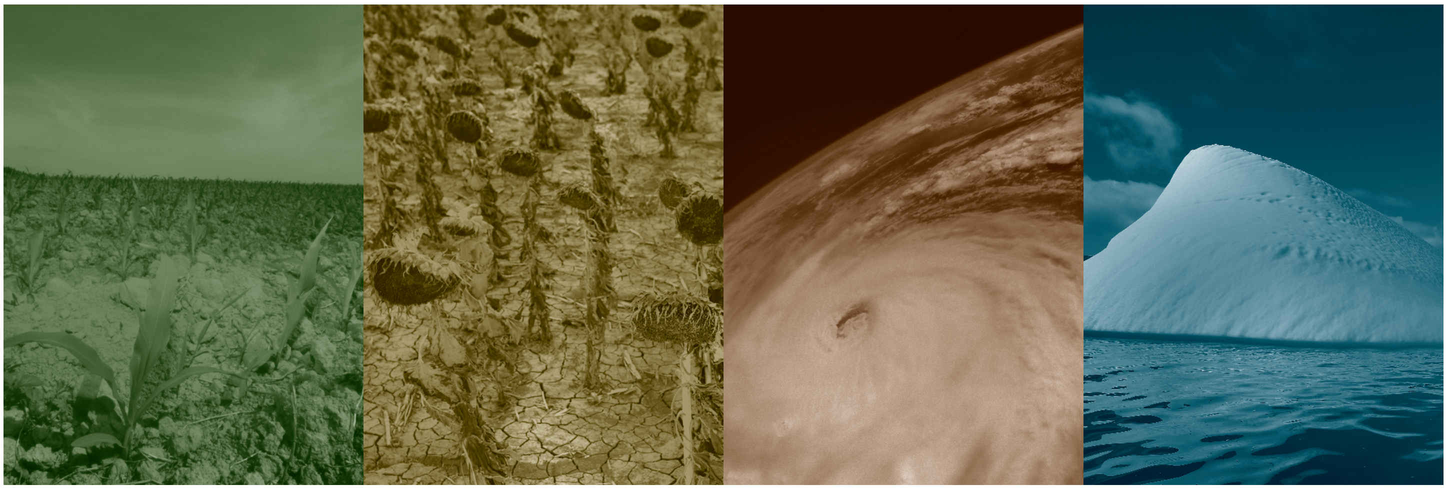
Assessing Health Vulnerability to Climate Change

A Guide for Health Departments



Climate and Health Technical Report Series

Climate and Health Program, Centers for Disease Control and Prevention

Arie Ponce Manangan[1], Christopher K. Uejio[2], Shubhayu Saha1, Paul J. Schramm[1], Gino D. Marinucci[1], Claudia Langford Brown[1], Jeremy J. Hess[1,3,4], George Luber[1]

[1]Climate and Health Program, Division of Environmental Hazards and Health Effects (DEHHE), National Center for Environmental Health (NCEH), Centers for Disease Control and Prevention (CDC) Atlanta, GA, USA

[2]Department of Geography, Florida State University, Tallahassee, FL, USA

[3]Department of Emergency Medicine, School of Medicine, Emory University, Atlanta, GA, USA

[4]Department of Environmental Health, Rollins School of Public Health, Emory University, Atlanta, GA, USA.

National Center for Environmental Health
Division of Environmental Hazards and Health Effects

CS249409-A

Executive Summary:

The changing climate is linked to increases in a wide range of non-communicable and infectious diseases[1]. There are complex ways in which climatic factors (like temperature, humidity, precipitation, extreme weather events, and sea-level rise) can directly or indirectly affect the prevalence of disease. Identification of communities and places vulnerable to these changes can help health departments assess and prevent associated adverse health impacts.

The Climate and Health Program at the Centers for Disease Control and Prevention (CDC) has developed the Building Resilience Against Climate Effects (BRACE) framework to help health departments prepare for and respond to climate change[2]. The BRACE framework is a five-step process that helps health departments to understand how climate has and will affect human health, and enables health departments to employ a systematic, evidence-based process to customize their response to local circumstances. The first step of the BRACE framework focuses on anticipating climate impacts and assessing associated health vulnerabilities. This document provides a suggested sequence of steps that health departments can undertake to assess such health vulnerabilities associated with climate change:

1) Determine the scope of the climate vulnerability assessment
    a. Identify the area of interest and the projected change in climate exposures at the smallest possible spatial scale.
    b. Identify the health outcome(s) associated with these climate exposures.
2) For these health outcomes, identify the known risk factors (e.g., socioeconomic factors, environmental factors, infrastructure, pre-existing health conditions).
3) Acquire information on health outcomes and associated risk factors at the smallest possible administrative unit (e.g., census block group, census tract, county) in accordance with data privacy regulations and availability.
4) Assess adaptive capacity in terms of the system's (e.g., communities, institutions, public services) ability to reduce hazardous exposure and cope with the health consequences resulting from the exposure.

5) Combine this information in a Geographic Information System (GIS) to identify communities and places that are vulnerable to disease or injury linked to the climate-related exposure.

The value of a vulnerability assessment is that it allows health departments to understand the people and places in their jurisdiction that are more susceptible to adverse health impacts associated with the climate-related exposures modified by climate change. This assessment of people and place vulnerability can then be used to implement more targeted public health action to reduce harm to people.

****

Introduction

This document provides guidance for health departments on how to assess local vulnerabilities to health hazards associated with climate change. A climate and health vulnerability assessment allows health departments to understand the people and places in their jurisdiction that are more susceptible to adverse health impacts associated with climate change. This assessment of people and place vulnerability can then be used to implement targeted public health interventions to reduce the burden of public health impacts.

This document provides a conceptual framework on how to define vulnerability to climate change, using terms and definitions found in the health and climate change scientific literature. Specifically, we define the term exposure as referring to climate-related exposures such as extreme heat or precipitation. We also provide an example of how to conduct a climate and health vulnerability assessment using a case study on heat vulnerability in Georgia. Although there are myriad climate factors that impact health (e.g., storm surge, increased atmospheric CO_2, extreme precipitation events, drought, etc.), heat vulnerability was selected as a case study because it was identified as the most important climate-sensitive health outcome of concern in a survey of the eighteen grantees of the CDC's Climate-Ready States and Cities Initiative. In addition, there is a wealth of research and available data on the topic of heat vulnerability.

Health vulnerability from climate change

The combination of projected changes in climate-related exposures (e.g., temperature, precipitation, sea-level rise) reported in the National Climate Assessment (NCA)[3] will result in amplification of existing health risks and introduction of new risks with a high degree of spatial variability. The Climate and Health Program at the Centers for Disease Control and Prevention (CDC) has developed the Building Resilience against Climate Effects (BRACE) framework to help health departments prepare and respond to these change (Figure 1). The BRACE framework incorporates an assessment of climate change impacts, a vulnerability assessment, the modeling of projected health impacts, an evidence-based evaluation of intervention options, a strategy for implementing interventions, and systematic evaluation of all activities in an iterative framework.

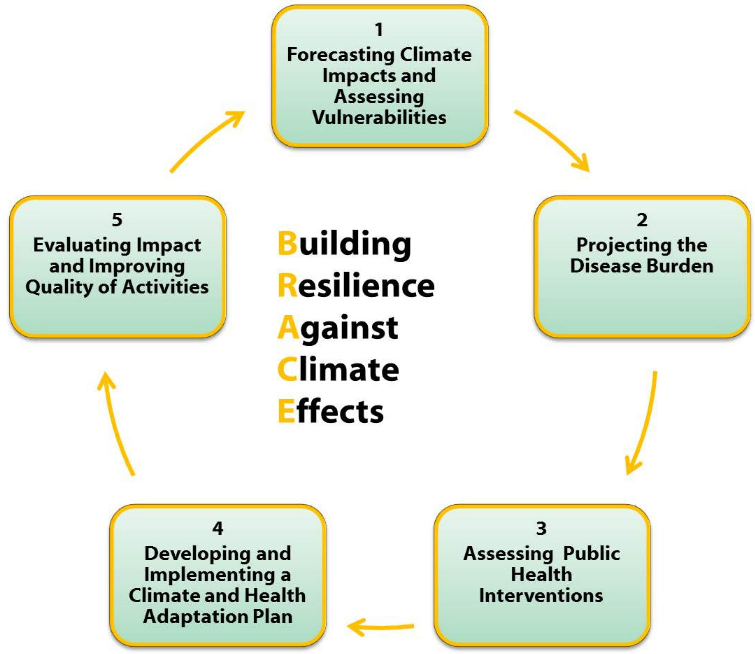


Figure 1. Building Resilience Against Climate Effects (BRACE) framework

The vulnerability assessment is critical in various stages as an agency works through the BRACE framework – (i) in step one, it guides health agencies to assess specific communities and places that are vulnerable to projected climate impacts; (ii) in step three provides knowledge on which specific public health interventions to implement in order to reduce the health burden; and (iii) in step four provides community characteristics (e.g., socioeconomic, environmental, infrastructural) in the development and implementation of a climate and health adaptation plan.

What is a climate and health vulnerability assessment?

A useful definition of 'vulnerability' in the public health context is the "the degree to which a system is susceptible to injury, damage, or harm"[4]. This broad definition emphasizes the importance of well-functioning institutions and the accessibility to quality healthcare that safeguards individual and population health[5,6]. Although there are multiple interpretations of the terms vulnerability, risk, and sensitivity in the global change literature[7,8], for this report we define vulnerability as being a function of exposure, sensitivity, and adaptive capacity[9-11]. This definition of vulnerability is consistent with the Third National Climate Assessment (2014): "Vulnerability is a function of the character, magnitude, and rate of climate variations to which a system is exposed, its sensitivity, and its adaptive capacity"[12]. The following diagram (Figure 2) illustrates the key connections between exposure, sensitivity, and adaptive capacity that collectively determine vulnerability to the health system resulting from climate change.

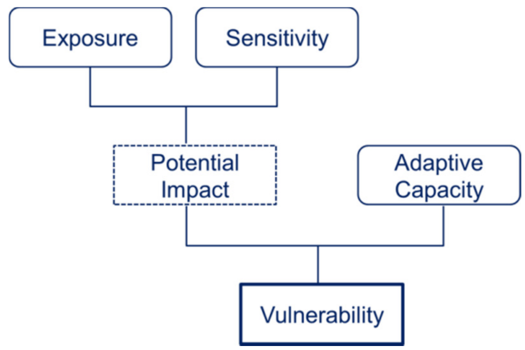


Figure 2. Vulnerability determined by exposure, sensitivity, and adaptive capacity (Source: Australian Greenhouse Office, 2005)

A climate vulnerability assessment identifies where health susceptibilities exist due to climate change, which will continue to alter the magnitude, frequency, duration, and geographic extent of various climate-related exposures that are detrimental to human health[3]. Sensitivity encompasses (1) the ability of a community to withstand these exposures and the range of associated impacts; and (2) physiological (e.g., co-morbidities or disabilities) and socio-economic (e.g., poverty) factors that increases the susceptibility of individuals to the exposure. The concept of sensitivity also includes access to functioning infrastructure that can influence how people withstand an exposure (e.g., availability of electricity during an extreme heat event). The potential public health impact, jointly produced by exposure and sensitivity, can be offset by adaptive capacity. Adaptive capacity refers to behavioral, institutional, and technological responses and adjustments to lessen the potential impact. Typically, such adaptations limit damages, provide recovery opportunities, and enhance coping with consequences[13].

Methodology for a climate and health vulnerability assessment

Conducting a climate and health vulnerability assessments involves five key steps: 1) determine the scope of the assessment, 2) identify known risk factors for potential health outcomes, 3) acquire spatial information on risk factors, 4) assess adaptive capacity, and 5) conduct an assessment of vulnerability.

1. Determine scope of assessment

In the first step, the scope of the assessment involves determining the climate-related exposure of concern, the geographic area to study, the time frame to consider future changes in exposure, and the potential health outcome(s) expected.

A. **Identify climate-related exposures**
   Climate-related exposures attributed to climate change would vary geographically and the rate of change would differ over time. For example, simulated difference for annual and seasonal mean temperature as reported in the National Climate Assessment[14] show variation across the continental US (Figure 3). Therefore, a health department needs to define the geographic and temporal scope of the vulnerability assessment. To prevent or adapt to detrimental health effects of climate change, the assessment could at least focus on near-term future projections (mid-century) or earlier. Climate scientists consider projections made less than 20 years into the future to be decadal climate predictions, which forecast multi-year climate variability. Conversely, long-term climate projections provide plausible estimates of mid-century or later changes. Health departments may choose a period that balances near-term public health planning, with long-term projections when climate change impacts become even larger. Due to the complexities of climate models, health departments may seek collaborations with climate scientists in their region in order to effectively interpret the data and assure that it coincides with the geographic and temporal scope of their vulnerability assessment.

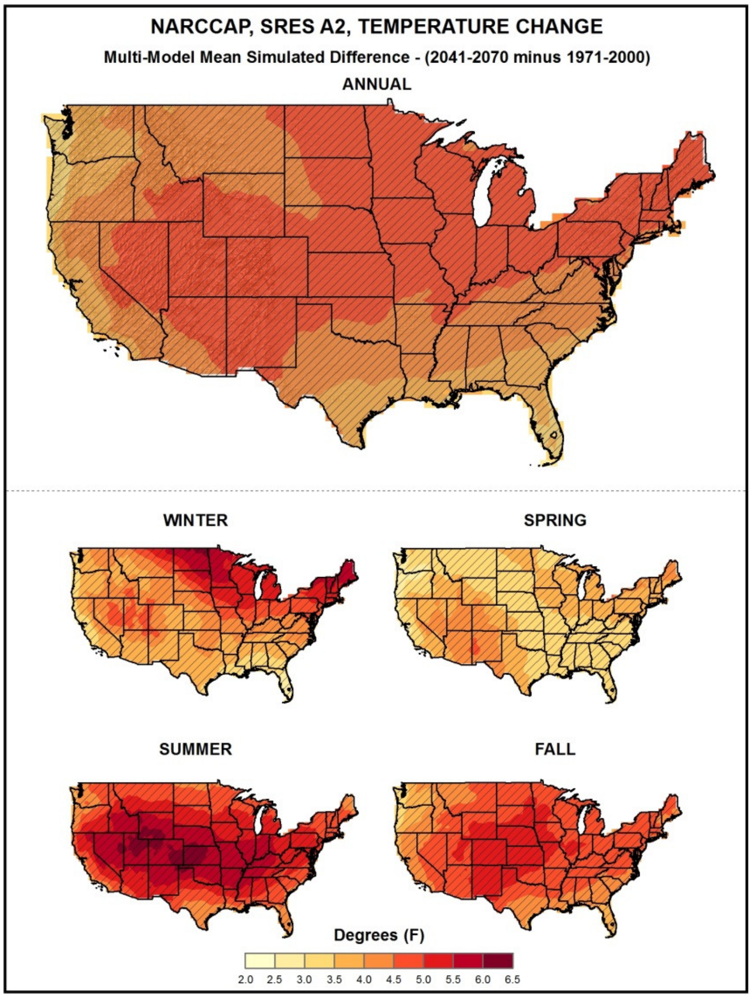


Figure 3. Simulated difference in annual and seasonal mean temperature (°F) for the contiguous United States, for 2041-2070 with respect to the reference period of 1971-2000. These are multi-model means from 11 North American Regional Climate Change Assessment Program (NARCCAP) regional climate simulations for the high (A2) emissions scenario. The A2 emission scenario is characterized by rapid population growth and increased agricultural productivity, resulting in continuous rapid growth in emissions. Color with hatching (category 3) indicates that more than 50% of the models show a statistically significant change in temperature, and more than 67% agree on the sign of the Seasonal changes are greatest for summer and smallest for spring. (Source: National Climate Assessment, 2014)

B. Identify climate-sensitive health outcomes

The pathways through which climate-related exposures affect human health are complex (see Figure 4). For some pathways, changes in hazardous exposures have direct health impacts (e.g., cardiovascular complications during heat waves or road fatalities during extreme weather). There are other pathways where changes in local climate alter ecological conditions that affect vector ecology, thus indirectly impacting human health[3] (e.g., increased mosquito-borne disease like Dengue Fever or Chikungunya transmission due to ecological alterations resulting from temperature and precipitation changes). The survival, biting frequency, and growth rate of the Dengue virus carrying mosquitoes, *Aedes aegypti* and *Aedes albopictus,* are affected by climate and weather patterns[15], which in turn affect the risk of human infection. Another example of climate affecting health indirectly relates to warming temperatures and increased CO_2 concentration, thereby increasing pollen production in ragweed[16]. The elevated pollen concentration increases the risk of exposure and subsequent onset of allergic respiratory illness. Health departments can use existing expertise and knowledge to choose the health outcome(s) with the largest projected impact.

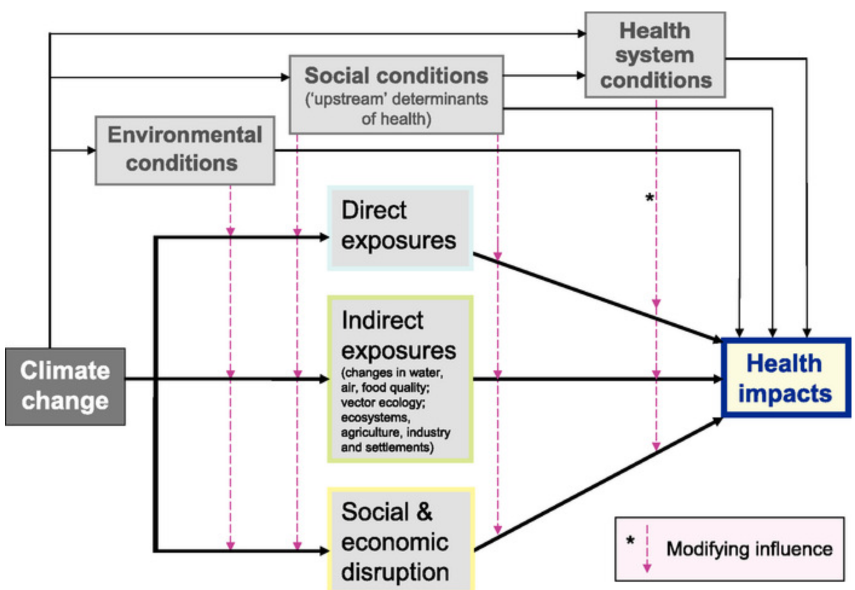


Figure 4. Schematic diagram of pathways by which climate change affects health, and concurrent direct-acting and modifying (conditioning) influences of environmental, social and health-system factors. (Source: Intergovernmental Panel on Climate Change, 2007)

2. Identify known risk factors for potential health outcome

For the health outcome(s) identified as being climate sensitive, a list of risk factors known to contribute to higher rates of disease and injury can be identified from scientific literature and consultation from disease subject matter experts. Potential health risk factors includes social (e.g., education, social isolation), economic (e.g., income, social assistance), housing (e.g., housing type and age, prevalence of air conditioning), and neighborhood (e.g., land cover, parks, proximity to road) information. Table 1 lists a subset of risk factors with potential data sources that were found to be associated with heat vulnerability at the census tract level[17].

Category	Data source (year)	Variable definition
Demographic variables	U.S. Census (2000)	Percent population below the poverty line
		Percent population with less than a high school diploma
		Percent population of a race other than white
		Percent population living alone
		Percent population ≥ 65 years of age
		Percent population ≥ 65 of age living alone
Land cover	National Land Cover Database (2001)	Percent census tract area not covered in vegetation
Diabetes prevalence	Behavioral Risk Factor Surveillance System (2002)	Percent population ever diagnosed with diabetes
Air conditioning	American Housing Survey (2002)[a]	Percent households without central AC
		Percent households without any AC

Table 1. Community Determinants of Heat Vulnerability (Reid et al. 2009)

3. Acquire spatial information on health outcomes and risk factors

To conduct the vulnerability assessment, data on health outcomes and risk factors are needed, preferably at smallest possible administrative unit (e.g., census block group, census tract, county). Analysis at larger geographic areas may mask the neighborhood level variations of health risk factors, but data availability and requirements of computer resources for analyses may limit the spatial scope of the assessment. Therefore, aggregating data at a less detailed scale (e.g., county) may be the only feasible option.

Demographic and socio-economic data for sub-populations that have known sensitivities to specific health outcomes (e.g., elderly living alone) are readily available from the US from the Census Bureau and may be available with high detail (e.g., census block or block-group), depending on the type of data. These census data can then be used in a Geographic Information

System (GIS) for mapping and analysis, by joining the census population data to the geographic data (e.g., census tracts, census blocks, or counties).

Other federal agencies also routinely collect information at various geographic scales. The United States Geological Survey (USGS) collects and provides data for land-cover, land use, and elevation (http://pubs.usgs.gov/fs/2012/3020/)[18]. The United States Department of Transportation (USDOT) provides road infrastructure data (. Annually updated demographic data sets from the American Community Survey (ACS) from the US Census Bureau can also provide additional data for a vulnerability assessment (http://www.census.gov/acs). Additionally, the Environmental Protection Agency (EPA) has produced projections on population density, impervious surfaces, and housing density, which can all be used as additional data layers for a vulnerability assessment (ICLUS Version 1.3; http://www.epa.gov/ncea/global/iclus/index.html)[19].

Many health departments can access standardized health data such as mortality records, hospitalizations, emergency room visits, emergency distress calls, or outpatient visits. These data can be used to map sensitive populations for a climate and health assessment. For example, the mortality rate from renal disease or diabetes per county can be used to map sensitive populations to heat-related illness; previous research has found that heat waves resulted in excess deaths from multiple causes including cardiovascular disease, diabetes, renal disease, and nervous system disorders[20]. However, issues can arise with the use of highly detailed morbidity or mortality data at the census tracts or even ZIP code level, because the number of cases may be too low to adequately calculate rates, or the data may be considered protected health information due to privacy concerns. An additional source of health data may be syndromic surveillance data, which is the use of surrogate data to measure a health outcome (i.e., the use of data other than case confirmed morbidity or mortality records to detect or measure health outcomes)[21]. Health data can also be used to validate a vulnerability index[22], or used to develop a vulnerability index using a spatial regression technique[23], which each methodology will be discussed in more detail later in the document.

4. Assess adaptive capacity

In conducting a vulnerability assessment, adaptive capacity can be broadly defined as the ability of a system (e.g., government, infrastructure, civil society, institutions, social capital in community networks) to adjust, limit, and cope with the potential hazards, due to climate change[13]. Assessing adaptive capacity is the evaluation of a system's ability to cope with the hazards resulting from climate change, which may be measured by access to financial resources (e.g., federal aid programs), health infrastructure (e.g., hospitals or ambulatory services, cooling centers), or access to technology (air conditioning)[24]. Adaptive capacity also refers to the ability of a system to reduce hazardous exposures[25], which can be measured by the implementation of government programs, initiatives, or policies. For example, city governments might implement initiatives to reduce heat exposure through urban planning and design (e.g., white roofs or urban tree planting), reflecting on a city's ability to reduce hazardous exposure. Another example would be government policies to mandate the planting of low pollen producing plants in hopes to reduce the allergy impact of urban greening projects[26]. Such a policy would reduce pollen exposure for those sensitive populations with chronic respiratory conditions such as asthma or those who suffer from allergic illness (e.g., hay fever); warmer temperatures and increased CO_2 concentrations as a result of climate change may increase pollen concentrations and produce earlier seasonal pollen exposure[16,27].

A multitude of factors determine a system's adaptive capacity (e.g., political, social, and environmental)[24], and although not all of these factors can be quantified directly, indirect measures of adaptive capacity may be available. For example, data on the number of households with central air-conditioning could theoretically be used as a measure of adaptive capacity for heat-related illness but are not readily available for all census tracts from the US Census Bureau.

5. Assessment of vulnerability

Both qualitative and quantitative methods can be used on a vulnerability assessment. An example of a qualitative assessment would be a series of questions asked about an organization's leadership ability and the accessibility of resources to cope with changes due to climate change[28], or in depth assessments of health infrastructure (hospitals, nursing homes) and their adaptive capacity to climate change. However, the primary focus of this document will be on quantitative assessment approaches. Two quantitative approaches commonly used to assess vulnerability using GIS are 1) overlay analysis of risk factors[29-31] and 2) spatial regression[23].

Overlay analysis is the underlying technique of methodologies that include risk factor analysis, environmental justice screening method(s), and social or medical vulnerability indices[29-33]. First, information on a suite of risk factors is collected from existing data sources related to the health outcome. Ideally, all of these risk factors would be measured in the same geographic units (e.g., county, census tract) so that they can be geographically aligned. Each risk factor is then divided into categories based on the underlying distribution, with the more vulnerable categories being assigned a higher "score." For each geographic unit (e.g., ZIP code, census tract, or county), the scores assigned to each risk factor are tallied to create a cumulative vulnerability score, or index. These units are then mapped on the basis of the cumulative vulnerability score. If health outcome data are available, the overlay analysis can be validated. The purpose of validation is to determine that places designated as highly vulnerable, according to a calculated index, have higher (relative) rates of morbidity or mortality for the health outcome of interest (i.e., is the vulnerability index congruent with actual health data?). There are multiple methods to validate an overlay index, which all require morbidity or mortality data. For example, a previous study by Reid et al., (2012) validated a heat vulnerability index using emergency department data to develop a regression model (generalized estimating equation Poisson regression) to determine the statistically significant relationship between the calculated vulnerability index and the incidence of heat-related hospitalizations[22]. Similarly, a study in California by English et al., (2012) used emergency department data to validate a climate change vulnerability index, by comparing the average relative risk (i.e., case date) between the derived vulnerability categories[34].

Some studies have combined these risk factors statistically using principal components analysis (PCA) to create a smaller number of hybrid factors [35]. PCA is a data reduction method that attempts to group multiple independent variables based on how they vary together (i.e., covariance). The hybrid factors that result from the use of PCA could be assigned weights corresponding to their relative importance and then combined to create a vulnerability map.

Spatial regression is another commonly used methodology for quantitatively characterizing vulnerability[23,36]. The primary distinction between spatial regression and an overlay analysis is at which step of the process one considers the health outcome. Spatial regression derives the most critical vulnerability characteristic based on the strength of statistical relationships between risk factors and the health outcome. Because of the direct connection between risk factors and health outcomes, spatial regression will likely exhibit stronger correspondence to health outcomes than overlays analysis. However, spatial regression requires more statistical expertise and can take more time to complete. Specifically, computing time increases as the size of the analysis become more detailed or the number of risk factors increases. Therefore spatial regression may be most appropriate for health departments with an abundance of resources in terms of intermediate to advanced statistical capabilities and personnel expertise, and the availability of highly detailed health data. In contrast, overlay analysis creates a vulnerability index from known risk factors of a health outcome and does not require health data, although the index can be validated with health outcome data in subsequent analysis. Overlay analysis is a popular and scientifically accepted method for identifying vulnerable populations, and can characterize general health-outcome vulnerability[22,30,34,37].

Vulnerability Assessment Case Study

A climate and health vulnerability assessment aims to identify the people and places that are most susceptible to hazardous exposures resulting from climate change. Previous vulnerability assessments have used overlay analysis for climate-sensitive health effects such as heat-related illness[29-32,37]. The following case study was developed to illustrate an application of the overlay analysis approach to assess health vulnerability to extreme heat. Using data for the state of Georgia, a description is provided of the indicators, their respective data sources and the methodology used to create an index representing vulnerability.

Heat-related illness in Georgia

Although heat-related illness in Georgia accounted for only approximately ten classified deaths annually from the period 1999 to 2010[38], a recent study in Georgia using data from 2002 to 2008 found that that on average 1,937 individuals visited emergency departments in the summer months for heat-related illness (i.e., any symptoms related to heat exhaustion, heat-edema, heat stroke, or heat-related accidents) every year[39]. Moreover, it is estimated that one in seven Georgia residents are employed in agriculture, forestry, and other related areas [40]. Thus, occupational exposure to extreme heat events is also of concern.

Factors associated with heat-related illness

This case study defined vulnerability using three groups of factors: sensitivity, adaptive capacity and exposure[25,34]. Four different measures were used for sensitivity to extreme heat. First, a poverty measure from the US Census bureau was included in the analysis because previous research has shown that this socioeconomic indicator was associated with increased heat-related mortality[41]. Second, US Census data on the percentage of householders living alone greater than or equal to 65 years of age were used because social isolation, particularly in the elderly, was found to increase the risk for heat-related illness[17,42]. Third, as a measure for renal disease, which was shown to have increased mortality during an extreme heat event[20], counts of hemodialysis patients were used, which were collected at the zip code level and provided by the

Center for Medicare and Medicaid Services. Other health outcomes could be used as well, as numerous studies on heat-related illness have shown a positive relationship between ambient temperatures and the number of heat-related hospitalizations and deaths [43], diabetes [44], cardiovascular issues[45] and diseases of the nervous system[6,20]. Lastly, communities with sparse vegetation have been associated with higher ambient temperatures[30] which can increase heat exposure for individuals. Satellite imagery from 2006 was classified to represent percent impervious surfaces (e.g., streets, rooftops), as provided by the US Geological Survey[46]. The factors representing sensitivity to extreme heat are listed in Table 2.

In the context of this case study, we defined adaptive capacity as the ability for a community to cope with a hazardous exposure. As a measure for adaptive capacity, we used the number of medical infrastructure facilities per county (i.e., total number of hospitals, surgical facilities, ambulatory services, and Red Cross shelters per county), which was compiled using data from the Homeland Security Infrastructure Program (HSIP). The number of heat events was used as a measure for hazardous heat exposure. A heat event was defined as two or more consecutive days when the heat index was >100°F. This information was obtained from the National Environmental Public Health Tracking Network [47] for every county in Georgia during 2002 - 2011. A more expansive healthcare infrastructure was considered to indicate a higher adaptive capacity to cope with the health impacts during extreme heat.

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

Table 2. Sensitivity factors for extreme heat used in the overlay analysis

Spatial overlay approach to construct vulnerability index

After identifying the six factors associated with heat-related illness to be used for the overlay analysis, the relevant data was acquired and imported into a Geographic Information System (GIS). We used a domain weighting approach, where the factors representing sensitivity, exposure, and adaptive capacity were weighted equally. Specifically, the factors of sensitivity (poverty, elderly living alone, renal disease, impervious surfaces) accounted for one third of the composite heat vulnerability index; historic heat exposure accounted for one third, and hospital insufficiency also account for one third of the composite vulnerability index. Within each layer, the data were classified and assigned different weighting factors, which allowed for capture of geographic variability within the data layer seen in the map of county heat-event exposure (see Figure 5). For example, poverty data was initially categorized (i.e., percent population under the poverty limit) into four categories (scores) using a quartile classification method, and then assigned a weighting factor according to increasing risk: (0.25, 0.5, 0.75, and 1.0). The category with the highest risk would be assigned 1.0 and the category representing the least risk would be assigned 0.25. Also of note, a data layer can be assigned a binary type of classification as either a 1 or 0, in the case that data represent presence or absence. After all weighting factors were calculated within each layer, that spatial index was created by overlaying each layer and adding the values that overlapped (i.e., an additive overlay index). Theoretically, further weight schemes could be used on each layer according to their known importance to the health outcomes. However, for this analysis, we weighted the factors representing sensitivity, exposure, and adaptive capacity equally.

Results

The final vulnerability maps for the state of Georgia (Figure 6) and a more detailed map of Atlanta (Figure 7) shows that vulnerability to heat-related illness extends beyond urban zones. In western metropolitan Atlanta, several areas are designated as high categories for vulnerability, due to the high percentage of impervious surfaces in combination with a percentage of elderly living alone. We also noted that several rural areas are also designated as most vulnerable, such as the towns of Douglas, Vidalia, and Waycross. These areas are located in the southern portion of Georgia, which experienced relatively more historic hazardous heat events, had less access to hospital infrastructure (i.e. decreased adaptive capacity), and had relatively higher percentages of people living alone. Furthermore, previous heat exposure in combination with hospital insufficiency accounts for two-thirds of the composite vulnerability index score, which in southern rural Georgia are both relatively high. Future work includes an addition of locations of cooling shelters to assess if vulnerable communities have access to these during extreme heat waves. Additionally, this kind of a vulnerability assessment could be validated by linking observed heat-related health data collected by the Georgia Department of Health[39].

Conclusion

A climate and health vulnerability assessment using an overlay analysis approach can identify communities and places susceptible to climate-sensitive health outcomes by incorporating data on sensitive populations, exposures to hazardous conditions, and measures on the ability to limit or cope with hazardous exposures. By identifying where vulnerabilities exist, public health departments can develop health interventions and health adaptation strategies that are tailored to a specific community. A vulnerability assessment can also identify communities that were not previously considered to be susceptible, using either a spatial regression or an overlay analysis approach, because the analysis incorporates multiple health determinants that represent sensitivity, exposure, adaptive capacity. The climate and health vulnerability assessment is a critical tool that can be used to help build resilience against the health effects related to climate change because it identifies where susceptibilities to hazardous exposures are likely to occur, provides community characteristics for the development and implementation of a climate and health adaption plan, and ultimately offers knowledge on viable public health interventions to implement.

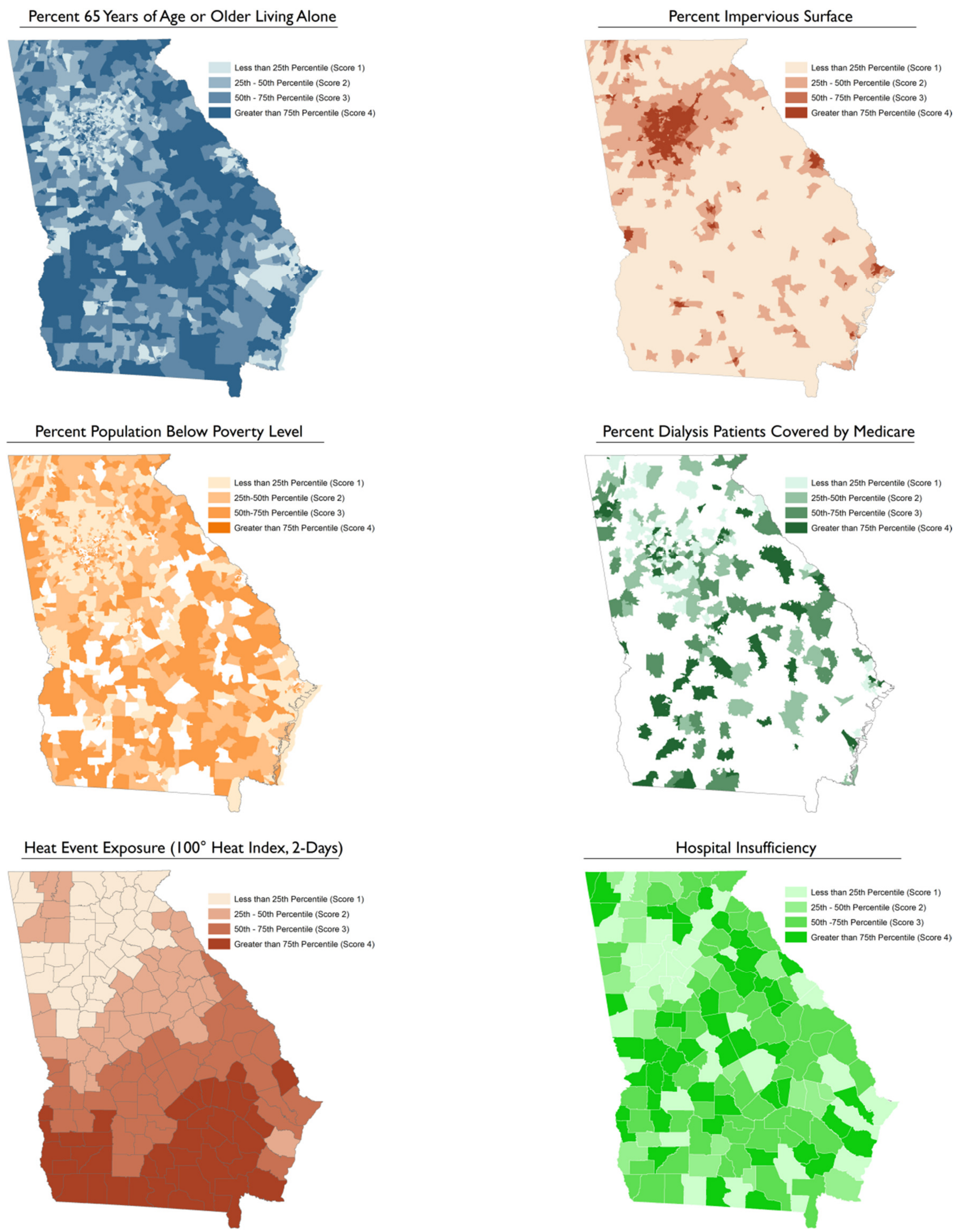


Figure 5. Spatial distribution of factors affecting vulnerability to extreme heat

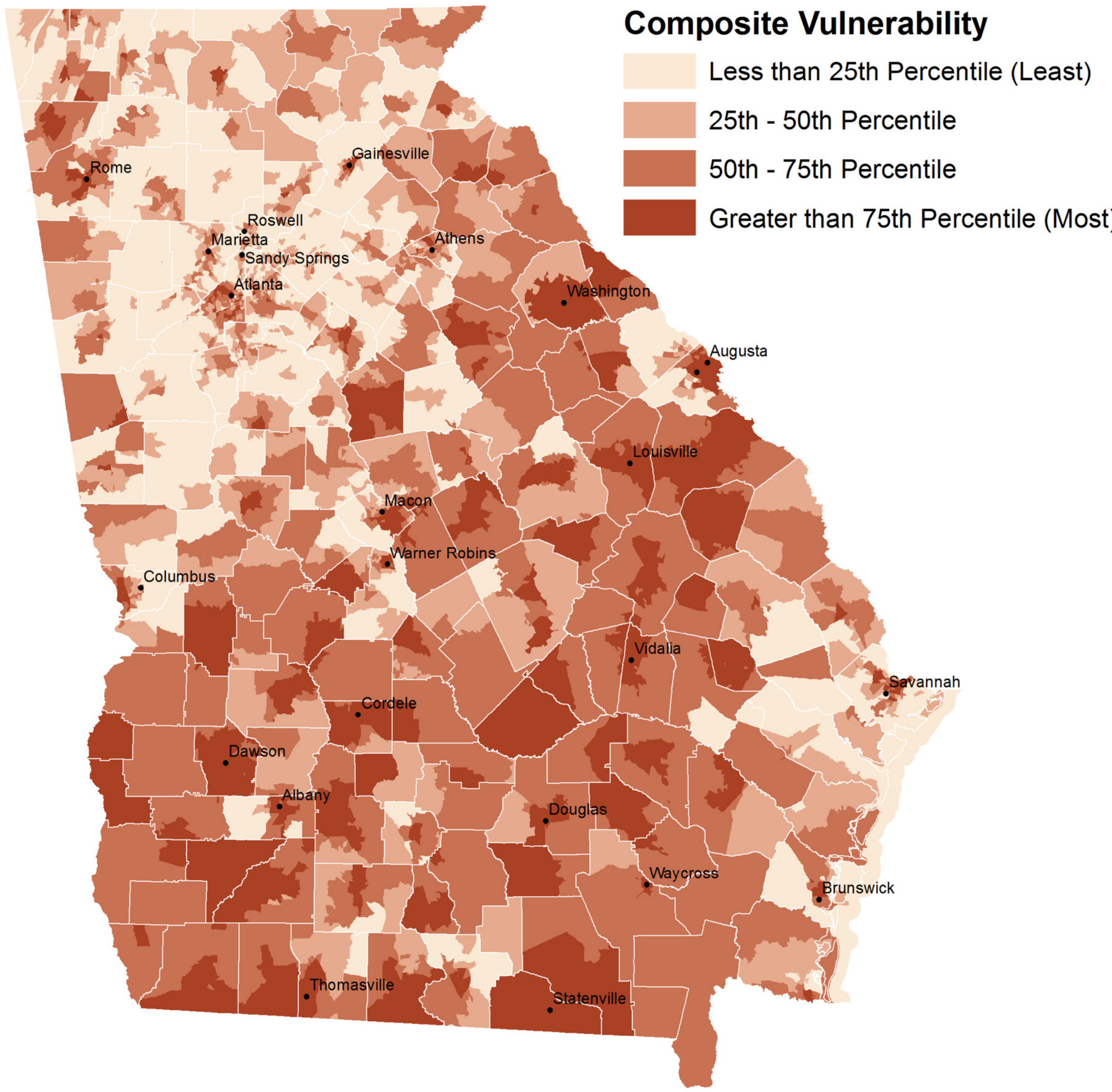


Figure 6. Spatial distribution of composite vulnerability index score (quartiles) in Georgia

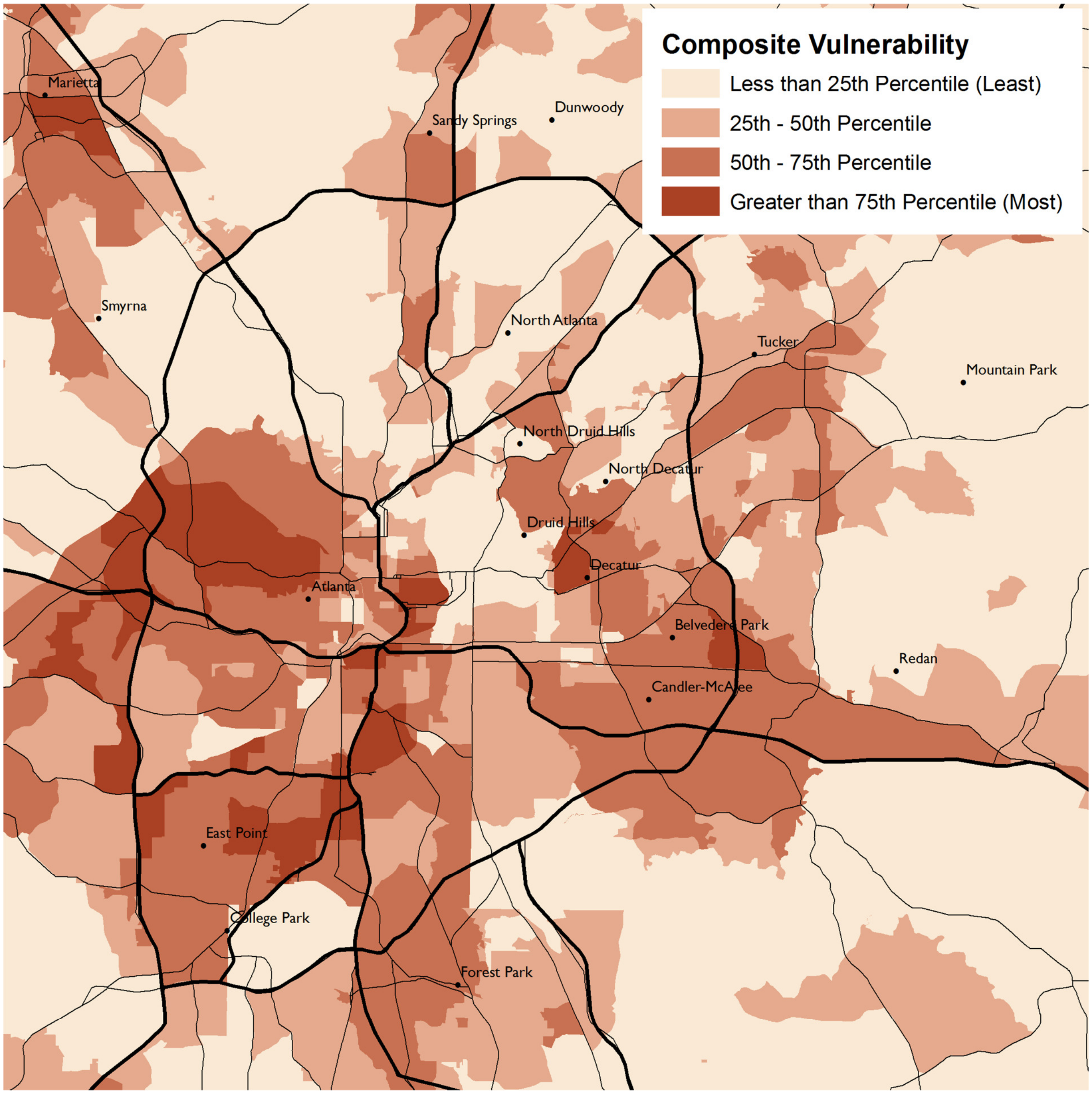


Figure 7. Spatial distribution of composite vulnerability index score (quartiles) in the Atlanta metropolitan area

References

1. Portier CJ, Carter SR, Dilworth CH, Grambsch AE, Gohlke J, et al. A Human Health Perspective On Climate Change: A Report Outlining the Research Needs on the Human Health Effects of Climate Change. In: Sciences EHPaNIoEH, ed. *Research Triangle Park, NC*, 2010.
2. Marinucci G, Luber G, Uejio C, Saha S, Hess J. Building Resilience against Climate Effects—A Novel Framework to Facilitate Climate Readiness in Public Health Agencies. *International Journal of Environmental Research and Public Health* 2014;11(6):6433-6458.
3. Luber G, Knowlton K, Balbus J, Frumkin H, Hayden M, Hess J, McGeehin M, Sheats N, Backer L, Beard CB, Ebi KL, Maibach E, Ostfeld RS, Wiedinmyer C, Zielinski-Gutiérrez E, Ziska L. Ch. 9: Human Health. Climate Change Impacts in the United States: The Third National Climate Assessment. In: Melillo JM, Richmond TTC, Yohe GW, eds. Vol. Forthcoming U.S. Global Change Research Program, 2014;220-256.
4. Smit B, Pilifosova O, Burton I, Challenger B, Huq S, Klein RJT, Yoh G. Climate Change 2001: Impacts, Adaptation and Vulnerability. In: McCarthy JJ, Canziani O, Leary NA, Dokken DJ, White KS, eds. Vol. Contribution of the Working Group II to the Third Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, UK, 2001;877-912.
5. Ebi K, Kovats R, Menne B. An approach for assessing human health vulnerability and public health interventions to adapt to climate change. *Environmental Health Perspectives* 2006;114(12):1930-1934.
6. Balbus J, Malina C. Identifying Vulnerable Subpopulations for Climate Change Health Effects in the United States. *Journal of Occupational and Environmental Medicine* 2009;51(1):33-37.
7. O'Brien K, Eriksen S, Nygaard LP, Schjolden A. Why different interpretations of vulnerability matter in climate change discourses. *Climate Policy* 2007;7(1):73-88.
8. Field CB, Barros V, Stocker TF, Qin D, Dokken DJ, Ebi KL, Mastrandrea MD, Mach KJ, Plattner G-K, Allen SK, Tignor M, Midgley PM. Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation. *A Special Report of Working Groups I and II of theIntergovernmental Panel on Climate Change*. Cambridge, UK, and New York, NY, USA 2012;582.
9. Cutter S, Boruff B, Shirley W. Social vulnerability to environmental hazards. *Social Science Quarterly* 2003;84(2):242-261.
10. Turner BL, Kasperson RE, Matson PA, McCarthy JJ, Corell RW, Christensen L, Eckley N, Kasperson JX, Luers A, Martello ML, Polsky C, Pulsipher A, Schiller A. A framework for vulnerability analysis in sustainability science. *Proceedings of the National Academy of Sciences of the United States of America* 2003;100(14):8074-8079.
11. Patt A, Schröter D, Cristina de la Vega-Leinert A, Klein R. Vulnerability research and assessment to support adaptation and mitigation: Common themes from the diversity of approaches. Assessing Vulnerability to Global Environmental Change. 2009;Making Research Useful for Adaptation Decision Making and Policy(1-25.).
12. Bierbaum R, Lee A, Smith J, Blair M, Carter LM, F. S. Chapin I, Fleming P, Ruffo S, McNeeley S, M. Stults L, Verduzco, Seyller E. Ch. 28: Adaptation. In: Melillo JM, Richmond TTC, Yohe GW, eds. *Climate Change Impacts in the United States: The Third National Climate Assessment* U.S. Global Change Research Program, 2014;670-706.
13. IPCC. Technical summary: climate change 2001: impacts, adaptation, and vulnerability. *A Report of Working Group II of the Intergovernmental Panel on Climate Change.*, 2001.
14. Climate Change Impacts in the United States: The Third National Climate Assessment. U.S. Global Change Research Program. In: Melillo JM, Richmond TTC, Yohe GW, eds U.S. Global Change Research Program, 2014;841.

15. Morin C, Comrie A, Ernst K. Climate and Dengue Transmission: Evidence and Implications. *Environmental Health Perspectives* 2013;121(11-12).
16. Ziska L, Gebhard D, Frenz D, Faulkner S, Singer B, Straka J. Cities as harbingers of climate change: Common ragweed, urbanization, and public health. *Journal of Allergy and Clinical Immunology* 2003;111(2):290-295.
17. Reid CE, O'Neill MS, Gronlund CJ, Brines SJ, Brown DG, Diez-Roux AV, Schwartz J. Mapping community determinants of heat vulnerability. *Environ Health Perspect* 2009;117(11):1730-6.
18. Homer CH, Fry JA, C.A. B. The National Land Cover Database, U.S. Geological Survey Fact Sheet 2012-3020. 2012:4.
19. EPA US. ICLUS Tools and Datasets. In: Agency USEP, ed. EPA/600/R-09/143F. Version 1.3.2 ed. Washington, DC, 2010.
20. Semenza JC, McCullough JE, Flanders WD, McGeehin MA, Lumpkin JR. Excess hospital admissions during the July 1995 heat wave in Chicago. *American Journal of Preventive Medicine* 1999;16(4):269-277.
21. Mandl KD, Overhage JM, Wagner MM, Lober WB, Sebastiani P, Mostashari F, Pavlin JA, Gesteland PH, Treadwell T, Koski E, Hutwagner L, Buckeridge DL, Aller RD, Grannis S. Implementing syndromic surveillance: A practical guide informed by the early experience. *Journal of the American Medical Informatics Association* 2004;11(2):141-150.
22. Reid CE, Mann JK, Alfasso R, English PB, King GC, Lincoln RA, Margolis HG, Rubado DJ, Sabato JE, West NL, Woods B, Navarro KM, Balmes JR. Evaluation of a Heat Vulnerability Index on Abnormally Hot Days: An Environmental Public Health Tracking Study. *Environmental Health Perspectives* 2012;120(5):715-720.
23. Uejio CK, Wilhelmi OV, Golden JS, Mills DM, Gulino SP, Samenow JP. Intra-urban societal vulnerability to extreme heat: The role of heat exposure and the built environment, socioeconomics, and neighborhood stability. *Health & Place* 2011;17(2):498-507.
24. Smit B, Wandel J. Adaptation, adaptive capacity and vulnerability. *Global Environmental Change-Human and Policy Dimensions* 2006;16(3):282-292.
25. Gallopin GC. Linkages between vulnerability, resilience, and adaptive capacity. *Global Environmental Change-Human and Policy Dimensions* 2006;16(3):293-303.
26. Ogren TL. *Allergy-free Gardening. The Revolutionary Guide to Healthy Landscaping.* Bekerley, Toronto: Ten Speed Press, 2000.
27. Ariano R, Canonica GW, Passalacqua G. Possible role of climate changes in variations in pollen seasons and allergic sensitizations during 27 years. *Annals of Allergy Asthma & Immunology* 2010;104(3):215-222.
28. Hinkel J, Bharwani S, Bisaroy A, Carter T, Cull T, Davis M, Klein R, Lonsdale K, Rosentrater L, Vincent K. PROVIA Guidance on AssessingVulnerability, Impacts and Adaptationto Climate Change. United Nations Environment Programme, 2013.
29. Reid C, O'Neill M, Gronlund C, Brines S, Brown D, Diez-Roux A, Schwartz J. Mapping Community Determinants of Heat Vulnerability. *Environmental Health Perspectives* 2009;117(11):1730-1736.
30. Harlan S, Brazel A, Prashad L, Stefanov W, Larsen L. Neighborhood microclimates and vulnerability to heat stress. *Social Science & Medicine* 2006;63(11):2847-2863.
31. Vescovi L, Rebetez M, Rong F. Assessing public health risk due to extremely high temperature events: climate and social parameters. *Climate Research* 2005;30(1):71-78.
32. Sadd JL, Pastor M, Morello-Frosch R, Scoggins J, Jesdale B. Playing It Safe: Assessing Cumulative Impact and Social Vulnerability through an Environmental Justice Screening Method in the South Coast Air Basin, California. *International Journal of Environmental Research and Public Health* 2011;8(5):1441-1459.

33. Flanagan B, Gregory E, Hallisey E, Heitgerd J, Lewis B. A Social Vulnerability Index for Disaster Management. *Journal of Homeland Security and Emergency Management* 2011;8(1).
34. English P, Richardson M, Morello-Frosh R, Pasto M, Sadd J, King G, Jesdale W, Jerrett M. Racial and Income Disparities in Relation to aProposed Climate Change VulnerabilityScreening Method for California. *THE INTERNATIONAL JOURNAL OF CLIMATE CHANGE: IMPACTS AND RESPONSES* 2012;4(2):1-18.
35. Cutter S, Finch C. Temporal and spatial changes in social vulnerability to natural hazards. *Proceedings of the National Academy of Sciences of the United States of America* 2008;105(7):2301-2306.
36. Tipayamongkholgul M, Lisakulruk S. Socio-geographical factors in vulnerability to dengue in Thai villages: a spatial regression analysis. *Geospatial Health* 2011;5(2):191-198.
37. Reid CE, Gamble JL. Aeroallergens, Allergic Disease, and Climate Change: Impacts and Adaptation. *Ecohealth* 2009;6(3):458-470.
38. Centers for Disease Control and Prevention. Underlying Cause of Death 1999-2010 on CDC WONDER Online Database, released 2012. Data are from the Multiple Cause of Death Files, 1999-2010, as compiled from data provided by the 57 vital statistics jurisdictions through the Vital Statistics Cooperative Program. http://wonder.cdc.gov/ucd-icd10.html Accessed Feb 19, 2014 3:23:18 PM, 2014.
39. Pillai S, Noe R, Murphy M, Vaidyanathan A, Young R, Kieszak S, Freymann G, Smith W, Drenzek C, Lewis L, Wolkin A. Heat Illness: Predictors of Hospital Admissions Among Emergency Department Visits-Georgia, 2002-2008. *Journal of Community Health* 2014;39(1):90-98.
40. Extension UoGC. Ag Stats. Accessed 02/19/2014, 2014.
41. Curriero F, Heiner K, Samet J, Zeger S, Strug L, Patz J. Temperature and mortality in 11 cities of the eastern United States. *American Journal of Epidemiology* 2002;155(1):80-87.
42. Naughton MP, Henderson A, Mirabelli MC, Kaiser R, Wilhelm JL, Kieszak SM, Rubin CH, McGeehin MA. Heat-related mortality during a 1999 heat wave in Chicago. *American Journal of Preventive Medicine* 2002;22(4):221-227.
43. Basu R, Samet J. Relation between elevated ambient temperature and mortality: A review of the epidemiologic evidence. *Epidemiologic Reviews* 2002;24(2):190-202.
44. Schwartz J. Who is sensitive to extremes of temperature? A case-only analysis. *Epidemiology* 2005;16(1):67-72.
45. Luber G, Sanchez C, Conklin L. Heat-Related Deaths, United States, 1999 to 2003. *Morbidity and Mortality Weekly Report*. Atlanta, GA: Centers for Disease Control and Prevention (CDC), 2006.
46. Fry J, Xian G, Jin S, Dewitz J, Homer C, Yang L, Barnes C, Herold N, Wickham J. Completion of the 2006 National Land Cover Database for the Conterminous United States. *PE&RS* 2011;77(9):858-864.
47. Centers for Disease Control and Prevention. Environmental Health Tracking Program. Extreme heat days and events. . Accessed From: www.cdc.gov/ephtracking. Accessed on April 15th, 2014 ed, 2014.