



REPORT

GUIDE TO COMMUNITY CLIMATE VULNERABILITY ASSESSMENTS

AUTHORS

Juan Declat-Barreto, Marissa J. Ramirez*, Kristi Pullen Fedinick*



*contributed equally

ACKNOWLEDGMENTS

Special thanks to:

Danna Walker for her copy-editing.

Leah Stecher and NRDC publications team for review and design efforts.

NRDC Science Center and internal reviewers including Kim Knowlton, Juanita Constible, and Sasha Forbes.

External reviewers Lara Hansen (EcoAdapt), Naomi Cytron (SF Federal Reserve), Devin Culbertson (Enterprise Community Partners), Lauren Valdez (Enterprise Community Partners). Content support Maddie Keating, Ariadne Villegas, and Deborah Faulkner.

The Strong Prosperous and Resilient Communities Challenge (SPARCC) initiative for supporting staff time and implementation of some of the ideas reflected in this report.

About NRDC

The Natural Resources Defense Council is an international nonprofit environmental organization with more than 3 million members and online activists. Since 1970, our lawyers, scientists, and other environmental specialists have worked to protect the world's natural resources, public health, and the environment. NRDC has offices in New York City, Washington, D.C., Los Angeles, San Francisco, Chicago, Montana, and Beijing. Visit us at nrdc.org.

NRDC Chief Communications Officer: Michelle Egan

NRDC Managing Directors of Communications: Lisa Goffredi and Jenny Powers

NRDC Publications Director: Mary Annaïse Heglar

NRDC Policy Publications Editor: Leah Stecher

Cover: © Trevor Holman

Design and Production: www.suerossi.com

© Natural Resources Defense Council 2020

Table of Contents

Overview	4
Introduction to Climate Vulnerability Assessments	6
Part One: The What, the Why, and the Who of Climate Vulnerability Assessments	7
Part Two: Developing a Climate Vulnerability Assessment	10
Part Three: Vulnerability Assessments in Practice—Case Studies	16
Appendix I: The Path to Integrating Climate Vulnerability Assessments	22
Appendix II: Additional Resources for Communities Applying Climate Vulnerability Assessments.....	23
Endnotes	24

Overview

This *Guide to Community Climate Vulnerability Assessments* is a primer for communities and community partners on how to complete a climate vulnerability assessment (CVA). Simply put, CVAs evaluate the vulnerability of people and places—exploring the adverse effects of climate change, the intersecting social implications, and our ability to respond to the expected conditions. CVAs provide a collaborative basis for addressing vulnerabilities in communities and serve to prioritize and align climate adaptation as a means of addressing poverty, improving health, and creating opportunities for wealth. The purpose of this guide is to introduce the concept of CVAs: what they are, why they matter, who should participate, and how they are developed. The guide can be applied to either a region or a project specific to where people live. Community organizations may find this guide most useful at the inception phase of a CVA as an overview of the process, enabling them to achieve better outcomes in their communities.

Traditionally, CVAs focus on assessing vulnerability to climate change as a first step in adaptation planning. However, this guide focuses on community-driven CVAs and identifies pathways for actions in an integrative process that can become part of a broader local adaptation plan or be undertaken directly.

This guide is broken into five parts:

- Part One, “The What, the Why, and the Who of Climate Vulnerability Assessments,” explores what a CVA is, provides useful climate terminology, and examines expected outcomes. This section also presents the important elements of building a successful CVA team by bringing together diverse perspectives and skill sets.
- Part Two, “Developing a Climate Vulnerability Assessment,” covers the process of executing the assessment, including steps to formulate the scope of the assessment, determine budgetary needs, perform managerial oversight, and incorporate local data.
- Part Three, “Vulnerability Assessments in Practice—Case Studies,” describes two CVAs and how they have been applied to inform local decision making. Maricopa County, Arizona, utilizes a data-rich environment to develop interventions designed to alleviate heat, such as increased shading vegetation. In Washington, D.C., the analysis produced better-designed public health solutions for addressing extreme temperatures through the District’s climate adaptation plan.
- Appendix I, “The Path to Integrating Climate Vulnerability Assessments,” provides a visual guide of the steps to take to perform an assessment, from start to finish.

- Appendix II, “Additional Resources for Communities Applying Climate Vulnerability Assessments,” offers other sources of information that may be useful to communities executing an assessment that goes beyond a technical analysis, such as how to engage partners and communicate the findings and outcomes from the assessment.

The primary audience for this guide is practitioners across sectors such as housing, transportation, land use, health, or community organizing, and especially those who work at the neighborhood level. This framework is tailored to groups that will build a team with the requisite skill sets to complete the assessment and garner the political and financial support to execute decisions and actions based on the assessment results. Climate vulnerability assessments of specific plans or built environment projects can include partners who are part of the project team and stakeholders related to the work.

Included in the guide is a technical introduction to developing a vulnerability index. While successful CVAs can be performed along a spectrum of data availability and usage or even as a thought exercise, they are most valuable when the data and resulting vulnerability index are used to accurately portray the people and places that are most vulnerable. The data in these assessments will include socioeconomic information on current conditions within a community as well as climate projections that allow us to understand future exposure to climate impacts. While not everyone needs to engage at such a specialized level, the guide is intended to be data driven; this leads to better-informed policies that are measurable and results oriented.

COMMUNITY-DRIVEN CLIMATE VULNERABILITY ASSESSMENTS IN ADDRESSING INEQUITY

Recently, a community development organization in Los Angeles completed a Climate Vulnerability Assessment (CVA) in partnership with a diverse set of local stakeholders. On the basis of the results, the organization, primarily focused on providing affordable housing and supportive services for vulnerable people in the region, determined there was a crucial need to provide efficient cooling to residents in the community while avoiding an increase in greenhouse gas emissions. Average temperatures in Los Angeles have risen by 1.5 degrees Fahrenheit since 1895.¹ Heat wave intensity and duration are expected to increase drastically due to a projected temperature rise of up to 4 °F by 2050, resulting in dire circumstances for vulnerable populations, such as homeless persons, the elderly, and people with preexisting health conditions or without respite from the heat.²

Addressing water shortages and providing climate-friendly landscaping were already priorities for the community. Through the CVA, however, the needs of vulnerable populations suffering from heat stress were elevated, resulting in a commitment from the organization to integrate public cooling shelters into their housing development plan and to consider climate vulnerability in future development plans. This solution provided multiple benefits. With the significant issue of homelessness and housing insecurity in the region, community spaces offer a hub for cultural, health, or financial amenities or simply a safe place for the neighborhood. The community cooling center provides a solution to the need for both community space and relief from the heat.

In the absence of climate policy direction at the national level, cities and local communities are starting to solve their own climate problems. While climate change is a global phenomenon, people experience its effects locally. Increasingly, frontline communities vulnerable to sea level rise or more extreme weather events are addressing climate impacts directly by taking part in climate vulnerability assessments. As in the Los Angeles example, community CVAs allow local groups to quantify, understand, and predict the effects of climate change—which is the first step in taking ownership of and mitigating these impacts.

CVAs can be conducted at various scales, but what makes them different and valuable compared with city or regional assessments is that they are local, cross-cutting, and grounded in every aspect of community life. The results inform local responses and equitable solutions to the escalating challenges of climate change. In communities, developing strategies to adapt to climate change can be difficult, and often overlooks those most in need of support. Tying the adaptation process to an impact assessment encourages people to move toward positive change for everyone.

The climate challenge that communities face is matched by the challenge of growing inequality. These two challenges are often incorrectly seen as distinct. Unless the flaws in current development policies and practices are addressed, historic patterns of health, racial, and economic disparities will be reinforced for people and communities already experiencing housing, energy, or economic insecurity. Disasters like Hurricane Michael in 2018, for example, demonstrate that climate impacts are not felt uniformly.³ In Mexico Beach, Florida, the most severe hurricane damage occurred in communities that were built before building code standards were implemented and among houses exempt from Florida's impact protection provisions. A majority of residents in these older buildings are of low income and may lack access to medical services or basic necessities because they are not fluent in English.⁴

New research reinforces the link between climate hazards and social inequality. Looking at disaster-prone U.S. counties incurring more than \$10 billion in damages between 1999 and 2013, African-American residents each lost an estimated \$27,000 in wealth during that period, and Latino residents lost \$29,000. However, white residents actually *gained* wealth, an average of \$126,000 per person.⁵

The best way to address the joint challenges of climate change and inequality is to adopt climate policies and make community investments that prioritize and reduce inequities, specifically focusing on local vulnerability needs according to race and ethnicity, gender, income, and growing wealth gaps. Addressing inequities is an important objective of a climate vulnerability assessment, which allows communities to utilize knowledge and data to identify and take care of their most vulnerable populations.

A community-driven climate vulnerability assessment is a powerful tool that offers a ground-up approach rooted in the needs and experiences of a community. CVAs provide the basis for community groups to work across sectors with public and private authorities and take immediate action to transition to a climate-resilient future. Additionally, places that don't experience sudden shocks and disasters, but rather undergo the incrementally increasing stress of climate change, may come to realize the value and urgency of putting safeguards in place. Using CVAs, communities are realizing that addressing climate vulnerability can be part of a strategy for building wealth, improving health, and working toward equitable participation in a resilient economy. And, as community leaders become more deeply involved in identifying and addressing vulnerabilities in their communities, they gain influence in policymaking, business or infrastructure investment decisions, or other community development opportunities that improve quality of life for current and future residents.



INTRODUCTION TO CLIMATE VULNERABILITY ASSESSMENTS

Vulnerability assessments are data-driven exercises designed to identify the people and places most vulnerable to climate change. They combine information on population, locations, exposures, and climate hazards into a policy-relevant format that helps identify the locations and populations most in need of mitigation or adaptation strategies in response to a changing climate (see “Definitions of Key Terms,” page 7). Climate vulnerability assessments can be powerful tools, but they come with challenges—such as technical capacity, data availability, and suitability—that must be considered carefully in order to effectively inform policy decisions.

This guide identifies the skill sets and data necessary to conduct climate vulnerability assessments that will be useful for local decision making. It is intended to serve as a primer for audiences that understand the need for data-driven assessments but do not necessarily have the climate science or vulnerability expertise required to conduct such assessments.

This guide will answer the following questions:

- What is vulnerability, and how useful is it as a framework for understanding opportunities for adaptation to, or mitigation of, climate change–related risks?
- What is a vulnerability assessment, and why is it important?
- What are the key skills necessary to effectively develop climate vulnerability assessments?
- How are vulnerability assessments developed, and how long do they take to complete?
- What are the data availability and suitability challenges and opportunities that have to be considered when developing a climate vulnerability assessment?
- What are the opportunities to translate research and analysis into action?

The first three parts of this guide cover key concepts of vulnerability and vulnerability assessments and outlines the value added and skills needed to complete a successful CVA. The guide provides information on how to develop a climate vulnerability assessment, including insight into project scoping, data sources, and data analysis. Finally, the two case studies illustrate the usefulness of vulnerability assessments in both data-rich and data-sparse scenarios.

Part One: The What, the Why, and the Who of Climate Vulnerability Assessments

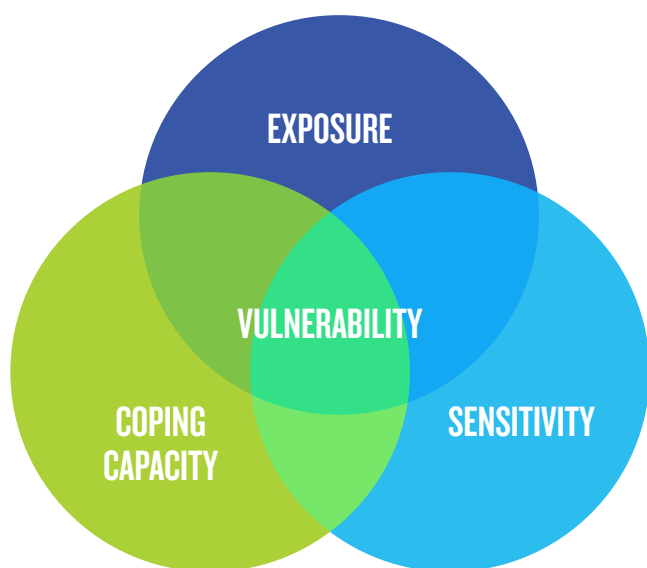
WHAT IS VULNERABILITY?

Vulnerability is a term used to describe susceptibility to harm and can be defined as the intersection of three factors: exposure, sensitivity, and adaptive (or coping) capacity.⁶

It can also be defined as the likelihood of a human or natural system or any of its components (e.g., people, plants, animals, and buildings) to be harmed due to exposure to a hazard (e.g., sea level rise).⁷ This makes vulnerability a particularly useful way to describe the susceptibility of populations (both human and ecological) to the harm, powerlessness, and marginality associated with climate change.⁸

Vulnerability can vary according to geography and social status. While factors that increase sensitivity (e.g., health issues or lack of access to transportation) and exposure to climate change–fueled hazards (e.g., extreme heat) can negatively impact livelihoods and personal well-being, adaptive capacity (i.e., the ability to cope with changes in the environment) can help offset some of the deleterious effects of exposure and sensitivity.⁹

FIGURE 1: VULNERABILITY IS DEFINED BY THE THREE DIMENSIONS OF EXPOSURE, SENSITIVITY, AND COPING CAPACITY



Adapted from Declerc-Barreto, 2013.¹⁰

DEFINITION OF KEY TERMS

EXPOSURE

Exposure describes the nature and magnitude of an environmental stress event (e.g., extreme temperature, flood, drought) and is usually quantified in terms of the probability that the event will affect people or a system, the duration of the event, and its spatial magnitude.¹¹ Climate hazard events, like extreme precipitation, typically have an impact at a regional or larger scale; consequently, exposure is usually characterized regionally. Depending on hazard type and data sources, differences in the magnitude of exposure can often be quantified at fine spatial or temporal scales.

SENSITIVITY

Sensitivity describes the socioeconomic or demographic characteristics (e.g., race or ethnicity, income and poverty status, educational level, linguistic barriers, type of housing, built environment characteristics) that can make people susceptible to the negative effects of an exposure. It is often measured at the individual, household, or community scale. Census data on these characteristics at the national, state, county, block group, and tract levels in the United States make it relatively straightforward to characterize sensitivity to climate hazards.

ADAPTIVE (OR COPING) CAPACITY

Populations make use of both formal and informal mechanisms—resources, assets, interpersonal relationships, and institutions—to cope with or adapt to climate hazards. *Adaptive capacity* captures these mechanisms' potential to avoid, minimize, or cope with the negative effects of climate exposure.¹² Adaptive capacity is more difficult to quantify than exposure and sensitivity due to the lack of publicly available data. Proper quantification of this element typically requires collection of data at the local level.

VULNERABILITY

Vulnerability is the susceptibility to adverse effects of climate change, including both climate variability and extremes. Vulnerability measures the intersection of exposure, sensitivity to harm, and the capacity to adapt to change.¹³

MITIGATION

Mitigation refers to reducing climate change by lessening the release of greenhouse gases that trap heat in the atmosphere. This can be done, for example, by reducing the burning of fossil fuels for power, transport, or heating, or by improving the carbon sinks that can store these gases, such as soil, oceans, and forests.

ADAPTATION

Adaptation is the process of making changes in human and natural systems in order to adjust to life under current or projected climates.

WHAT IS A VULNERABILITY ASSESSMENT?

Vulnerability assessments are a helpful mechanism to identify the people and places most vulnerable to climate change at the local level. Community-scale vulnerability assessments can also be used to identify the specific vulnerabilities of a project or development of interest within a larger region.¹⁴ Developing a climate vulnerability assessment (CVA) involves identifying key exposures, sensitivities, and adaptive capacities in order to understand the potential consequences of climate change. These elements are identified and quantified by combining geospatial data, usually in the smallest geographic unit available (e.g., neighborhood, census block, or census tract), socio-demographic characteristics, the natural and built environments, and indicators of climate exposure. Having this information can inform decisions regarding what kinds of adaptation response are appropriate for each local community. Ideally, a vulnerability assessment allows communities to identify the most effective adaptation policies, the local capacities to tackle these challenges, and the steps necessary to implement adaptation responses.

To perform a vulnerability assessment, the three dimensions of vulnerability (exposure, sensitivity, and adaptive capacity; see Figure 1) are combined into what's known as a vulnerability index, which allows us to see all potential vulnerabilities at once, usually laid over a map. Unlike directly measurable phenomena, like daily maximum temperature or percentage of a population over the age of 65, vulnerability is a conceptual construct that cannot be directly measured. It is, instead, a unitless prediction of the probability or likelihood that a population will experience an adverse impact to its social, economic, or psychological well-being due to a specific hazard, such as a storm or drought event. Vulnerability indexes are a way to combine and simplify “complex and dynamic socio-ecological processes that occur at multiple spatial and temporal scales.”¹⁵ Vulnerability indicators can also be evaluated (or validated) against known and measured human well-being and livelihood outcomes (e.g., lost lives, reduced income) to assess how accurately these indicators predict populations and locations that are the most vulnerable.

WHY IS CONDUCTING A CLIMATE VULNERABILITY ASSESSMENT IMPORTANT?

Vulnerability assessments developed with quantitative data (e.g., location and magnitude of temperature exposure, raw counts or percentages of sensitive subpopulations by census tract) can be used to determine the areas with the lowest or highest vulnerability (as well as those that fall in the midrange). Visual representations of vulnerability—like maps—can be overlaid with larger political or administrative units (e.g., wards, districts, or urban planning areas) to help accurately target specific areas with the right political resources to successfully plan and implement local-level interventions.

Vulnerability assessments can also bring together a variety of stakeholders, including impacted populations, to help frame critical questions and identify opportunities to ensure the equitable access to climate change mitigation and adaptation tools across communities, cities, and regions.

WHAT CAN BE LEARNED FROM VULNERABILITY ASSESSMENTS?

As outlined in the United Nations Environment Programme's (UNEP) Vulnerability and Impact Assessment for Climate Change, there are four key questions that vulnerability assessments can help communities answer:¹⁶

1. What are the key exposures and sensitivities leading to vulnerability, and how effective are the applied coping strategies?
2. What are the key consequences of climate change impacts on the environment and human well-being?
3. What are the adaptation responses that could address the estimated impacts of climate change while helping build resilience in natural and human systems?
4. What are the types of interventions, capacities, and main steps needed to be undertaken to implement adaptations?

WHAT PEOPLE AND CRITICAL SKILLS ARE NEEDED TO DEVELOP A CLIMATE VULNERABILITY ASSESSMENT?

Developing a vulnerability assessment is a collective effort that requires knowledge and skills in leadership; project scoping and management; and research, data analysis, and mapping. Project planning and communication are also important to stakeholder engagement. Project teams tasked with developing a vulnerability assessment should have all these skills represented or partner with other organizations and specialists to produce effective results.

Leadership

Local or regional leaders in the public and private sectors can articulate a local/regional vision and help galvanize political and financial support for a vulnerability assessment. Leaders can raise the profile of the local/regional vulnerability assessment by connecting it to broader state, national, or global efforts to mitigate or adapt to climate change. For example, leaders in the health care and academic sectors, as well as city, county, or state political officials and community leaders, can be engaged to develop an inclusive, collaborative vision for a vulnerability assessment.



Project scoping and management

Professionals with local policy, legal, or governance skills can help narrow down the specific areas of policy intervention that will be considered. Defining this scope in advance will allow the team to design a vulnerability assessment that most efficiently informs the specific decisions that will need to be made.

Research and analytical skills

Researchers with academic credentials or equivalent professional experience in social and environmental sciences bring data, analysis, mapping, and other technical knowledge to the vulnerability assessment team. Skills should include expertise in geographic information systems/remote sensing, statistical and geostatistical methods, and data modeling and visualization.¹⁷ Researchers who have engaged in collaborative, participatory, or community-based research with climate-vulnerable or other frontline communities; local political officials or leaders; or stakeholders who are otherwise familiar with the local/regional political or community culture can help develop a scientifically rigorous research design that is inclusive and collaborative. Researchers with experience in developing scientific research useful for policy decision making and objectives can help develop an actionable vulnerability assessment. Local university partners can be useful in identifying researchers who could provide these skills to assist in the development of a climate vulnerability assessment.



HOW CAN A CLIMATE VULNERABILITY ASSESSMENT BE TRANSLATED INTO LOCAL ACTION?

The opportunities for integrating the results of a climate vulnerability assessment into action will vary by sector and scale of the project. For example, the Washington State Department of Transportation leveraged its vulnerability assessment findings to prepare for climate risks associated with transportation infrastructure.¹⁸ The recommendations they developed as a result of the assessment will be used to guide planning, design, programming, and investment decisions for more resilient transportation systems.

The city of Cambridge, Massachusetts, developed a Climate Change Preparedness and Resilience Plan, informed by a climate vulnerability assessment that identified Cambridge's key physical and social vulnerabilities.¹⁹ Through a multi-stakeholder engagement process, the city and community formulated a strategy to address the impacts and reduce their greenhouse gas emissions.

In Detroit, the Detroiters Working for Environmental Justice led a community-driven climate vulnerability assessment that became the basis for the city's Climate Action Plan, which includes actionable solutions on issues of water infrastructure, public health responses, business, solid waste, and homes.²⁰

Part Two: Developing a Climate Vulnerability Assessment

BEFORE YOU BEGIN

During the planning phase before a vulnerability assessment begins, three areas must be addressed: the *general process and scope* of the assessment, *political and financial support* available to conduct it, and the *technical issues* that could arise when performing it.²¹

General process and scope

A general scoping process can help ensure that the assessment will meet the needs of the project and inform the decisions being made. Many initial questions about process and scope are covered in the four key questions developed by UNEP for vulnerability assessments (see Part One), but additional details should also be considered during the scoping of individual projects. For example:

- What specific questions should the vulnerability assessment answer?
- What decisions should the vulnerability assessment support?
- What is the time frame for planning, development, refinement, and finalization of the vulnerability assessment?
- What are the necessary and available technical capacities and skills to conduct the vulnerability assessment?

Political and financial support

After completing the process and scoping phase, team members assisting with the creation of the assessment should identify the political and financial support necessary to complete the project. For example:

- What is the budget for planning, developing, refining, and finalizing the vulnerability assessment?
- Who will manage development of the vulnerability assessment?

Technical issues

Finally, the successful completion of a vulnerability assessment requires the identification of possible technical barriers in the assessment process and should identify ways in which to overcome these barriers. Useful questions to answer include:

- What is the availability of the data needed to conduct the vulnerability assessment? Are there data gaps? Will there be costs for data acquisition?

- Where and how will the data and analysis used to develop the vulnerability assessment be stored?
- Will it be necessary to sign data-sharing agreements with data providers?
- Will the vulnerability assessment use data on individuals' medical records and other personal health information subject to privacy protections under the Health Insurance Portability and Accountability Act (HIPAA) or other regulations?²²
- If there are regulatory obligations related to HIPAA or other statutes, will it be necessary to obtain approval from an institutional review board to use such data?²³
- Will any models be developed that can be used for future scenario analysis?

Steps for generating a vulnerability assessment

The primary product of a vulnerability assessment is the vulnerability index, which can layer vulnerabilities to all potential exposures on top of one another to form a vulnerability map. As described earlier, vulnerability can be defined as an outcome of exposure, sensitivity, and adaptive capacity. Functionally, we can specify a formula for vulnerability as follows:

$$\text{Vulnerability} = (\text{Exposure} * \text{Sensitivity}) - \text{Adaptive Capacity}$$

In this framing, vulnerability *increases* with increasing exposure and sensitivity, but *decreases* with increasing adaptive capacity. We can assess the relationship between individual community-level indicators of exposure, sensitivity, and (where possible) adaptive capacity and build them into an index of climate hazard vulnerability mapped at the community level.

The Centers for Disease Control and Prevention (CDC) provides “cookbook”-style guidance with steps to develop community-level vulnerability assessments (see box page 16). Although the CDC’s guide focuses on public health outcomes of climate, the sequence of steps is both relevant and easily adaptable to a broad spectrum of climate hazards and outcomes. We will provide greater detail in the following section, but these steps provide a good initial overview of the process.

CDC'S SEQUENCE OF STEPS TO DEVELOP INDEX-BASED VULNERABILITY ASSESSMENTS

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, preexisting 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
4. Assess adaptive capacity in terms of the ability of the system (e.g., communities, institutions, public services) 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

Adapted from CDC's BRACE framework.²⁴

EXPLORING EXPOSURE, SENSITIVITY, ADAPTIVE CAPACITY, AND VULNERABILITY INDEXES

Preliminary analysis of exposure

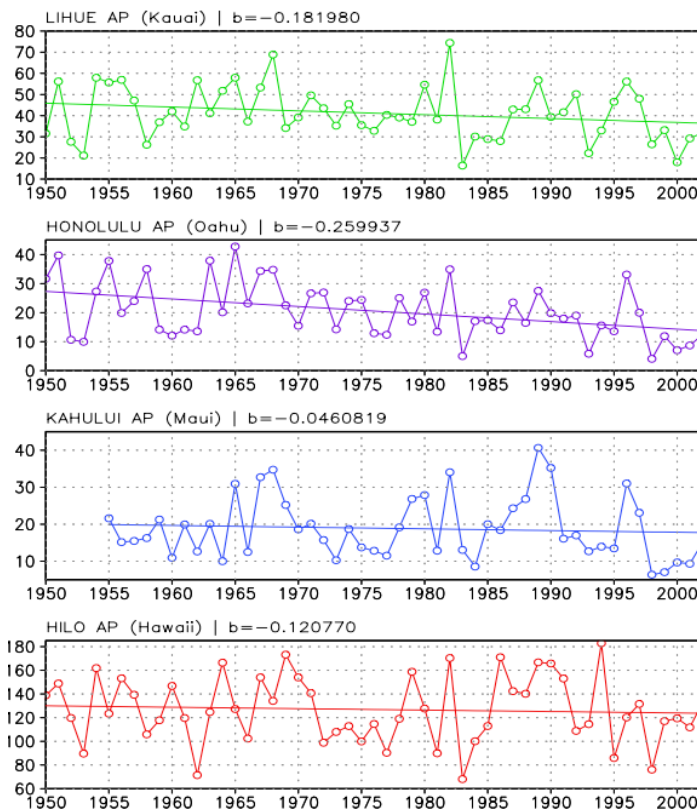
The first step in the development of a climate vulnerability assessment is to understand how much the climate hazard of interest is likely to vary in the study area over time and space (e.g., the projected amounts of sea-level rise in a region over a given time). This preliminary analysis can help you more accurately limit the assessment to the relevant time frame and geographic areas.

For example, a 2003 drought vulnerability assessment in Hawaii began with time series plots of annual rainfall data from rain gauges in four specific locations (airports) across the archipelago (Figure 2).²⁵

The preliminary analysis found a clear downward trend in precipitation that accelerated during the last 20 years of data and was most pronounced at the Honolulu location (purple graph) compared with the Lihue, Kahului, and Hilo locations (green, blue, and red, respectively, in Figure 2).²⁶

Through the preliminary analysis, the downward trend in precipitation was identified as a statewide issue in Hawaii. The study's scope was therefore set to encompass the entire state.

FIGURE 2: PRELIMINARY EXPLORATION OF CLIMATIC DATA CAN HELP IDENTIFY TRENDS IN EXPOSURE USEFUL FOR VULNERABILITY ASSESSMENTS



Source: University of Hawaii and Social Science Research Institute (SSRI), 2003.

DEFINITION OF KEY TERM

A **correlation analysis** measures the strength of the relationship between two variables. A high correlation means that the two variables have a strong relationship, while a low correlation implies that they are hardly related to each other. Positive correlations indicate that as one variable increases, so does the other. A negative correlation implies that as one variable increases, the other decreases. For example, in general, income has a positive correlation with educational achievement, and land surface temperature has a negative correlation with tree canopy.

Preliminary analysis of sensitivity and adaptive capacity

Performing a preliminary analysis of sensitivity and adaptive capacity will provide an important understanding of the ways in which social, economic, demographic, and built environment factors (e.g., impervious pavement, roof reflectivity) shape vulnerability at the regional level. For this exploratory analysis, start by assembling a comprehensive list of variables that are thought or known to be individual or community-level predictors of vulnerability to climate impacts. Preliminary variables can be climate hazard specific, but in general, choosing variables that describe individuals with low socioeconomic status and lack of material resources (e.g., low income, lack of access to transportation) is an adequate starting point because these populations have been shown to be at higher risk of adverse impacts across the spectrum of climate hazards.²⁷

The assembled variables should be subjected to a correlation analysis to understand how variables change with respect to one another. This analysis can also help contextualize the results of the vulnerability assessment (e.g., showing which populations are most affected by higher temperatures) and help remove variables that are not related to the outcome of interest.

For example, the team planning an epidemiological study of extreme heat vulnerability in Maricopa County, Arizona, began with an exhaustive list of variables identified in the heat-health research literature as predictors of extreme heat mortality and morbidity.²⁸ On examination of the correlation coefficients, it was found that housing tenure (i.e., percentage of renters versus homeowners) and housing stock age had a very high correlation (i.e., statistically significant correlation coefficients very close to ± 1.0) with the Latino immigrant and poverty variables; they were therefore excluded from the final analysis as being redundant (see Table 1). Elimination of redundant variables is generally prudent because vulnerability indexes or other explanatory models based on too many variables with a high degree of covariance (i.e., a strong relationship with one another) can lead to a model that finds a higher degree of climate vulnerability than actually exists (see the correlation analysis in Table 4A).

TABLE 1: PRELIMINARY ANALYSIS OF CLIMATE VULNERABILITY RISK FACTORS CAN HELP IDENTIFY THE DYNAMICS BETWEEN SOCIOECONOMIC STATUS AND BUILT ENVIRONMENT CHARACTERISTICS

VARIABLE NAME	INCLUDE IN FINAL ANALYSIS	EXCLUDE FROM FINAL ANALYSIS
Ethnic minority	✓	
Latino immigrant	✓	
No high school diploma	✓	
Living below poverty line	✓	
Above 65 years of age	✓	
Living alone	✓	
Land Surface temperature	✓	
Impervious surface	✓	
Housing Tenure (renter vs. owner)		✓
Housing stock age		✓

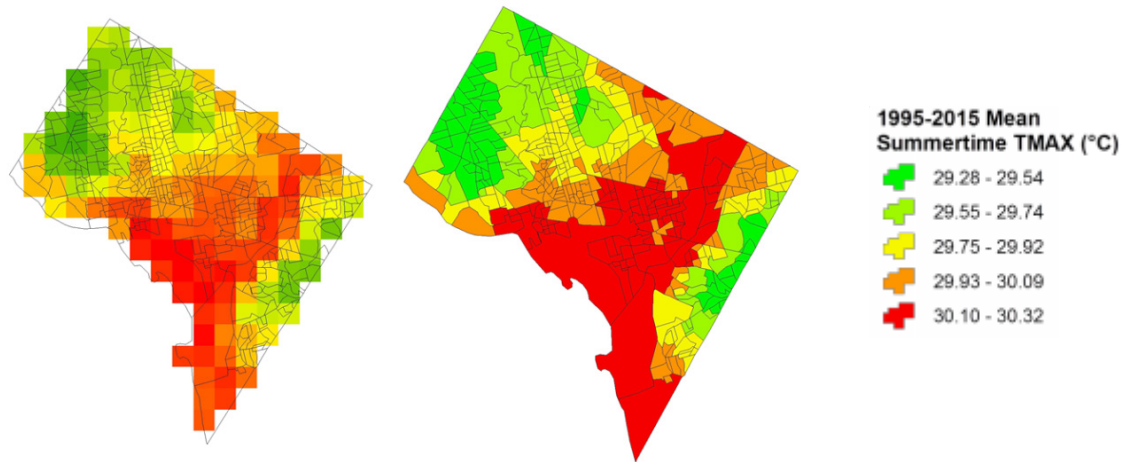
Adapted from Harlan et al. 2013.²⁹

Ensuring the proper scale of variables across space and time

Given the availability of demographic information, census tracts or census block groups are typically the geographical scale of choice for U.S.-based community-level vulnerability assessments. If other spatial units of aggregation are preferred, such as zip codes, planning villages, or districts, it will be necessary to aggregate demographic data to those units.

Data from other sources, however—for example, on health outcomes, temperature, air pollutant concentrations, land use/land cover, or housing characteristics—are collected at different spatial scales. This creates the need to aggregate to a common spatial unit. Processing data to a usable format is commonly done by using the geoprocessing functions of a geographic information system (GIS). For instance, we can use data from satellite imagery to obtain land surface temperature data by averaging surface temperature from each pixel within a census tract (Figure 3). Once data transformation of such data sources is completed, these data can be incorporated with available census tract or census block group data in a vulnerability assessment.

FIGURE 3: TEMPERATURE DATA PROVIDED IN A GRIDDED PIXEL FORMAT (LEFT) CAN BE AGGREGATED TO CENSUS AGGREGATION UNITS LIKE CENSUS BLOCK GROUPS (RIGHT) IN A VULNERABILITY ASSESSMENT. HERE, THE AVERAGE TEMPERATURE VALUE OF PIXELS REPRESENTING 1 SQUARE KILOMETER EACH HAS BEEN CALCULATED FOR CENSUS BLOCK GROUPS IN WASHINGTON, D.C.



Source: Deplet-Barreto, based on NASA DAYMET.³⁰

Besides spatial scale issues, there are time scale mismatches that need to be considered as well. For example, census data and hazard data may have been collected at different times. There are far fewer tools available to resolve temporal mismatches, but awareness of these mismatches is important when determining how the assessment can and should be used.

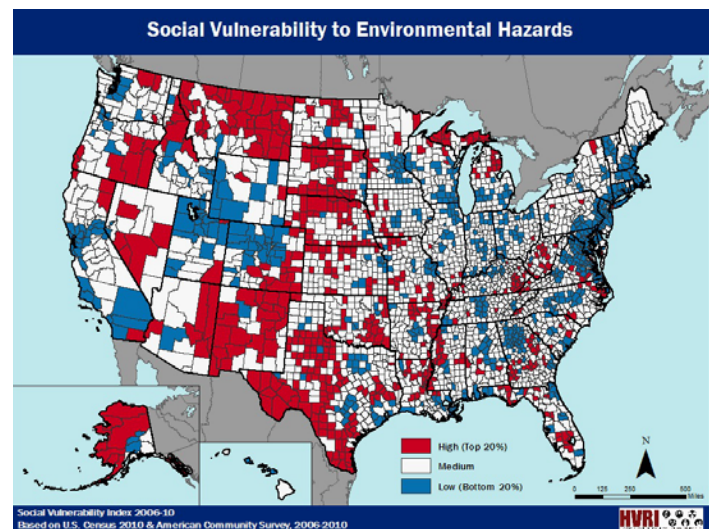
Vulnerability indexes

Vulnerability indexes allow researchers to examine population vulnerability to a variety of variables simultaneously instead of one by one. A climate vulnerability assessment can be used to produce a climate vulnerability index—that is, a map of overall vulnerability to the selected climate risks. Although vulnerability assessments can be conducted without generating vulnerability indexes, combining multiple climate risk factors into one indicator can visually provide more useful information than individual maps of isolated risk factors. Furthermore, vulnerability indexes can help visualize social and spatial relationships among risk factors that may not otherwise be evident.

Construction of community-level vulnerability indexes is an increasingly popular technique used by academic, public health, and climate impact researchers to identify the locations of climate-vulnerable people and places. The availability of public, geospatially explicit data on climatic phenomena, socio-demographic characteristics of populations, and the natural and built environments, combined with improvements in GIS and other computational geospatial analytical and mapping platforms, has increased the development and use of fine-scale vulnerability indicators.

For example, the CDC’s Social Vulnerability Index (SVI) uses census data to map the social vulnerability of every census tract in the United States, synthesizing 29 socioeconomic variables (Figure 4). The SVI is useful to identify special-needs and other vulnerable populations.³¹

FIGURE 4: THE SOCIAL VULNERABILITY TO ENVIRONMENTAL HAZARDS INDEX (SVI) PIONEERED THE USE OF REGIONAL AND LOCAL-SCALE INDEXES OF RISKS TO HAZARDS



Source: University of South Carolina Hazards & Vulnerability Research Institute.

DATA SOURCES, CHALLENGES, AND OPPORTUNITIES OF CLIMATE VULNERABILITY ASSESSMENTS

Obtaining data to conduct a vulnerability assessment

Vulnerability assessments should use, to the greatest extent possible, publicly available data that are periodically updated. Data needs will vary if there is a need to create separate climate vulnerability indexes that represent past, present, and future conditions. Data on climate exposures, as well as on socioeconomic, demographic, and built environment characteristics, are systematically assembled

by various government agencies and should be used wherever possible. Doing so increases both reproducibility over time and comparability across other study areas of vulnerability assessments. Table 2 gives example data sets and provides a starting point for locating data sources that may be useful to conducting a climate change vulnerability assessment.

TABLE 2: PUBLICLY AVAILABLE DATA SOURCES TO CONDUCT VULNERABILITY ASSESSMENT

DIMENSION	DATA SET	SOURCE	SPATIAL UNIT
CLIMATE HAZARDS			
Flooding	National Hazards Flood Layer	Federal Emergency Management Agency	Polygon
Drought	U.S. Drought Monitor	National Drought Mitigation Center	Polygon
Sea-level rise	Sea-level rise data and trends	NOAA National Climate Data Center	Polygon
Surface temperature	Landsat	U.S. Geological Survey	Pixel
Air temperature (observed)	Various data products, e.g., air temperature, relative humidity, wind direction	NOAA National Climate Data Center	Pixel and weather stations
Air temperature (modeled)		NASA	Pixel
Air quality	DAYMET Air data	Environmental Protection Agency	Air quality monitor
SOCIOECONOMIC AND DEMOGRAPHIC			
Poverty/Income	American Community Survey	U.S. Census Bureau	Census tract or block group
Race/Ethnicity	Decennial Census	U.S. Census Bureau	Census tract or block group
Disability status	American Community Survey	U.S. Census Bureau	Census tract or block group
Educational achievement	American Community Survey	U.S. Census Bureau	Census tract or block group
Language(s) spoken at home	American Community Survey	U.S. Census Bureau	Census tract or block group
Housing characteristics	Tax Assessor Data	County or Municipal Assessor's Office	Parcel/building
Age	Decennial Census	U.S. Census Bureau	Census tract or block group
BUILT ENVIRONMENT			
Land use/Land cover	National Land Cover Data Set	U.S. Geological Survey	Pixel

Adapted from Deplet-Barreto, 2013.³²



Data challenges and opportunities

Developing effective vulnerability assessments requires careful consideration of the data used to represent climatic hazards and vulnerabilities. One of the main challenges in characterizing climatic hazards is making sure that the spatial and temporal data on climate indicators line up with vulnerability outcomes. These will vary from hazard to hazard. For example, exposure to ozone over a 24-hour period is associated with increased mortality and morbidity from asthma attacks or cardiovascular disease, suggesting that air pollutant data should be broken down by day. On the other hand, drought and associated vulnerability outcomes typically will vary more seasonally than daily, implying that drought risks should be considered over longer time frames.³³

Characterizing temperatures in cities provides a few unique challenges and opportunities. For example, fine-scale or community-level land surface temperatures over a region can be obtained through satellite imagery, but publicly available satellite data are usually limited to daytime snapshots at a particular point in time. Alternatively, weather station data from professionally operated sensor networks can be obtained for longer periods of time and other temporal scales (e.g., hourly, daily, monthly) but are typically available only for the few locations where weather stations are located, limiting spatial resolution in favor of temporal variability. Therefore, characterizing temperature-related hazards usually involves a trade-off between spatial and temporal detail.

Publicly available data from federal agencies are provided in a uniform format and are periodically updated; these should be used whenever possible. For example, demographic data from the U.S. Census Bureau or satellite imagery from the U.S. Geological Survey (USGS) are reliable, public data sources available for download and integration into vulnerability assessments. Census data contain a wealth of information describing a population's social, demographic, and economic characteristics, such as race/ethnicity, poverty status, income, language proficiency, disability, educational achievement, and so on. Similarly, data describing built and natural environments are available from USGS and local county tax assessors' parcel data. The most systematic remotely sensed USGS data describing land use/land cover as well as the thermic, geologic, and topographic characteristics of the built and natural environments are available through various satellite imagery programs, such as Landsat.

TIME REQUIRED TO COMPLETE A VULNERABILITY ASSESSMENT

The time needed to complete a vulnerability assessment depends on a number of factors, including data availability, accessibility of technical resources, and complexity of the questions being asked. Simple assessments with readily available data, performed by technical experts proficient in executing a vulnerability assessment, can be completed in a relatively short time ranging from a matter of weeks to 1–3 months, depending on data needs. Complex assessments in which data need to be collected (e.g., health information, adaptive capacity information) can take months or longer to complete.

Part Three: Vulnerability Assessments in Practice— Case Studies

Here we provide case studies of vulnerability assessments in two U.S. metropolitan areas. The first, based in Maricopa County, Arizona (including Phoenix and its suburbs), sought to understand the social and environmental predictors of extreme heat vulnerability in a southwestern U.S. region. The second case study, focused on Washington, D.C., sought to identify specific areas of the city that were most vulnerable to summertime outdoor heat and related health impacts. These two cases reflect two different types of scoping (one research-centered, the other based on city-directed questions) and are useful illustrations of how different types of data can help inform local decision making for climate adaptation planning.

CASE STUDY 1: SOCIAL AND ENVIRONMENTAL PREDICTORS OF EXTREME HEAT VULNERABILITY IN MARICOPA COUNTY, ARIZONA

This case study presents a climate vulnerability assessment created to understand the social and environmental determinants of extreme heat mortality in a hot and arid metropolitan region in the U.S. Southwest.³⁴ More specifically, this climate vulnerability assessment addressed the question: *What characteristics of urban neighborhoods affect the risk of residents dying from extreme heat?*

This data-rich case study relied upon a complete data set for sensitivity, exposure, adaptive capacity, and a related health outcome.

Data Sources and Analysis

To complete this analysis, multiple variables (including race/ethnicity, age, educational status, access to air-conditioning, built environment characteristics, temperature, and health outcomes) were used to map social and environmental determinants of extreme heat mortality, as shown in Table 3.

Data from a range of sources were collected for this analysis, including publicly available data from the U.S. Census Bureau and the USGS. Air-conditioning/cooling information at the census block group level was calculated using data obtained from Maricopa County Tax Assessor 2010 parcel registry records. Data on heat-related deaths were obtained from a surveillance system specifically designed by the Maricopa County Department of Public Health to identify weather-associated heat-caused and heat-related deaths.³⁵

A heat vulnerability index (HVI) for census block groups in Maricopa County was developed and mapped. In the first stage of the analysis, statistical correlations of individual and neighborhood-scale risk factors for heat-related death were generated (Table 4A).

TABLE 3: VARIABLES AND DATA SOURCES USED IN NEIGHBORHOOD HEAT MORTALITY STUDY IN PHOENIX, ARIZONA

VARIABLE NAME	DATA SET	SOURCE
Ethnic minority	2010 Census	U.S. Census Bureau
Latino immigrant*	2010 Census and American Community Survey	U.S. Census Bureau
No high school diploma	American Community Survey	U.S. Census Bureau
Living below poverty line	American Community Survey	U.S. Census Bureau
65 years of age and above	2010 Census	U.S. Census Bureau
65 years of age and above and living alone	2010 Census	U.S. Census Bureau
No AC/Cooler	Decennial Census	U.S. Census Bureau
Unvegetated area	Landsat	U.S. Geological Survey
Landsurface temperature	Landsat	U.S. Geological Survey
Heat health outcomes	Heat-related deaths	Maricopa County Department of Public Housing

*This variable was built as a composite of the foreign-born, Spanish-only speaking population.

Adapted from Deplet-Barreto, 2013.³⁶

TABLE 4A: CORRELATIONS ANALYSIS OF HEAT-HEALTH INDIVIDUAL AND COMMUNITY RISK FACTORS IN MARICOPA COUNTY, ARIZONA

Variable	Ethnic minority	Latino immigrant	< Poverty line	No HS diploma	Age ≥ 65 years	Age ≥ 65 years x living alone	Living alone	No AC/ cooler	Unvegetated area		Land surface temp	
									Mean	SD	Mean	SD
Mean	0.34	0.11	0.12	0.20	0.13	0.08	0.24	0.13	-0.21	-0.11	54.28	2.14
SD	0.26	0.12	0.13	0.19	0.17	0.09	0.14	0.22	0.07	0.06	1.94	1.19
Ethnic Minority	1.00											
Latino immigrant	0.81**	1.00										
< Poverty line	0.74**	0.71**	1.00									
No HS diploma	0.84**	0.80**	0.73**	1.00								
65 years of age and above	-0.40**	-0.25**	-0.18**	-0.14**	1.00							
65 years of age and above and living alone	-0.26**	-0.14**	-0.03	-0.02	0.88**	1.00						
Living alone	-0.16**	-0.09**	0.10**	-0.60**	0.45**	0.63**	1.00					
No AC/cooler	0.67*	0.64**	0.57**	0.68**	-0.16**	-0.04	-0.06	1.00				
Unvegetated area, 24 July 2000 (mean)	0.16**	0.17**	0.22**	0.20**	0.00	0.02	0.04	0.15**	1.00			
Unvegetated area, 24 July 2000 (SD)	0.10**	0.13**	0.11**	0.10**	-0.14**	-0.08**	-0.06**	0.16**	0.69**	1.00		
Land surface temperature, 24 July 2000 (mean)	0.35**	0.32**	0.33**	0.37**	-0.11**	-0.06**	-0.08**	0.32**	0.78**	0.67**	1.00	
Land surface temperature, 24 July 2000 (SD)	-0.08**	-0.13**	-0.07**	-0.06**	0.10**	0.04	0.00	-0.18*	-	-	-0.54**	1.00
									0.47**	0.86**		

Means, SDs, and Pearson’s correlations for variables in the 2000 U.S. Census Maricopa County block groups (n = 2,081).

Adapted from Harlan et al., 2013.³⁷

Most of the heat risk factors in Table 4A were correlated to land surface temperatures, which allowed them to be placed together into three groups of related variables.³⁸ The resulting groupings or “factors” were given different names to reflect common characteristics of the grouped variables: socioeconomic vulnerability, elderly/isolation, and unvegetated areas (Table 4B).

In the final stage of the analysis, scores for each “factor” were assigned to census block groups. An HVI was created for each census block group by adding together the three factor scores. The HVI was then evaluated against heat-related deaths (geolocated at decedents’ residential address) in order to link the deaths to the socioeconomic and built environment characteristics that influence heat-related mortality in census block groups (Figure 5).

The results suggested that the three main drivers of heat deaths—socioeconomic vulnerability, age-based and social isolation, and unvegetated areas—varied widely throughout Phoenix. The highest vulnerability was found in the industrial corridors in and around downtown Phoenix and East Valley areas, where many low-income Latino immigrants and other populations of color live, and in the retirement communities in the northwestern fringe of the region, where the population is mostly elderly. Furthermore, it was found that many deaths (including those of many homeless individuals) occurred in the downtown and industrial corridors of the metro region.

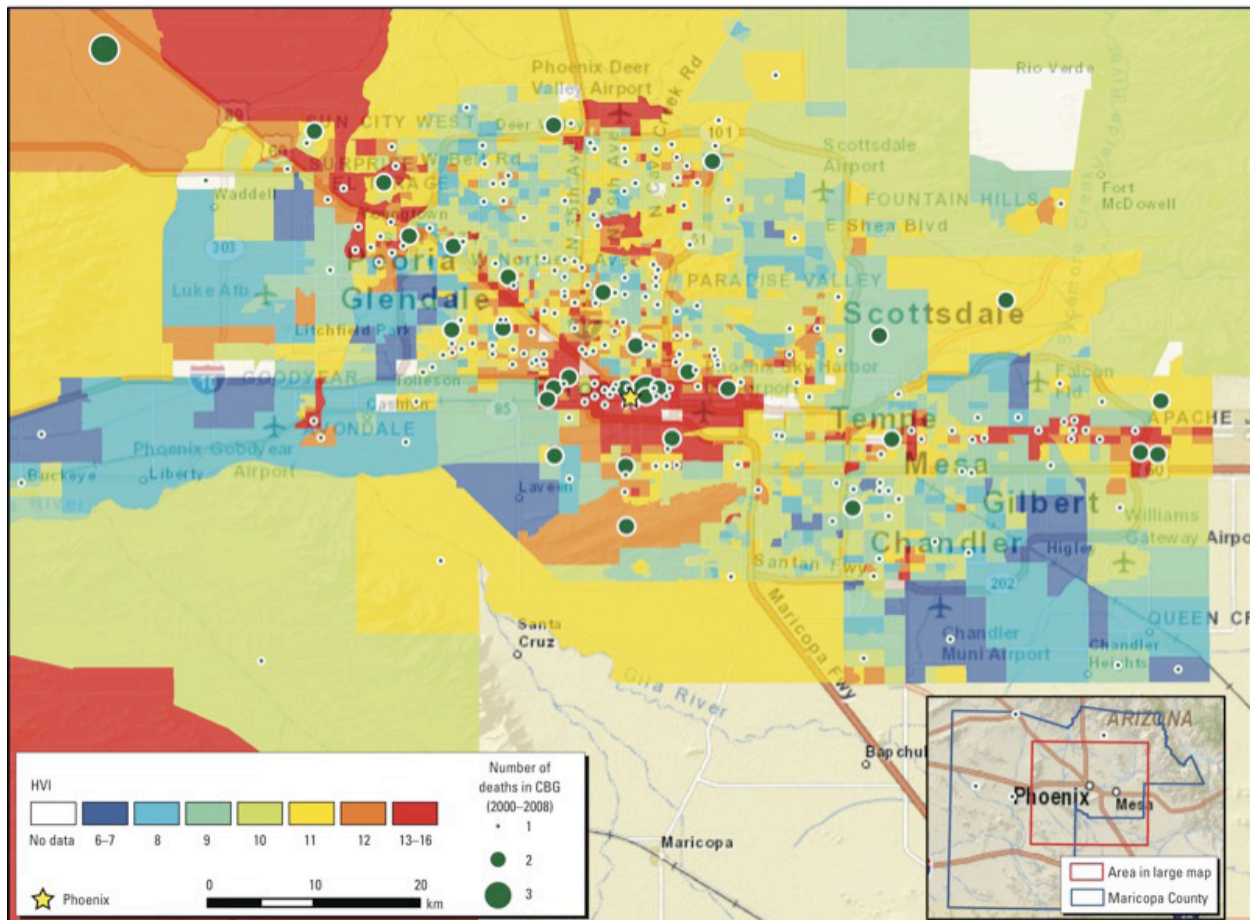
TABLE 4B: INDIVIDUAL AND NEIGHBORHOOD-SCALE COMBINED HEAT RISK FACTORS TO DESCRIBE HEAT VULNERABILITY IN MARICOPA COUNTY, ARIZONA

Variable	Factor Loading		
	Factor 1: Socioeconomic Vulnerability	Factor 2: Elderly/Isolation	Factor 3: Unvegetated area
Ethnic minority	0.91	-0.25	0.04
Latino immigrant	0.90	-0.11	0.06
< poverty line	0.86	0.04	0.09
No high school diploma	0.92	0.03	0.06
No central AC/cooler	0.79	-0.03	0.09
65 years of age and above	-0.19	0.88	-0.04
65 years of age and above and living alone	-0.03	0.96	-0.02
Living alone	0.01	0.77	0.01
Unvegetated area, (mean)	0.14	0.06	0.91
Unvegetated area, (SD)	0.05	-0.10	0.92

Factor extraction was performed using varimax rotation so that the factors are uncorrelated with each other. The numbers in the columns are factor loadings that represent correlations between the variables and factors and also the weights of each variable on the factors.

Adapted from Harlan et al., 2013.³⁹

FIGURE 5: HEAT VULNERABILITY IN METRO PHOENIX⁴⁰



Analytical Challenge

One of the main challenges of conducting this research was obtaining death certificate data from the county coroner. Obtaining and analyzing human subjects' medical information was guided by an institutional review board-approved protocol, a time- and resource-intensive process critical to ensuring that research involving human subjects is done in an ethical and legal way.

Opportunities to Translate Analysis Into Action

The map provides valuable information that urban planners can use to prioritize modifications to the built environment that can help mitigate extreme heat and incorporate equitable outcomes. For example, based on a growing body of research and concern about urban heat island impacts, zoning codes in downtown Phoenix have recently been updated to require pedestrian-friendly and walkability features such as shading.⁴¹ Equitable interventions focused on climate justice would target the areas of greatest need according not only to high temperatures and shading vegetation deficits, but also to the presence of vulnerable populations, two criteria that the information developed in this research provides.⁴²

The vulnerability assessment map also provides critical information to identify populations with similar vulnerability profiles but different socio-demographic characteristics. For example, the three major population clusters of high vulnerability (in red in Figure 5) are made up, generally speaking, of elderly people (in the northwest area), low-income Hispanics and African-Americans (in the central part of the city), and low-income individuals (of multiple races and ethnicities) in the suburban corridors in the eastern part of the metro area. These populations have different needs related to safety from extreme heat and therefore will require targeted interventions in order to reduce their vulnerabilities to adverse heat health outcomes.⁴³

CASE STUDY 2: MAPPING EXTREME HEAT VULNERABILITY TO INFORM THE DISTRICT OF COLUMBIA'S CLIMATE ADAPTATION PLAN

This case study reports on a research partnership between climate and health scientists and the government of the District of Columbia (Washington, D.C.) to map heat-vulnerable populations and elements of the built environment.⁴⁴ The main goal of the project was to provide fine-scale (e.g., census block group) information that could be used to develop climate adaptation strategies focused on public health and on built environment modifications. The project sought to answer the following questions:

- *What areas of the city contain the most heat-sensitive populations according to individual heat-health risk factors?*
- *What areas of the city have the highest outdoor heat exposure potential due to impervious surfaces and low tree canopy cover?*
- *What areas of the city are most vulnerable to adverse heat-health outcomes based on both heat sensitivity of the population and heat exposure in the built environment?*

This case study illustrates the utility of performing a vulnerability assessment even when sensitivity data such as heat-health outcomes or adaptive capacity such as tree canopy cover or cooling center access are not immediately available. The data set in the Maricopa County study benefited from additional data on heat-related mortality to identify variables associated with heat vulnerability. However, even if health outcome data are not available, an assessment can still be performed to identify vulnerable areas and people.

Data Sources and Analysis

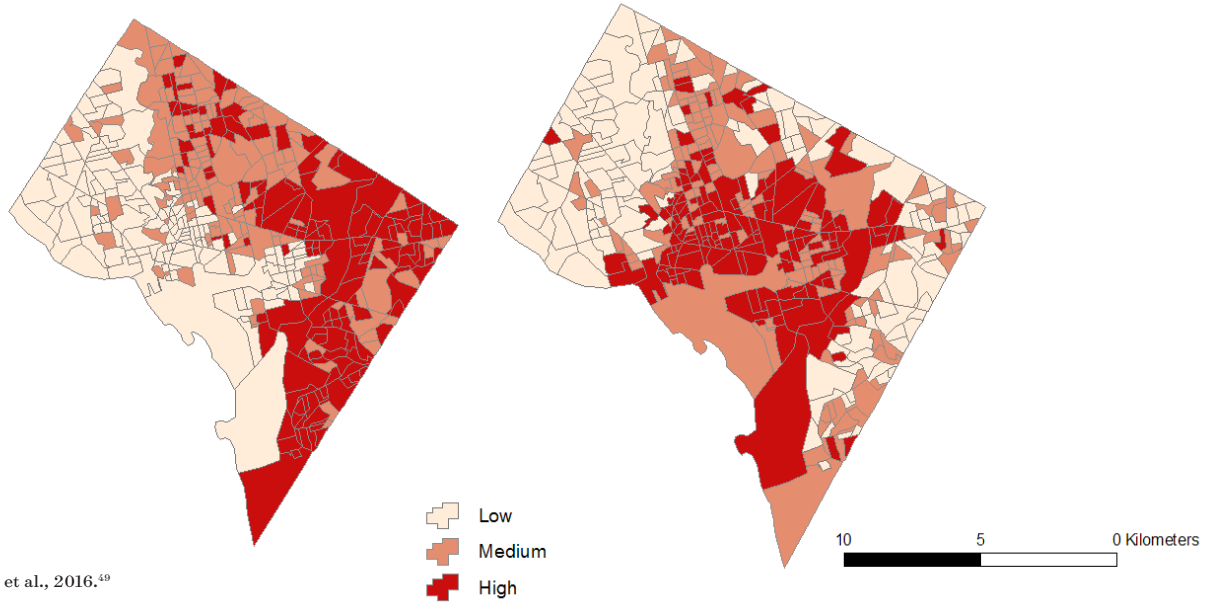
To locate sensitive populations within the study area, heat-vulnerable populations were identified and mapped using 2010 U.S. Census and GIS data. Heat-sensitive populations included people of color and individuals with low educational achievement (i.e., without a high school diploma or General Education Development [GED] equivalent), living at or under the poverty threshold, receiving government nutritional assistance, living with at least one physical or mental disability, or without air-conditioner units in their dwelling.

Elements of the built environment associated with higher temperatures (i.e., impervious surfaces and absence of tree canopy) were identified using Landsat data from the USGS.⁴⁵ Twenty-year surface temperature averages were calculated using NASA Daymet data.⁴⁶ These variables were assembled for census block groups in the District, statistical normalization was applied to the variables (to ensure that the exposure and sensitivity variables were comparable to one another), and the scores were added to build individual indexes representing sensitivity and exposure (Figure 6).⁴⁷ Index scores were classified into one of three categories representing low, medium, or high exposure/sensitivity conditions.

The sensitivity and exposure indexes were then combined into a heat vulnerability index (Figure 7).⁴⁸

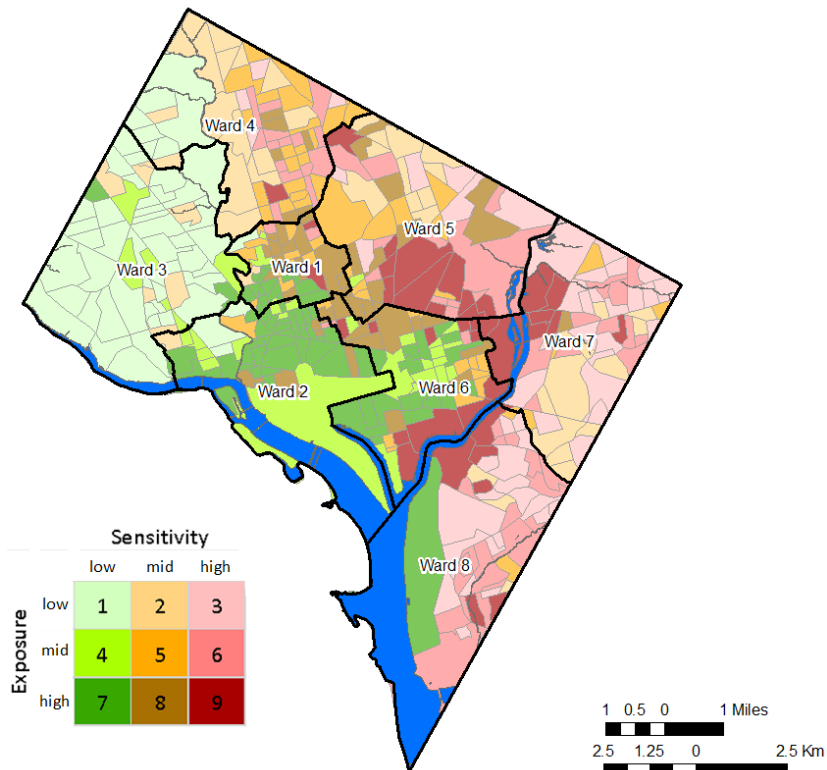
FIGURE 6: SENSITIVITY AND EXPOSURE TO EXTREME HEAT IN WASHINGTON, D.C.

Sensitivity (a) includes percentages not white, no high school diploma, living in poverty, elderly, receiving food stamps, with disability, and with no AC. Exposure (b) includes percentages impervious surface (mean), impervious surface (SD), no tree canopy, mean daily maximum air temperature (May–September, 1995–2015). Sensitivity and exposure vary greatly across the District of Columbia.



Adapted from Deplet-Barreto et al., 2016.⁴⁹

FIGURE 7: THE HEAT VULNERABILITY INDEX CAPTURES THE COMBINATION OF SENSITIVITY AND EXPOSURE TO EXTREME HEAT IN THE DISTRICT OF COLUMBIA



Adapted from Deplet-Barreto et al., 2016.

The cells numbered 3, 6, and 9 indicate areas of the city with high sensitivity (e.g., lower income, lower educational attainment) across low, medium, and high exposure to heat. These combinations are most commonly found in Wards 5, 7, and 8, which are areas of the city with varying levels of exposure and with poorer and otherwise more sensitive populations. Wards 1, 2, and 3, conversely, have populations with mostly low sensitivity across all exposure values (i.e., values of 1, 4, and 7).

Analytical Challenges

Obtaining fine-scale weather data to understand temperature variability was particularly challenging for this study. The District of Columbia has only one professionally operated weather station, which makes it difficult to tease out differences in temperature across the District. Instead of using directly measured temperature values, the weather data from Daymet is generated using a computer model. Because the data are modeled, Daymet may not accurately capture temperature variations across the city. This challenge highlights the need for more and better data (i.e., with higher spatial and temporal resolution) to adequately characterize intra-city differences in heat exposure.⁵⁰

Opportunities to Translate Analysis Into Action

Bringing together scientists and policymakers, such as with this partnership between climate and health scientists and the District government, increases the potential for the development of actionable research findings. The three maps generated by this collaborative effort (socioeconomic sensitivity, built environment exposure, and heat vulnerability index) can help climate adaptation efforts to better design public health interventions during the hot season and inform longer-term urban landscape changes that can reduce exposure to extreme outdoor temperatures.

Project results were shared with District of Columbia government policymakers working in sustainability, public health, and urban planning capacities. It is expected that the project will inform both the District's climate adaptation plan and Resilient DC, the District's climate resilience strategy.⁵¹



Washington, D.C.

© Ansh via Unsplash

Appendix I: The Path to Integrating Climate Vulnerability Assessments

Figure 8 provides a visual breakdown of the steps to completing a climate vulnerability assessment, starting with identifying risks and understanding your goals, then building partnerships across science and community leaders, collecting and analyzing data, and developing and implementing solutions to reduce impacts from climate risk. Refer to this pathway guide when planning and implementing the assessment.

FIGURE 8: SIX STEPS TO A SUCCESSFUL COMMUNITY VULNERABILITY ASSESSMENT



Appendix II: Additional Resources for Communities Applying Climate Vulnerability Assessments

The person or group leading a climate vulnerability assessment may benefit from a few additional resources. This report outlines a technical approach, but these assessments can be adapted to the goals or needs of the community, including utilizing less technical processes that rely on qualitative data and local knowledge. Tools such as the ones below provide additional ideas for developing cross-sectoral partnerships in completing a CVA; communicating and messaging climate-adaptive solutions with other stakeholders; and centering climate justice, equity, and the social dimensions of climate change.

We recommend:

[U.S. Climate Resilience Toolkit](#)⁵² provides extensive information and tools on how to assess vulnerability and how others are approaching and analyzing this issue, including data and case examples from across the country.

[CAKEx.org](#)⁵³ is a resource for climate adaptation case studies and research.

[Thriving Earth Exchange](#)⁵⁴ provides resources for taking community-based science from ideas to action. Its four-step process of scoping priorities, matching with scientists, designing solutions, and sharing the results support the use of science in advancing community goals.

[Rapid Climate Vulnerability Assessment](#)⁵⁵ (RCVA) introduces what such an assessment is and how communities can use this resource to ensure their project work is designed to be resilient to climate change without the use of vulnerability indexes. A webinar provides an overview of RCVAs and resources for developing a one-day climate workshop in your community.

[Climate Justice Alliance](#)⁵⁶ is a national network of frontline communities working to take climate-resilient action across the country by building a just transition away from extractive development in favor of solutions that place equity in the forefront.

[The Climate Optimist](#)⁵⁷ is a resource for climate messaging to help make the case to partners and influencers through positive attitudes focused on solving climate change.

ENDNOTES

- 1 California Office of Environmental Health Hazard Assessment, *Indicators of Climate Change in California: Report Summary*, August 2013, <https://oehha.ca.gov/media/downloads/climate-change/risk-assessment/climatechangeindicatorssummaryaugust2013.pdf>.
- 2 Union of Concerned Scientists, “Preparing for Climate Change Impacts in Los Angeles: Strategies and Solutions for Protecting Local Communities,” December 2012, <https://www.ucsusa.org/resources/preparing-climate-change-impacts-california>.
- 3 “Hurricane Michael Strikes Some of the Nation’s Most Vulnerable,” Cision PR Newswire, October 10, 2018, <https://www.prnewswire.com/news-releases/hurricane-michael-strikes-some-of-the-nations-most-vulnerable-communities-300729106.html>.
- 4 “Hurricane Michael,” Direct Relief, <https://directrelief.maps.arcgis.com/apps/CompareAnalysis/index.html?appid=621eff2a506a4614bec051059e2dd030> (accessed January 22, 2020).
- 5 Junia Howell and James R. Elliott, “Damages Done: The Longitudinal Impacts of Natural Hazards on Wealth Inequality in the United States,” *Social Problems* 66, no. 3 (August 2019): 448-467, <https://academic.oup.com/socpro/article/66/3/448/5074453>.
- 6 Patricia Romero-Lankao, Hua Qin, and Katie Dickinson, “Urban Vulnerability to Temperature-Related Hazards: A Meta-Analysis and Meta-Knowledge Approach,” *Global Environmental Change* 22, no. 3 (August 2012): 670-683, <https://www.sciencedirect.com/science/article/abs/pii/S0959378012000490>. B. L. Turner II et al., “A Framework for Vulnerability Analysis in Sustainability Science,” *Proceedings of the National Academy of Sciences* 100, no. 14 (July 8, 2003): 8074-8079, <https://www.pnas.org/content/100/14/8074>.
- 7 Jerry M. Melillo, Terese (T. C.) Richmond, and Gary W. Yohe, eds., *Climate Change Impacts in the United States: The Third National Climate Assessment*, May 2014, http://s3.amazonaws.com/nca2014/high/NCA3_Climate_Change_Impacts_in_the_United%20States_HighRes.pdf.
- 8 W. Neil Adger, “Vulnerability,” *Global Environmental Change* 16, no. 3 (2006): 268-281, https://www.geos.ed.ac.uk/~nabo/meetings/glthec/materials/simpson/GEC_sdarticle2.pdf. Intergovernmental Panel on Climate Change (IPCC) Working Group I, *Fifth Assessment Report (AR5) of the IPCC (Technical Report)*, 2013, https://www.ipcc.ch/site/assets/uploads/2018/02/WGIAR5_all_final.pdf.
- 9 Arie Ponce Manangan et al., “Assessing Health Vulnerability to Climate Change: A Guide for Health Departments,” Centers for Disease Control and Prevention, (updated July 16, 2018), <https://www.cdc.gov/climateandhealth/pubs/assessinghealthvulnerabilitytoclimatechange.pdf>.
- 10 Juan Declet-Barreto, *Socio-Ecological Understanding of Extreme Heat Vulnerability in Maricopa County, Arizona*, Ph.D. dissertation, Arizona State University, 2013. <https://repository.asu.edu/items/20820>.
- 11 Adger, “Vulnerability.” Romero-Lankao, Qin, and Dickinson, “Urban Vulnerability to Temperature-Related Hazards.”
- 12 Ibid.
- 13 Billie L Turner, Roger E. Kasperson, Pamela A. Matson, et al. A framework for vulnerability analysis in sustainability science. *Proceedings of the National Academy of Sciences*. 2003; 100(14): 8074–8079. <https://www.pnas.org/content/100/14/8074>.
- 14 *Community-scale* refers to the geographic area being assessed; this could be a neighborhood, city, or region that is defined by the members of the community. Geographic enumeration units such as census tracts or block groups make up this self-defined area.
- 15 Declet-Barreto, Socio-Ecological, page 9 <https://repository.asu.edu/items/20820>.
- 16 United Nations Environment Programme, “Vulnerability and Climate Change Impact Assessments for Adaptation: VIA Module,” November 2009, https://wedocs.unep.org/bitstream/handle/20.500.11822/11217/ClimateChange_Manual_Final.pdf?sequence=1&isAllowed=y.
- 17 For an overview of geographic information systems and their applications, see “What is GIS?” (accessed January 22, 2020) <https://www.esri.com/en-us/what-is-gis/overview>; for an overview of What is Remote Sensing? and its applications, see The Definitive Guide (accessed December 25, 2019) <https://gisgeography.com/remote-sensing-earth-observation-guide/>.
- 18 Washington State Department of Transportation, “Climate Impacts Vulnerability Assessment,” report submitted to the Federal Highway Administration, November 2011, <https://www.wsdot.wa.gov/sites/default/files/2017/11/15/ENV-Climate-VulnerabilityAssessment.pdf>.
- 19 City of Cambridge, Massachusetts, Community Development Department, “Climate Change Preparedness and Resilience Plan,” June 2011, <https://www.cambridgema.gov/CDD/Projects/Climate/climatechangeresiliencandadaptation.aspx>.
- 20 Detroiters Working for Environmental Justice, “Detroit Climate Action Plan,” October 2017, https://detroitenvironmentaljustice.org/wp-content/uploads/2017/10/CAP_WEB.pdf.
- 21 Center for Science in the Earth System, Joint Institute for the Study of the Atmosphere and Ocean, University of Washington, and King County, Washington, *Preparing for Climate Change: A Guidebook for Local, Regional, and State Governments*, September 2007, <http://www.cses.washington.edu/db/pdf/snoveretalgb574.pdf>.
- 22 Health Insurance Portability and Accountability Act of 1996 (HIPAA), Pub. L. No. 104-191, 110 Stat. 1936 (1996).
- 23 An institutional review board (IRB) is “a board, committee, or other group formally designated by an institution to review research involving humans as subjects.” “Institutional Review Board and the HIPAA Privacy Rule,” U.S. Department of Health and Human Services, National Institutes of Health, August 15, 2003, <https://privacyruleandresearch.nih.gov/irbandprivacyrule.asp>.
- 24 Manangan, Assessing Health Vulnerability to Climate Change, page 8.
- 25 University of Hawaii and Social Science Research Institute, *Drought Risk and Vulnerability Assessment and GIS Mapping Project*, September 2003, <http://files.hawaii.gov/dlnr/cwrmp/planning/drva2003.pdf>.
- 26 Ibid.
- 27 Susan Cutter et al., *Social Vulnerability to Climate Variability Hazards: A Review of the Literature*, Hazards and Vulnerability Research Institute, Department of Geography, University of South Carolina, June 17, 2009, <http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.458.7614&rep=rep1&type=pdf>.
- 28 Sharon L. Harlan, Juan Declet-Barreto, Will L. Stefanov, and Diana B. Petitti, “Neighborhood Effects on Heat Deaths: Social and Environmental Predictors of Vulnerability in Maricopa County, Arizona,” *Environmental Health Perspectives* 121, no. 2 (February 2013): 197-204, <https://www.ncbi.nlm.nih.gov/pubmed/23164621>.
- 29 Ibid.
- 30 Peter E. Thornton et al., “Daymet: Daily Surface Weather Data on a 1-km Grid for North America, Version 3,” Oak Ridge National Laboratory, Distributed Active Archive Center for Biogeochemical Dynamics, updated April 5, 2019, https://daac.ornl.gov/DAYMET/guides/Daymet_V3_CFMosaics.html.

- 31 “What Is the SVI?” Centers for Disease Control and Prevention, updated September 12, 2018, <https://svi.cdc.gov>.
- 32 Declet-Barreto, Socio-Ecological, page 9 <https://repository.asu.edu/items/20820>.
- 33 To ensure a vulnerability assessment with a proper time scale, choose the time frame that fits the variable being considered.
- 34 Harlan et al., Neighborhood Effects, <https://www.ncbi.nlm.nih.gov/pubmed/23164621>.
- 35 Ibid.
- 36 Declet-Barreto, Socio-Ecological, page 9 <https://repository.asu.edu/items/20820>.
- 37 Harlan et al., Neighborhood Effects, <https://www.ncbi.nlm.nih.gov/pubmed/23164621>.
- 38 Ibid.
- 39 Ibid.
- 40 Ibid.
- 41 City of Phoenix, *Downtown Phoenix Urban Forum Project, “Zoning and Urban Form Standards”*, (6-1 – 6-27). July 2, 2008, https://www.phoenix.gov/pddsites/Documents/PZ/pdd_pz_pdf_00344.pdf.
- 42 For a discussion of climate justice in Phoenix, see Juan Declet-Barreto, “Climate Justice Requires Prioritization of the Poor and Vulnerable,” Union of Concerned Scientists, blog entry, April 22, 2019, <https://blog.ucsusa.org/juan-declet-barreto/climate-justice-requires-prioritization-of-poor-and-vulnerable>.
- 43 “Extreme Weather and Public Health,” Arizona Department of Health Services, <https://azdhs.gov/preparedness/epidemiology-disease-control/extreme-weather/heat-safety/index.php#heat-maps> (accessed January 22, 2020).
- 44 This partnership was facilitated by the Thriving Earth Exchange, a project of the American Geophysical Union. Thriving Earth Exchange, “Planning Health Resilient Urban Design: Washington, D.C.” updated March 24, 2017, <https://thrivingearthexchange.org/project/washington-dc/>.
- 45 Surface temperature data from Landsat imagery provides a daytime value for each pixel. Because the data are spatially explicit and not temporally explicit beyond the year, diurnal variability cannot be captured. Selecting the minimum or maximum value across all 20 years as opposed to an average or median will eliminate the rest of the variability in those years. The choice was made to use the 20-year average to best represent spatial and temporal variability.
- 46 Peter E. Thornton, “Daymet: Daily Surface Weather Data on a 1-km Grid for North America.”
- 47 In this context, *normalization* refers to the transformation of all variables into a common scale, a necessary step because some variables were expressed in percentages while others were calculated in degrees C.
- 48 Larissa Larsen et al., “Revised Heat Vulnerability Maps,” email communication to District of Columbia Focus Group Participants, 2014.
- 49 Juan Declet-Barreto, Kate Johnson, and Olga Wilhelmi, “Mapping Extreme Heat Vulnerability in Support of the District of Columbia’s Climate Adaptation Plan,” Thriving Earth Exchange, 2018. <https://thrivingearthexchange.org/wp-content/uploads/2016/03/TEX-DC-Policy-Brief-2018-01-31.pdf>.
- 50 Vivek Shandas et al., “Integrating Satellite and Ground Measurements for Predicting Locations of Extreme Urban Heat,” *Climate* 7, no. 1 (January 2019): 5-13, <https://doi.org/10.3390/cli7010005>.
- 51 Government of the District of Columbia, “Resilient DC: A Strategy to Thrive in the Face of Change,” 2019, <https://app.box.com/s/d40hk5ltvcn9fqaslviaje0xbnbsfwga>.
- 52 Climate Resilience Toolkit, <https://toolkit.climate.gov/> (accessed January 22, 2020).
- 53 Climate Adaptation Knowledge Exchange, <https://www.cakex.org/> (accessed January 22, 2020).
- 54 Thriving Earth Exchange, (updated 2019), <https://thrivingearthexchange.org/>.
- 55 Hansen, L.J. and M. Ramirez. 2020. Rapid Climate Vulnerability Assessment Tool for Climate-Informed Equitable Community Development. Strong, Prosperous and Resilient Community Challenge. http://www.sparchub.org/wp-content/uploads/2020/06/RCVA_REPORT_SINGLEPG-1.pdf.
- 56 Climate Justice Alliance: Communities United for a Just Transition, <https://climatejusticealliance.org/> (accessed January 22, 2020).
- 57 Climate Optimist, (updated 2019), <https://www.climateoptimist.org/>.