Reducing Vulnerability to Extreme Heat Through Interdisciplinary Research and Stakeholder Engagement

Olga Wilhelmi and Mary Hayden

Abstract Extreme heat is a leading cause of weather-related human mortality in the United States and many countries worldwide. To reduce the negative impacts of extreme heat on human health, it is essential to understand which populations are most vulnerable. In this chapter, we discuss the interdisciplinary facets of extreme heat vulnerability, present a conceptual and analytical framework for characterizing and reducing urban vulnerability to extreme heat, and provide an example of an interdisciplinary project that examines current and future extreme heat risk within the context of North American cities. We focus on a science-policy interface of heat-health research by highlighting the stakeholder engagement as a critical component of the entire research process. We conclude with observations on how this research framework and the stakeholder engagement process can be applied to other public health and hazardous weather studies where decision-making is informed by science.

Keywords Extreme heat · Vulnerability · Stakeholders · Interdisciplinary research · Stakeholder engagement

1 Introduction

Extreme heat is a leading cause of weather-related human mortality in the United States (National Oceanic and Atmospheric Administration 2014) and many countries worldwide (Hajat and Kosatsky 2010). Typically, heat-related negative health outcomes occur when daily temperature exceeds a normal range for a given climate, local setting, and availability of adaptations (Patz et al. 2005). Climate change,

O. Wilhelmi (✉) · M. Hayden
Research Applications Laboratory, Climate Science and Applications Program,
National Center for Atmospheric Research, Boulder, CO, USA
e-mail: olgaw@ucar.edu

M. Hayden
e-mail: mhayden@ucar.edu

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urbanization, and demographic trends suggest that extreme heat will remain a major hazard in the United States (Intergovernmental Panel on Climate Change 2012; Oleson et al. 2013), disproportionately affecting vulnerable populations. For both public health and climate adaptation planning, it is essential to better understand which populations are most vulnerable and how to reduce the negative health impacts of extreme heat on these populations (Balbus and Malina 2009; Wilhelmi and Hayden 2010; Harlan et al. 2013).

Characterizing and reducing societal vulnerability to extreme heat are complex problems that require the combined effort of several disciplines. It is essential that we are able to understand the interactions among biological, social, and physical systems, in a context-specific environment, and to connect research results to policy. The multifaceted nature of extreme heat vulnerability requires the implementation of effective urban heat mitigation and climate adaptation policies; this in turn necessitates active collaboration among researchers and a wide range of stakeholders (Wilhelmi and Hayden 2010).

In this chapter, we discuss the interdisciplinary aspects of extreme heat vulnerability; present a conceptual and analytical framework for characterizing and reducing urban vulnerability to extreme heat; and provide an example of an interdisciplinary project that examines current and future extreme heat risk in North American cities. We focus on a science-policy interface of heat-health research by highlighting the stakeholder engagement as a critical component of the entire research process. We conclude with observations on how this research framework and the stakeholder engagement process can be applied to other public health and weather hazards studies where decision-making is informed by science.

2 Extreme Heat Vulnerability: An Interdisciplinary Perspective

More than half of the world's population live in cities, where the combined effect of warm summer temperatures and urban heat islands (UHI) produce numerous negative health outcomes (Wilhelmi et al. 2012; World Meteorological Organization and World Health Organization 2015). While local climate, urban meteorology, and the occurrence of extreme heat events play important roles in health outcomes, societal vulnerability often determines the magnitude and the distribution of negative impacts of extreme heat on human health (Wilhelmi and Hayden 2010; Uejio et al. 2011; Harlan et al. 2006, 2014; Johnson et al. 2009, 2012; Rosenthal et al. 2014). Therefore, research on vulnerable populations as well as epidemiological studies on heat-health thresholds has grown significantly over the past decade.

Despite the growing body of knowledge about urban vulnerabilities to extreme heat, the complex interplay of ecological, social, political, and medical factors contributing to heat stress makes it challenging to prevent heat-related mortality.

The complexity of heat hazards also derives from the fact that the thresholds above which there are negative health outcomes vary significantly among geographic regions, across urban–rural gradients and even among neighborhoods within a city (Wilhelmi et al. 2012). Research frameworks on extreme heat vulnerability (Wilhelmi and Hayden 2010) and a number of case studies (Uejio et al. 2011; Harlan et al. 2006; Johnson et al. 2009; Harlan et al. 2012) demonstrate that both urban land cover (a factor in UHI formation) and demographic characteristics contribute to health outcomes.

In large cities with highly variable socioeconomic fabrics, infrastructure and housing types, vulnerability is expected to be even more complex. The relative importance of individual and household heat health risk factors has been investigated in several U.S. cities (e.g., Smoyer 1998; Uejio et al. 2011; Harlan et al. 2012). These integrated neighborhood-level studies show that urban land surface characteristics, associated with UHI formation, coupled with socio-demographic characteristics can be linked with heat-related morbidity or mortality data to identify first order vulnerability indicators and highlight zones of elevated vulnerability within urban areas. Recent advances in geospatial methods and analysis tools allow for spatially explicit characterization of heat-related vulnerabilities even in seemingly homogeneous urban environments (Wilhelmi et al. 2004). Various case studies of local-level urban vulnerability to extreme heat show the importance of interdisciplinary approaches to analyzing and predicting heat-health outcomes (Uejio et al. 2011; Harlan et al. 2012; Heaton et al. 2014).

2.1 Vulnerability

The notion of *vulnerability* has evolved over the past few decades from a concept primarily based on the severity of the natural hazard itself to a much more comprehensive construct involving social capital, poverty level, and access to resources, among other factors (Bankhoff et al. 2003; Eakin and Luers 2006). Here, following Wilhelmi and Hayden (2010), we define vulnerability as a function of *exposure* (i.e., climate and synoptic weather conditions that are exacerbated by the reflective, storage, and transportation characteristics of urban materials and vegetation), *sensitivity* (i.e., the extent to which a system or population can absorb impacts without suffering long-term harm), and *adaptive capacity* (the potential of a system or population to modify its features/behavior so as to better cope with existing and anticipated stresses). Adaptive capacity influences *adaptation*, which refers to the actual adjustments made to cope with the stressors and reduce the risk of negative health outcomes. Vulnerability is also influenced by *drivers*, namely factors that shape the characteristics of the system such as climate change, public policies, and other macro-scale environmental, socioeconomic, and political stressors.

Current thinking in terms of adaptation to heat stress emphasizes technological interventions such as improved infrastructure and access to air conditioning (McMichael 2000; Klinenberg 2002). However, social and economic inequalities that exist at a local level (e.g., access to air conditioning, social isolation) create differential vulnerabilities as well as differential adaptive capacities (McMichael 2000; Klinenberg 2002; O'Brien 2004; Harlan et al. 2006, 2013).

Determining the differential vulnerabilities and adaptive capacities on a local level is essential to reducing negative health outcomes from extreme heat events. Smit and Wandel (2006) note that "in the climate change field, adaptations can be considered as local or community-based adjustments to deal with changing conditions within the constraints of the broader economic-social political arrangements." This highlights the importance of *scale* as internal to the system indicating that what occurs at the household level also affects the community, which is in turn, influenced by the macro forces that shape the ability of individuals to adapt to challenging conditions. Here we refer to *scale* as to the size of a unit at which the problem is studied and analyzed. *Scale* allows us to conceptualize processes and interactions that exist in social and physical structures and represent or generalize these processes in spatial, temporal, and thematic analyses (Montello 2001). Therefore, to associate data on health disparities to a neighborhood scale (i.e. Census block group), it is important to consider the influence of individual/household-scale socio-economic characteristics and behavioral processes, as well as community/city-scale extreme heat preparedness and adaptation programs, as determinants of extreme heat vulnerability and adaptive capacity (Pickett and Pearl 2001).

3 Interdisciplinary Research on Extreme Heat: The SIMMER Project

In 2010–2014, the authors of this chapter participated in a NASA-funded project, the System for Integrated Modeling of Metropolitan Extreme heat Risk (SIMMER), (Wilhelmi et al. 2014). This project focused on understanding extreme heat, human health, and urban vulnerability in present and future climates. The primary goals of the SIMMER's interdisciplinary team were to: (1) advance the methodology for assessing current and future urban vulnerability from heat waves through the integration of physical and social science models, research results, and NASA data; and (2) develop models and tools for building local capacity for heat hazard mitigation and climate change adaptation in the public health sector.

SIMMER employed an extreme heat vulnerability framework (Wilhelmi and Hayden 2010) and focused on specific research objectives: (1) Characterize and model present and future extreme heat events at regional and local scales; (2) Improve representation of urban land cover and its accompanying radiative and thermal characteristics at local and regional scales; (3) Determine the combined impact of extreme heat and the characteristics of urban environmental and social systems on human health; and (4) Characterize societal vulnerability and responses to extreme heat (i.e., mitigation and adaptation strategies).

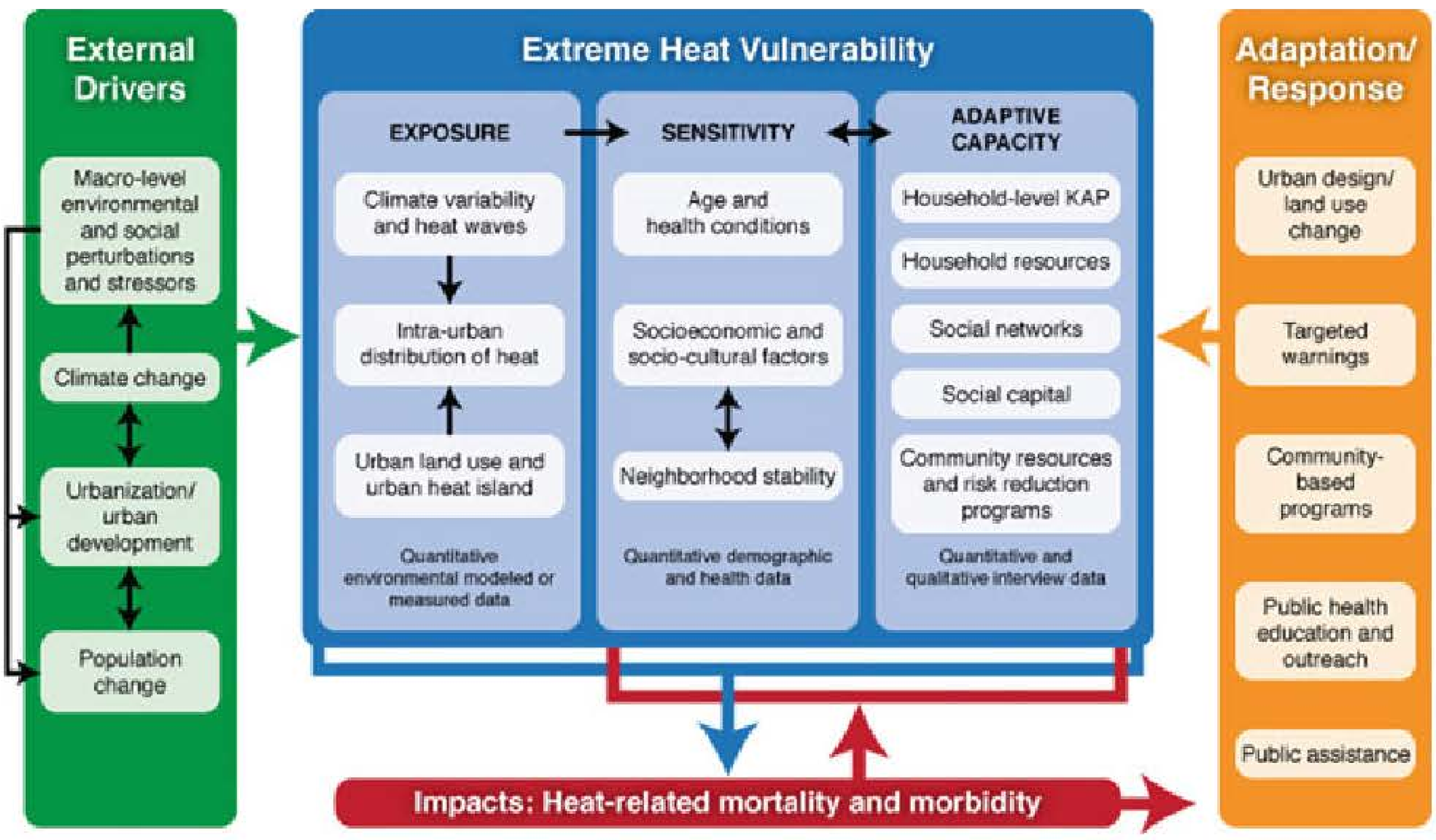

Fig. 1 Extreme heat vulnerability framework (*source* Wilhelmi and Hayden 2010)

In the Wilhelmi and Hayden (2010) framework (Fig. 1), vulnerability is represented as a function of exposure, sensitivity and adaptive capacity. Each of these components of vulnerability consists of a set of dynamic, spatially variable indicators. Exposure to extreme heat can be characterized by the intra-urban distribution of heat, which is influenced by local meteorological conditions and urban land use. Sensitivity is explained by characteristics of the individuals and the communities that make people more susceptible to the impacts of extreme heat, such as age, pre-existing health conditions, socio-economic and cultural factors, and neighborhood stability (e.g., whether people own or rent their homes). Adaptive capacity is characterized by the social and behavioral factors such as knowledge, attitude, and practices with regard to extreme heat, social networks, the household resources for coping with extreme heat, and local-level programs targeted at reducing extreme heat impacts.

Exposure, sensitivity, and adaptive capacity are affected by external drivers, such as climate change, macro-scale socio-economic and environmental stressors, and urbanization trajectories. For example, the pathway of urban development (e.g., large-scale urban agglomerations) can influence urban land use and consequently, the UHI, which disproportionately affects human exposure to excessive heat during the day and nighttime (Wilhelmi et al. 2012). Macro-scale socio-economic stressors, such as economic downturns, affect the sensitivity of the socio-ecological system, through impacts on housing, employment (i.e., decreased neighborhood stability, increased socio-economic disadvantage, limited household resources for cooling), and health conditions of individuals (e.g., limited access to healthcare).

Vulnerability to extreme heat can be reduced by carefully designed adaptation and response strategies. Understanding how each component of extreme heat vulnerability as well as the interactions among the components affect human health within each urban neighborhood and in time (i.e., throughout the day and the summer season) is essential for heat preparedness, response, and long-term adaptation. For example, when the UHI effect amplifies hot summer temperatures and the exposure of urban residents to extreme heat, implementing measures for reducing the UHI through urban planning and building design need to be initiated. In another example, when the people are unaware of the dangerous impacts of extreme heat on human health and are unable to recognize the symptoms of heat stress, public health education and outreach is needed.

The SIMMER project identified and measured each component of the vulnerability framework (Fig. 1) using quantitative or qualitative methods. For example, quantitative measurements included meteorological and remote sensing observations, climate model simulations, population characteristics, mortality records, and close-ended survey data. These types of data were analyzed numerically. Qualitative observations helped to explain and contextualize vulnerability and heat hazard phenomena and included open-ended survey and focus group data. The SIMMER project included regional-and local-scale analyses. The regional-scale study domain covered the contiguous United States and portions of southern Canada at $\sim 15\ km^2$. A local, intra-urban scale ($1\ km^2$; U.S. Census block group) study was conducted in Houston, Texas, the fourth largest city in the U.S. The research team collaborated with scientists and public health practitioners in Houston, as well as Toronto, Canada to ensure that the concepts, methods, and models developed for Houston were applicable to other cities.

Key findings from the SIMMER project included characterizing urban properties in urban meteorological simulations (Monaghan et al. 2014), and the role of adaptive capacity in understanding vulnerability to extreme heat (Hayden et al. 2015). New methods for accurately estimating urban land surface temperature from satellite imagery have been proposed and tested (Hu and Brunsell 2013; Hu et al. 2014). Climate model simulations showed substantial increase in high heat stress days and nights across the United States by the mid-21st century (Oleson et al. 2013). New statistical methods for modeling risk of heat related mortality and morbidity advanced our understanding of heat risk factors, and the spatiotemporal distribution of vulnerability within cities (Heaton et al. 2014, 2015). The results of the entire project have been discussed in the context of public health policies and interventions through a stakeholder engagement process (Hart et al. 2014). We now discuss this stakeholder engagement process in detail as a model for solution-driven interdisciplinary research and connection to policy.

3.1 Stakeholder Engagement

The SIMMER project employed both interactive and iterative processes (Lemos and Morehouse 2005), which included stakeholder engagement from the beginning of the problem definition to the dissemination of the results and co-production of

Fig. 2 Iterative and interactive process of stakeholder engagement

possible problem solutions (Fig. 2). Public health practitioners were our primary stakeholders in both Houston and Toronto; they were involved from the inception of the project, were knowledgeable about the vulnerable populations within their communities, and had been engaged in multiple on-the-ground public health campaigns in their cities. Involvement of public health practitioners from Houston, TX and Toronto, Canada helped to identify a roadmap for not only characterizing social vulnerability to extreme heat, but also ensuring that scientific information and research results could be used to inform public health interventions and initiate dialog for further collaborations on urban environmental health.

Figure 2 illustrates the interactive and iterative nature of the stakeholder engagement in the SIMMER project. We initially engaged public health practitioners in both cities and invited them to participate in the study design to ensure the relevance of the proposed research to their real-world problems. We worked together to identify and map vulnerable neighborhoods within Houston and Toronto; this allowed us to target specific Census block groups for our household-level telephone surveys. Once the data had been collected and analyzed, we met with our stakeholders to determine how our research results could be put into practice and what steps were necessary to reduce population vulnerability to extreme heat. Through this process, knowledge gaps and current best practices were identified; this led to discussions on potential solutions to existing problems related to heat.

Literature shows that involving stakeholders in research can have different models of engagement. Carney et al. (2009) synthesized the literature and identified several approaches to engage stakeholders in research. Among those are (1) study *of* stakeholders (i.e., studying knowledge, perceptions, attitudes, and practices regarding a particular issue); (2) study that includes active input *from* stakeholders (i.e., collaborating and incorporating stakeholders' insights, expertise, and ideas); and (3) study *for* stakeholders (i.e., disseminating research results in a usable and useful format). Below we discuss how the SIMMER project applied all three approaches in the context of extreme heat and human health.

3.1.1 Stakeholders' Knowledge, Attitudes, and Practices with Regard to Extreme Heat in Houston

The decision-making process for the reduction of negative heat-related health outcomes requires input from a variety of stakeholders to ensure the success and sustainability of efforts to reduce vulnerability. Generally, the stakeholders are persons, groups, or organizations that have interests in extreme heat mitigation and response (Wilhelmi et al. 2004). Engaging parties involved in the preparedness and response processes, particularly in the face of projected increases in extreme heat events, is important to developing an understanding of the strengths and weaknesses of existing prevention policies.

We conducted an on-line survey that was delivered to a pre-defined list of stakeholders from multiple sectors, namely public health, energy, local and state government, emergency response, to better understand extreme heat preparedness and response. The objectives of this survey were (1) to better understand roles and facilitate coordination among governmental and non-governmental organizations in response to extreme heat, and (2) to examine stakeholder knowledge of existing preparedness and response plans and strategies for future mitigation/adaptation to extreme heat.

3.1.2 Stakeholder Identification

Potential stakeholders were identified through a three-step process. First, website searches of organizations that appeared to be important partners in reducing vulnerability to extreme heat were identified. Then, staff members on those sites whose job titles indicated they were involved in public outreach, education, heat awareness, were targeted. Finally, additional stakeholders were identified through our collaboration with the Houston Department of Health and Human Services. Thus, stakeholders were drawn from multiple organizations in the Houston area including, for example, the University of Houston Strategic Energy Alliance and the University of Texas Health Sciences Center, non-profit organizations such as the American Red Cross and the Salvation Army, community organizations such as Ready Houston, government organizations representing, emergency management and homeland security, the National Weather Service Office, and public service organizations including utility and transportation companies and local television stations.

3.1.3 The Online Stakeholder Survey

The online survey was developed in collaboration with the Houston Department of Health and Human Services and distributed following a modified version of the Dillman tailored design method (Dillman 2014) to eighty-eight stakeholders that had been identified through the aforementioned three-step process. Emails, surveys, and reminder emails were sent out to stakeholders from April to June 2012. Through this survey, and in keeping with the survey objectives noted earlier, we hoped to: (1) determine stakeholders' knowledge and implementation of measures to reduce the negative health impact of extreme heat, and (2) assess perceptions of the relative efficacy of the existing tools/mechanisms to reduce population vulnerability to extreme heat. Thirty-three of the eighty-eight stakeholders who had been initially identified responded to the survey for a response rate of 37.5 %.

Stakeholders were first asked to identify the organization with which they worked and the type of preparedness and response in which they participated. When asked, "What specific services does your organization provide with regard to extreme heat? Please check all that apply," 45 % of survey respondents indicated that one of their roles in their organization was communication of messages to the public, followed by 36 % who were involved in community outreach and intervention, and 33 % who cited communication with other Houston organizations. Twenty-one percent noted that they coordinated activities among Houston organizations in preparation for heat events while 21 % also indicated that they provide weather surveillance (Fig. 3).

An important component of preparedness and response is determining the stakeholders' perceptions of the efficacy of a particular activity. Stakeholders were asked to determine the effectiveness of specific activities undertaken to manage health risks from extreme heat in Houston. The majority of stakeholders felt that weather surveillance for extreme heat was moderately effective to effective, while UHI mitigation was considered the least effective by stakeholders who rated it moderately to somewhat effective (Fig. 4).

Stakeholders were asked what activities their organizations recommended to their clientele during an extreme heat event. The most often cited recommendations were to stay indoors in an air-conditioned place (47 %), avoid outdoor activity during the hottest part of the day (44 %), and drink plenty of water to stay hydrated (44 %). The activities least often recommended were to use a swimming pool (3 %), followed by taking cool showers (9 %), and exercising indoors in a cool place (9 %).

Because climate projections for Houston show a significant increase in the number of high heat stress days and nights (Oleson et al. 2013), we asked stakeholders to describe how health risks from extreme heat might change in the future. The majority (69 %) responded that that risk of negative health outcomes would

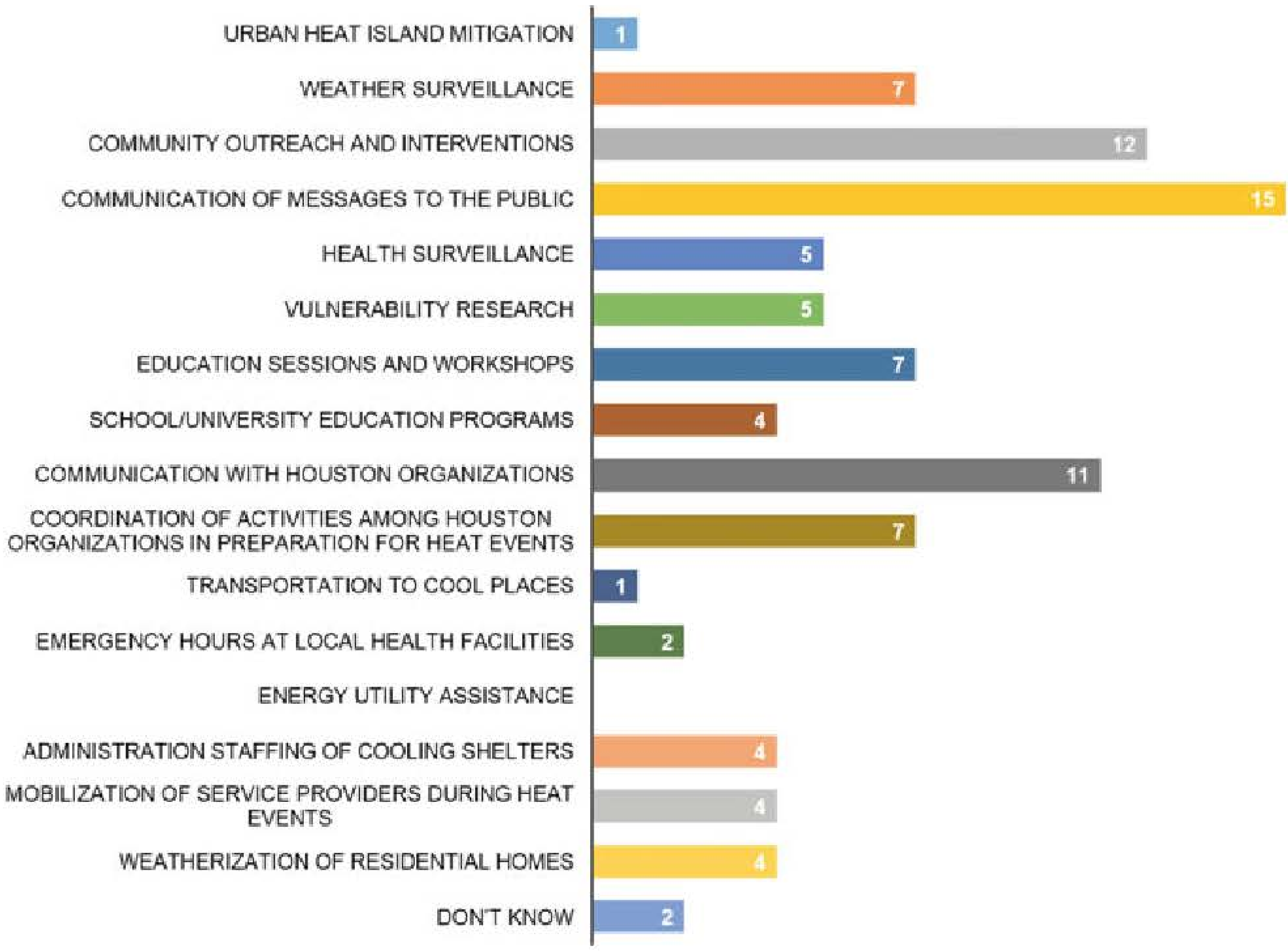

Fig. 3 Number of survey respondents (n = 33) involved in activities specific to extreme heat preparedness and response. "*What specific services does your organization provide with regard to extreme heat? Please check all that apply.*" SIMMER Online Stakeholder Survey

increase in the future because of growth in the population of those with underlying medical conditions (e.g., obesity, diabetes, mental health issues, etc.) as well as the growth in the number of senior citizens in the population (63 %). Other areas of concern were the potential for additional extreme weather-related impacts that might overwhelm the system (59 %), reduced financial resources to cope with the heat (53 %), growth in minority populations (47 %), increased UHI effect (44 %), aging housing infrastructure (44 %), and growth in the number of homeless people in the population (44 %). Far fewer of our respondents were concerned about urbanization (28 %) or increased unemployment (22 %).

In addition to asking how health risks might increase in the future, we were interested in ascertaining what the respondents felt might reduce future vulnerability to extreme heat events (Fig. 5). Fully 38 % of the responders noted that improvements in the preparedness and response capacity would reduce vulnerability, and 34 % of respondents felt that community-based adaptation such as the increased numbers of cooling centers and/or community centers would decrease the risk of negative health outcomes related to extreme heat.

We were also interested in assessing stakeholders' perceptions as to what would improve preparedness and response to extreme heat events from the perspective of their organization. The majority (56 %) felt that increased population awareness of the health risks associated with extreme heat would improve preparedness and

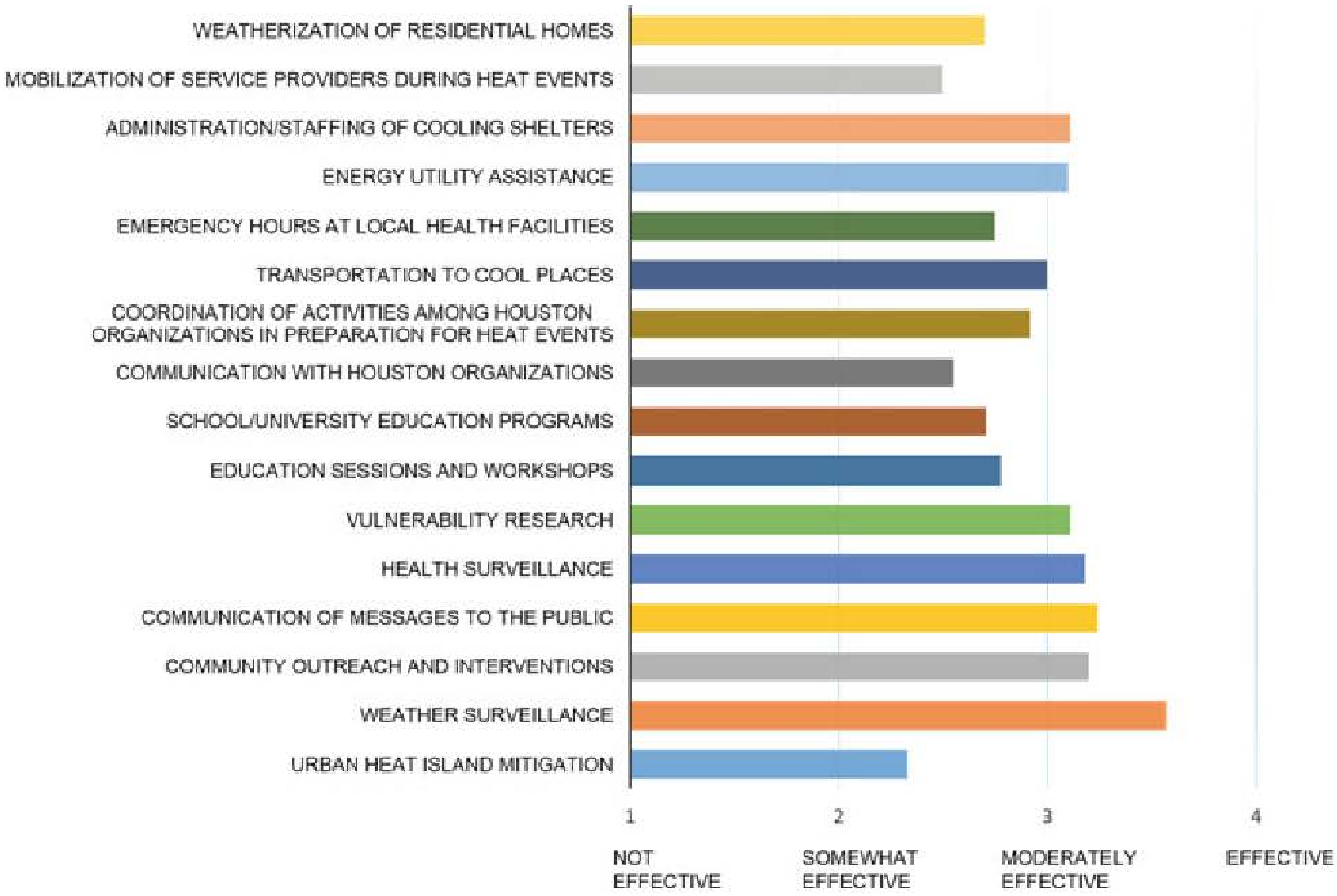

Fig. 4 Stakeholders' assessment of the effectiness of the activities specific to extreme heat preparedness and response. "*How effective are the activities below at managing health risks from extreme heat in Houston on a scale of 1–5 where 1 is not effective and 5 is very effective? Check all that apply*." SIMMER Online Stakeholder Survey

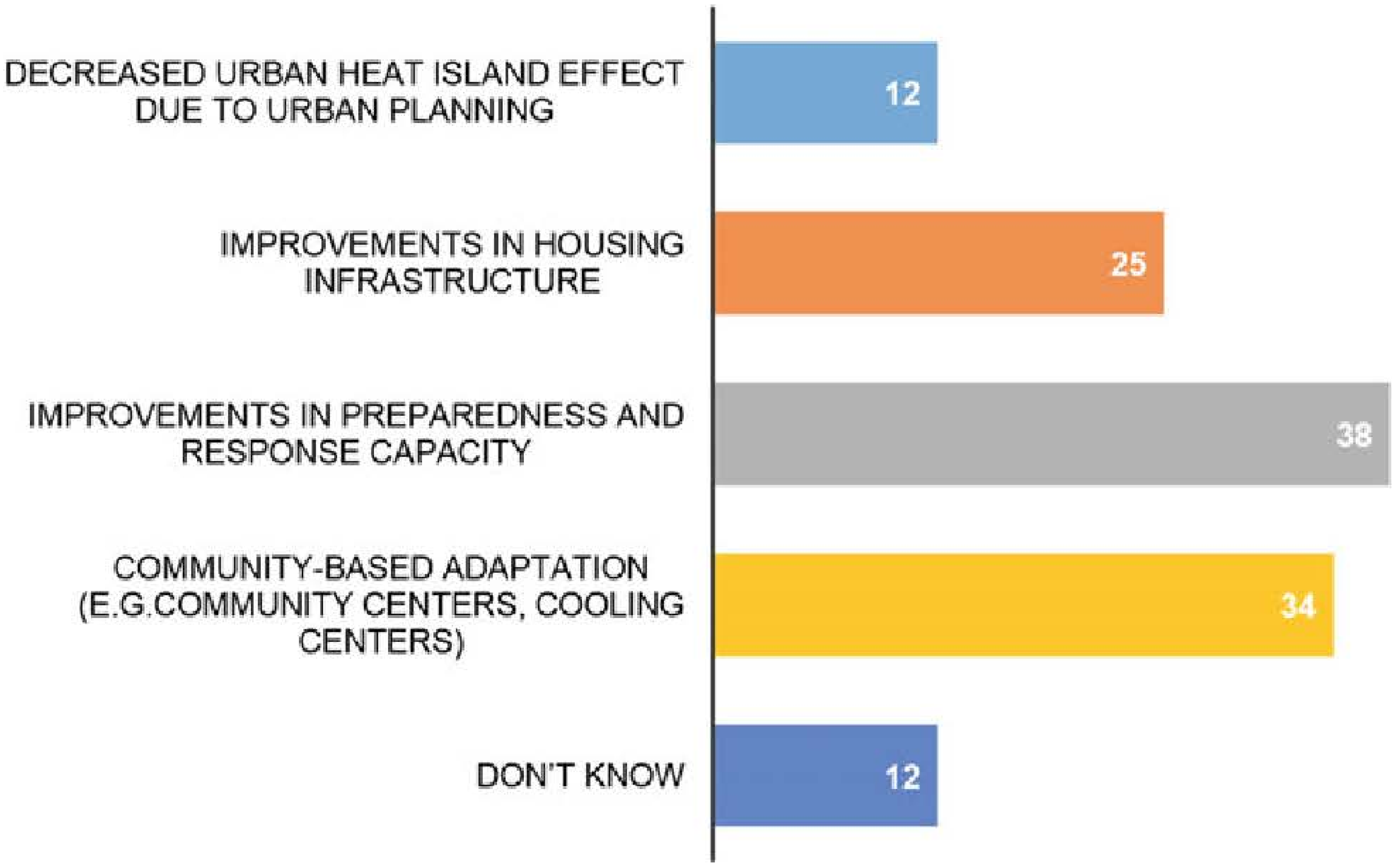

Fig. 5 Percent of stakeholders that identified specific pathways for reducing extreme heat vulnerability. "*Describe how you think the vulnerability to health risks from extreme heat may decrease in the future.*" SIMMER Online Stakeholder Survey

response. Thirty-one percent felt that more funding was important. Better preparation for unexpected hazardous events, extension of heat services currently provided by the community or other agencies/organizations, and more communication with the Houston Department of Health and Human Services were considered equally valuable by stakeholders (28 %).

Understanding stakeholders' knowledge and assessment of the efficacy of existing prevention and response activities is critical to developing successful strategies and timely responses in the future. Furthermore, determining opportunities for reducing vulnerability provides a direction for improving on the current strategies.

3.1.4 Extreme Heat Preparedness and Response in Houston: Co-production of Knowledge

Building local capacity for heat hazard mitigation and climate change adaptation was one of the main goals of the SIMMER project. Stakeholder workshops provide an effective mechanism for capacity building which includes a researcher-stakeholder dialog, collaborating on a problem defined in a specific and localized context, and promoting coordination among local practitioners. The stakeholder workshops also present an opportunity to (1) review science and policy accomplishments; (2) identify gaps in extreme heat planning, preparedness and response; and (3) outline activities specific to the gaps that would reduce future heat-related health impacts. A one-day stakeholder workshop, organized by the Houston Department of Health and Human Services and the National Center for Atmospheric Research in 2013 focused on these three objectives in the context of extreme heat and human health in Houston.

The 43 workshop attendees represented diverse organizations in public and private sectors, non-governmental organizations, and academia. The practitioners included experts in public health, policy, emergency management, weather forecasting, broadcast media, transportation, housing and energy management, urban and regional planning. The researchers at the workshop represented a variety of disciplines, including epidemiology, physical, social, and behavioral sciences. The meeting agenda included broad discussions about the vulnerability of Houston residents to extreme heat, presentations about research, existing heat-related preparedness and mitigation programs strategies, as well as local public health initiatives that address the heat-health interactions.

One of the main goals of the stakeholder workshop was to improve collaborations and coordination among local and regional organizations that may be involved in heat-related activities, but do not have working relationships or even knowledge of each other's activities. It is common that organizational hierarchies, funding structures, lack of inter-agency communication, and other institutional barriers prevent coordinated efforts in tackling important social and environmental problems. Given the common interests, close geographic proximity of various institutions, and limited resources within each organization, coordination among local government agencies, non-profit organizations, and the private sector can lead to more efficient process for developing extreme heat mitigation and response programs and services. Long term, this could lead to policy changes based on new data analyses and better coordination among public health officials, city planners, emergency responders resulting in reduced vulnerability among city residents. For example, a coordinated effort among public health and urban planning organizations could lead to reduced exposure to extreme heat in vulnerable neighborhoods through planned changes in green space, urban parks, and cool pavement.

Typically, during workshops that focus on co-production of knowledge and improved coordination, researchers represent one type of actor and act as facilitators. Prioritizing heat-related issues when there are myriad pressing issues facing urban areas is challenging. It is important to provide support for solution-oriented dialog among diverse actors, so that deliberations and planning during the workshop could lead to meeting the participants' shared goals. Mutual learning and identification of concrete steps for addressing the problem at hand are desirable outcomes of the stakeholder workshops. Below we describe specific findings and the action items that were generated at the 2013 SIMMER stakeholder workshop in Houston.

At the Houston workshop, we divided the participants into small working groups; each with a mix of stakeholders from different agencies and areas of work. Their first task was to discuss current gaps and challenges in extreme heat planning, preparedness, and response. The second task focused on identifying specific activities to fill these gaps and reduce future heat-related impacts. Through this participatory approach, six main themes emerged from the working group discussions: (1) Effectiveness of cooling centers; (2) Heat-related advisories, products, and services; (3) Communication and messaging; (4) Policy; (5) Research; and (6) Collaboration and coordination (Table 1).

Table 1 Current gaps in extreme heat preparedness and response in Houston, TX and the proposed solutions to address these gaps

Gaps	Solutions
I. Limited use of and awareness about the *cooling center*	1. Clearly define what a cooling center is and advertise broadly, using different media for different populations (e.g., TV, social media, printed materials in utility bills, booklets in grocery stores) 2. Expand services that are offered by the cooling centers (i.e., longer hours, more activities for different age groups, provision to allow pets, especially during an extreme heat event) 3. Consider using buses as additional, mobile cooling centers 4. Provide transportation assistance to/from cooling centers 5. Investigate whether there are safety concerns among Houston residents about leaving home, traveling to and from cooling centers. Address these safety concerns

(continued)

Table 1 (continued)

Gaps	Solutions
II. Triggers for initiating *heat advisories* are not health related. Lack of heat-related *products and services* for populations with special needs	1. Evaluate threshold for heat advisories using heat health outcomes 2. Provide messages that are health-specific and provide information about cooling options along with heat advisories 3. Consider providing tailored heat advisories (more local, for super neighborhoods[a], for example) or using different messaging for different populations (e.g., elderly, athletes, outdoor workers) 4. Consider issuing heat advisories during or after high-impact events (e.g., hurricanes) that may also affect power loss
III. Lack of effective *communication*, especially to vulnerable populations, about heat-related symptoms, heat hazard, and available resources for heat-health risk reduction	1. Clearly define heat hazard and heat-related symptoms and educate the public early in the season. Introduce *Heat Awareness* day 2. Use multi-media to communicate heat hazards and ways to protect oneself (e.g., Websites, social media, TV, radio, billboards along the highways, utility bills) 3. Integrate heat-related information with hurricane education and communication (e.g., town halls, community meetings; a "Heat" module in "Together Against the Weather" program; booklets in grocery stores, pharmacies, churches, schools) 4. Include specific cooling instructions during heat advisories 5. Reach out to vulnerable populations during heat advisories through door-to-door contact, reverse 911 calls and emergency text alerts. Use addresses from *Meals on Wheels* and WIC databases
IV. Local *policies and procedures* Home Owners Associations and new residential construction does not always take climate or urban heat island into consideration	1. Offer weatherization analyses 2. Provide utility subsidy to population at 125 % of federal poverty levels 3. Incorporate ideas from this workshop into *Houston-Galveston Area Council* hazard mitigation plan 4. Reduce UHI effect: focus on areas with low tree canopy 5. Evaluate HOAs/new construction policies on roof colors and building materials 6. Promote policies that build sense of community 7. Participate in *Neighbors Night Out* program

(continued)

Table 1 (continued)

Gaps	Solutions
V. Additional *research* is needed to investigate extreme heat and human health relationships in the context of air quality, a changing climate, different geography and demographics	1. Investigate relationships between heat illness (e.g., hospital admissions, emergency room visits, and heat distress 911 calls) and heat advisories 2. Investigate how to integrate the SIMMER "Beat the Heat" GIS tool with weather forecast data for more targeted warnings and advisories of heat related illness 3. Investigate cumulative effects of air pollution and heat on health outcomes in Houston 4. Investigate heat-related risks under climate change scenarios 5. Investigate heat-health risk differences among cities in the region 6. Conduct research on acclimatization to heat among different populations
VI. Lack of sustained *inter-agency collaboration and coordination* of heat-related activities. "*Heat champion*" is needed to lead and coordinate heat-related actions and strategies	1. Identify an organization to serve as the "heat champion" to help coordinate activities. Identify "heat" ambassadors in communities, schools, organizations for bottom up public involvement 2. Create "heat" e-mail list of all interested/involved organizations 3. Establish closer collaboration among Health Departments, National Weather Service and broadcast meteorologists 4. Establish closer collaborations among Health departments, National Weather Service, emergency managers, and operators/managers of cooling centers 5. Establish closer collaboration among cooling centers and transportation services 6. Establish closer collaboration among utilities and emergency management (e.g., do not shut off power in a heat event) 7. Establish collaborations among WIC, Meals on Wheels and Health Departments (e.g., booklets or verbal messages to distribute, check on indoor temperature)

2012 Houston Stakeholder Workshop

[a]Super neighborhoods were created to encourage residents of neighboring communities to work together to identify, prioritize, and address the needs and concerns of the broader community. This creates a manageable framework for community action and allows the city to provide services more efficiently. (http://www.houstontx.gov/superneighborhoods/guidelines.html)

For example, one important topic discussed at the workshop was the effectiveness of cooling centers. During heat emergencies, the Houston public libraries and many Multi-Service Centers are designated as *cooling centers*. These cooling centers are open to the public and provide an air-conditioned environment for those who need to escape the heat during the day and cool off. However, many Houston residents, especially some of the most vulnerable ones, are unaware of such services or do not use the cooling centers due to various constraints (Hayden et al. 2015). The stakeholders discussed a number of approaches to address these limitations, including broader and more targeted advertising, expansion of services and working hours, and transportation to/from cooling centers.

Effectiveness of heat advisories as well as more general topics of communication about extreme heat risk and protective actions were among other themes that came out of the stakeholder discussions. The workshop participants discussed more tailored heat advisories that could be issued using place-based heat exposure information and contain specific messaging for different populations (e.g., elderly, athletes, outdoor workers). The stakeholders recognized that more could be done to communicate the extreme heat risk and considered a number of approaches, ranging from establishing a *Heat Awareness* day to multimedia communication and public education strategies. These and other topics are presented in Table 1.

While the workshops can energize and motivate the participants to collaborate and tackle shared challenges, it is not uncommon that the post-workshop activities are limited or non-existent. Even at the Houston stakeholder workshop, it was emphasized that a "*heat champion*" is needed to lead and coordinate heat-related actions and strategies. In the absence of such a person, group or organization, it can be challenging to have a focused and sustained effort in implementing proposed strategies. One approach for keeping the dialogue going is to focus on one tangible product or tool, such as a Geographic Information System (GIS). GIS in general, and participatory GIS, in particular, is an increasingly popular way to connect different stakeholders as well as community members, using geography (or urban space) as a common ground (Barlam 2006). Having a common platform where the stakeholders can visualize and query data about their city, the neighborhoods, and the population can help to create a shared vision, contribute to mutual learning, and provide a mechanism for moving forward to reduce population vulnerability.

3.1.5 Disseminating Research Results to Stakeholders

In the early stages of the SIMMER project, the stakeholders from the public health sector indicated the need for a web-based GIS tool that could synthesize extreme heat observations, model simulations, and social vulnerability research data. "Beat the Heat in Houston" was developed with those recommendations in mind, and the prototype was demonstrated at the stakeholder meeting in Houston. The workshop participants were invited to test the tool and fill out a survey on the tool content, usability, and "look and feel." Five volunteers from weather forecasting and public health sectors completed the testing, responded to an on-line survey and provided feedback on the tool development. In addition to these volunteers, the project partners from Houston Department of Health and Human Services provided detailed comments on the GIS data and functionality that would be useful for the City Government and for the public. Based on these inputs, the SIMMER project produced two GIS-based outputs: a web-based tool, "Beat the Heat in Houston" for the general public and an ArcGIS map package for the Houston City Government. These two outputs were each tailored to specific audiences and to the different types of decision making, which are discussed below.

The city government SIMMER project partners received a map package containing information on vulnerable populations, UHI, health outcomes, relative risk of heat-related mortality (for data description see Heaton et al. 2014), and parcel-based information on the use of air conditioning in Houston residences. The content and the format of this information can be easily integrated with other urban planning and public health GIS systems and serve as a heat preparedness and response platform for Houston. The publicly available on-line "Beat the Heat in Houston" tool contained information about the Houston UHI (neighborhood-specific maximum daily temperature during summer months), locations of cooling centers and other public air-conditioned buildings (including their addresses and hours of operations), and Centers for Disease Control-based recommendations on how to protect oneself from heat. Figure 6 shows the screenshot of the "Beat the Heat" GIS tool.

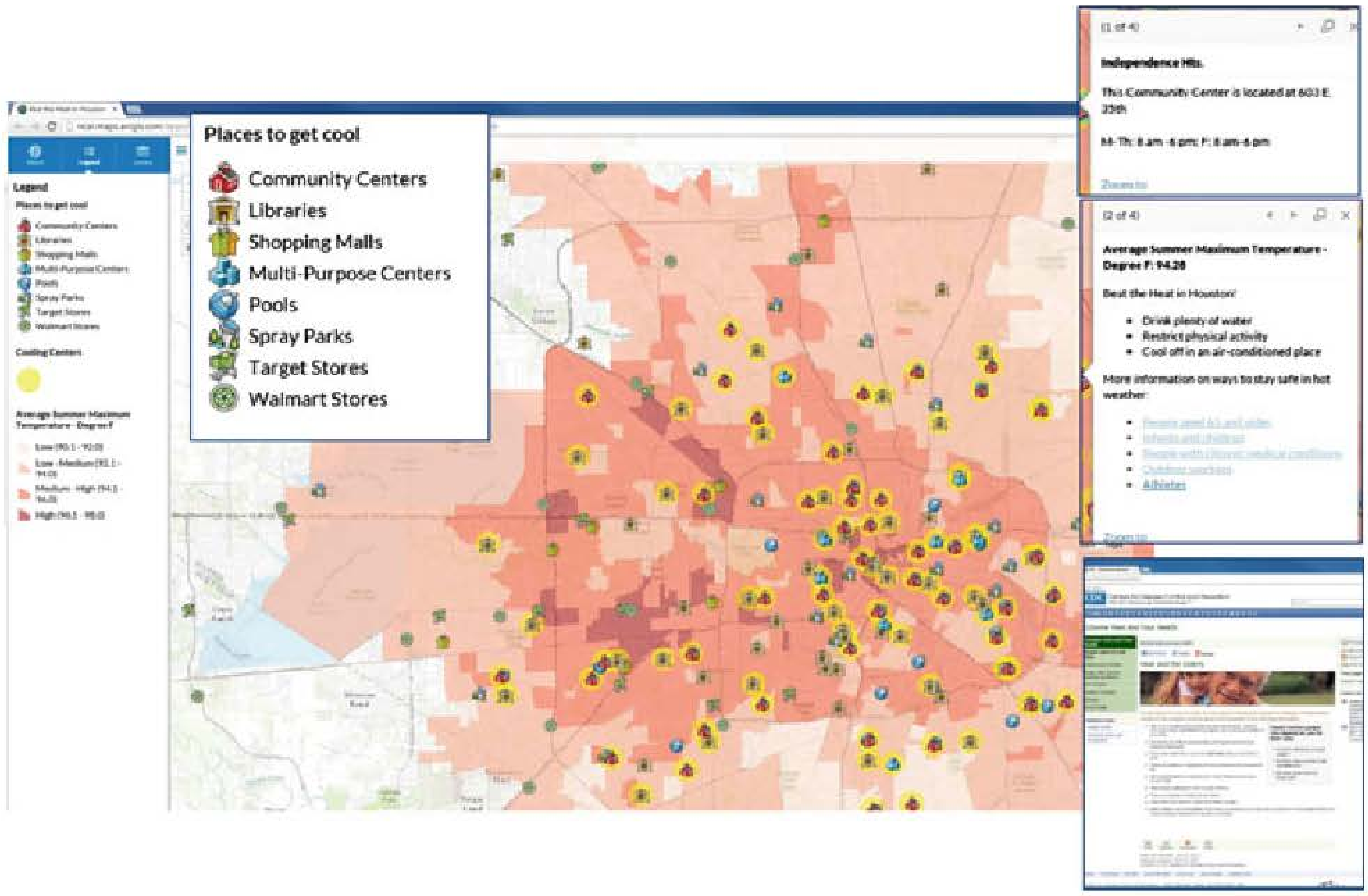

Fig. 6 "Beat the heat in Houston", a web-based tool that provides actionable information to Houston residents about summer heat and ways to cool off

GIS (whether commercial or open source) is an ideal platform for disseminating results of an interdisciplinary, complex project to the stakeholders and the public (Dragićević 2004; Balram 2006). The choice of software depends on the resources and expertise available to stakeholders. Web-based mapping solutions, such as ArcGIS Online, allow users to interact with the data with only a web browser and Internet access. While the public can use simple graphical user interfaces for visualizing information and connecting maps and images with concrete examples of protective actions and behaviors, the decision makers can use GIS for understanding the relationship between extreme heat exposure and social vulnerability as part of the hazard mitigation planning process. GIS has been widely used in hazard mitigation, disaster response, urban planning, and public health interventions and surveillance (Wilhelmi et al. 2004; Radke et al. 2013). Because extreme heat preparedness and response includes all these aspects of decision making, GIS can be useful for reducing future impacts of extreme heat on human health.

4 Summary and Best Practices for Stakeholder Engagement

In this chapter we described the interdisciplinary aspects of extreme heat risk and vulnerability, using concepts, methods and findings from the SIMMER project. Our focus on a stakeholder engagement process and the science-policy interface emphasizes the importance of participatory approaches and provides a framework for linking complex science to decision making. We now synthesize how the overall research framework and specific findings from the SIMMER stakeholder engagement process in Houston can be applied to other locations and public health and weather hazards studies where decision making is informed by interdisciplinary science.

4.1 Decision-Maker Engagement

It is imperative to *engage with local decision makers from the beginning* of the research proposal development to make sure that local needs, issues of concern at all levels (i.e., neighborhood, community, city, and region), and knowledge gaps are considered in the research plan. This will then provide a conduit for stakeholders to ensure that limited resources are targeted to the most vulnerable populations, and it allows for the characterization of vulnerability in a more explicit manner so that underlying disparities can be addressed more effectively.

4.2 Dual Engagement Approach

An integrated *top-down and bottom-up approach* is needed to positively affect health outcomes in response to extreme heat. Stakeholders from multiple sectors and levels of governance, both formal and informal, need to be engaged (Wilhelmi and Hayden 2010). We need to involve stakeholders from multiple levels, including community groups, but we also need to make a concerted effort to reach the actual members of the most vulnerable populations—households within a community. One of the limitations of many studies is a focus on stakeholders outside of the household level; these stakeholders may or may not have a voice that represents the actual community at risk. Bypassing household level decision makers may lead to erroneous assumptions about people's needs and their access to resources; this limitation can be overcome by conducting household surveys, community forums and/or town hall meetings to determine the level of trust in community leaders and other decision makers.

4.3 Early Stakeholder Involvement

Stakeholders must be involved from the inception of the project; however, this is not a one-time engagement. *Regular communication* between the research team and stakeholders is critical. No research project design is perfect from the outset, and may need to be tweaked periodically in order to safeguard not only the integrity of the work, but also to determine whether the needs of stakeholders are being addressed by the research. By engaging in an interactive and iterative process, the focus can remain on the co-production of solutions to the problem.

4.4 Stakeholder Adaptive Capacity

Stakeholders are crucial to building local adaptive and coping capacity to extreme heat, especially when they share common goals and interests. Therefore, an effort should be made to engage stakeholders in heat-health research as well as science-informed decision and policy making. As discussed in this chapter, addressing a complex environmental hazard such as extreme heat requires participation of stakeholders from different sectors (i.e., public health, urban planning, energy, transportation) and from different levels of decision-making (i.e., community representatives, non-governmental organizations, city, county and state officials). While there could be a large number of individuals or organizations who are interested in or concerned with reducing impacts of extreme heat on human health, the direct, day-to-day involvement of these parties in scientific research and/or coordinated preparedness and response activities can vary greatly. Often, resource and time constraints or institutional priority setting limits active participation. While it is essential to have an open and inclusive communication between all interested stakeholders (i.e., though workshops, town hall meetings, or web-based fora), it is also important to have strong leadership and clear guidelines for moving forward. One of the recommendations from the stakeholder meeting in Houston was to identify a "*Heat Champion*"—an individual or an organization who will lead and coordinate heat-related preparedness and response activities. Without *strong leadership* the momentum gained during stakeholder meetings can be lost, once the participants return to their day-to-day lives.

4.5 Relevance to Local Needs

Stakeholder engagement helps to ensure that the research is relevant to local needs and the findings can reach not only the decision makers but also the most vulnerable members of the community. It is important to consider local context, demographics, culture, languages, and history in messaging in particular, and communication strategies, in general. Just like the decision-support tools must be tailored to the users' needs, the messaging about extreme heat and its risks must be tailored to specific audiences. Extreme-heat risk communication that leads to protective actions is an emerging area of research and more work needs to be done to test the efficacy of risk messages targeted at certain sub-populations (i.e., elderly, athletes, outdoor workers). Also, as discussed at the stakeholder workshop in Houston, more work can be done to increase the effectiveness of dissemination of heat-health information by including a variety media (i.e., Websites, social media, TV, radio, billboards along the highways, utility bills, phones). *Providing tailored messages through a variety of sources* helps not only to reach more people but also to make the information more useful.

The findings presented in this chapter are largely based on our work in Houston, Texas. Cities like Houston do not have to wait for a major heat wave or an extreme heat event to be concerned with the impacts of heat on human health. Hot and humid summers are common, thus placing many vulnerable urban residents at risk from heat. There are many other cities around the world that face similar conditions and therefore need to be prepared for reducing future impacts of extreme heat on human health. The *model of stakeholder engagement*, presented here, can be applied in different urban settings, geographies and even cultural contexts. While the number and composition of stakeholders may vary, depending on the local context, the process of involving stakeholders in research, identifying gaps in preparedness and response as well as locally-relevant solutions, can apply in most setting. The transferable key elements of this work are: (1) interdisciplinary, mixed-method research that involves both stakeholders and the community members; (2) participatory process to generate ideas and solutions for reducing future risk.

References

Balram S (ed) (2006) Collaborative geographic information systems. Igi Global

Balbus JM, Malina C (2009) Identifying vulnerable subpopulations for climate change health effects in the United States. Int J Occup Environ Med 51:27–33

Bankhoff G, Frerks S, Hillhorst D (2003) Mapping vulnerability. Earthscan Press, Sterling 236 pp

Carney S, Whitmarsh L, Nicholson-Cole SA, Shackley S (2009) A dynamic typology of stakeholder engagement within climate change research. Tyndall Center for Climate Change Research, Working Paper, 128

Dillman DA, Smyth JD, Christian LM (2014) Internet, phone, mail, and mixed-mode surveys: the tailored design method. Wiley, New York

Dragićević S (2004) The potential of web-based GIS. J Geogr Syst 6(2):79–81

Eakin H, Luers A (2006) Assessing the vulnerability of social-environmental systems. Ann Rev Environ Resour 31:6.1–6.30

Hajat S, Kosatsky T (2010) Heat-related mortality: a review and exploration of heterogeneity. J Epidemiol Community Health 64:753–760

Harlan SL, Brazel AJ, Prashad L, Stefanov WL, Larsen L (2006) Neighborhood microclimates and vulnerability to heat stress. Soc Sci Med 63:2847–2863

Harlan SL et al (2012) Neighborhood effects on heat deaths: social and environmental predictors of vulnerability in Maricopa County, Arizona. Environ Health Perspect 121(2):197–204

Harlan SL, Declet-Barreto JH, Stefanov WL, Petitti DB (2013) Neighborhood effects on heat deaths: social and environmental predictors of vulnerability in Maricopa County, Arizona. Environ Health Persp (Online) 121(2):197

Harlan SL et al (2014) Heat-related deaths in hot cities: estimates of human tolerance to high temperature thresholds. Int J Environ Res Public Health 11(3):3304–3326

Hart H, Gower S, Wilhelmi O, Yagouti A (2014) Integrated models for heat-health decision making: linking complex science to policy for heat-health decision making. In: SIMMER workshop report, Toronto (Canada), 40 pp. Online at: http://ral.ucar.edu/csap/events/heat-health-decision-making/

Hayden M, Wilhelmi O, Cavanaugh J, Greasby T, Banerjee D, Nepal V (2015) Is air-conditioning the answer? Understanding adaptive capacity to extreme heat: results from a household survey in Houston, TX. To be submitted Climate Risk Management

Heaton MJ, Sain SR, Greasby TA, Uejio CK, Hayden MH, Monaghan AJ, Boehnert J, Sampson K, Banerjee D, Nepal V, Wilhelmi OV (2014) Characterizing urban vulnerability to heat stress using a spatially varying coefficient model. Spat Spatio-Temp Epidemiol 8:23–33

Heaton MJ, Sain SR, Monaghan AJ, Wilhelmi OV, Hayden MH (2015) An analysis of an incomplete marked point pattern of heat-related 911 calls. J Am Stat Assoc (in press). doi:10.1080/01621459.2014.983229

Hu L, Brunsell NA (2013) The impact of temporal aggregation of land surface temperature data for the surface urban heat island (SUHI) monitoring. Remote Sens Environ 134:162–174

Hu L, Brunsell NA, Monaghan AJ, Barlage M, Wilhelmi OV (2014) How can we use MODIS land surface temperature to validate long-term urban model simulations? J Geophys Res Atmos 119(6):3185–3201

Intergovernmental Panel on Climate Change (2012) In: 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 (eds) Managing the risks of extreme events and disasters to advance climate change adaptation. A special report of working groups I and II of the intergovernmental panel on climate change. Cambridge University Press, Cambridge, 582 pp

Johnson DP, Wilson JS (2009) The socio-spatial dynamics of extreme urban heat events: the case of heat-related deaths in Philadelphia. Appl Geogr 29:419–434

Johnson DP, Stanforth A, Lulla V, Luber G (2012) Developing an applied extreme heat vulnerability index utilizing socioeconomic and environmental data. Appl Geogr 35(1):23–31

Klinenberg E (2002) Heat wave: a social autopsy of disaster in Chicago. University of Chicago Press, Chicago

Lemos MC, Morehouse B (2005) The co-production of science and policy in integrated climate assessments. Glob Environ Chang Human Policy Dimensions 15(1):57–68

McMichael AJ (2000) The urban environment and health in a world of increasing globalization: issues for developing countries. Bull World Health Organ 78(9):1117–1126

Monaghan AJ, Hu L, Brunsell NA, Barlage MP, Wilhelmi OV (2014) Evaluating the impact of urban morphology configurations on the accuracy of urban canopy model temperature simulations with MODIS. J Geophys Res Atmos 119:6376–6392. doi:10.1002/2013JD021227

Montello DR (2001) Scale in geography. In Smelser NJ, Baltes B (eds) International encyclopedia of the social and behavioral sciences, pp 13501–13504

National Oceanic and Atmospheric Administration (2014) Weather fatalities. Online at: http://www.nws.noaa.gov/om/hazstas.shtml. Updated 3 July 2014

O'Brien K, Leichenko R, Kelkar U, Venema H, Aandahl G et al (2004) Mapping vulnerability to multiple stressors: climate change and globalization in India. Glob Environ Change 14: 303–313

Oleson KW, Monaghan A, Wilhelmi O, Barlage M, Brunsell N, Feddema J, Hu L, Steinhoff DF (2013) Interactions between urbanization, heat stress, and climate change. Clim Change. doi:10.1007/s10584-013-0936-8

Patz JA, Campbell-Lendrum D, Holloway T, Foley JA (2005) Impact of regional climate change on human health. Nature 438(17):310–317

Pickett KE, Pearl M (2001) Multi-level analyses of neighbourhood socio-economic context and health outcomes: a critical review. J Epidemiol Community Health 55:111–122

Radke SL, Johnson R, Baranyi J (2013) Enabling comprehensive situational awareness. Esri Press, New York, 204 p

Rosenthal JK, Kinney PL, Metzger KB (2014) Intra-urban vulnerability to heat-related mortality in New York City, 1997–2006. Health Place 30:45–60

Smoyer KE (1998) Putting risk in its place: methodological considerations for investigating extreme event health risk. Soc Sci Med 47:1809–1824

Smit B, Wandel J (2006) Adaptation, adaptive capacity, and vulnerability. Glob Environ Change 16:282–292

Uejio CK, Wilhelmi OV, Golden JS, Mills DM, Gulino SP, Samenow JP (2011) Intra-urban societal vulnerability to extreme heat: the role of heat exposure and the built environment, socioeconomics, and neighborhood stability. Heath Place 17:498–507

Wilhelmi OV, Hayden MH (2010) Connecting people and place: a new framework for reducing urban vulnerability to extreme heat. Environ Res Lett 5:014021

Wilhelmi OV, Purvis KL, Harriss RC (2004) Designing a geospatial information infrastructure for the mitigation of heat wave hazards in urban areas. Nat Hazards Rev 5(3):147–158

Wilhelmi O, de Sherbinin, A, Hayden M (2012) Exposure to heat stress in urban environments: current status and future prospects in a changing climate. In: King B, Crews K (eds) Chapter 12 in ecologies and politics of health. Routledge Press, Routledge

Wilhelmi O, Monaghan A, Hayden M, Sain S, Feddema J, Oleson K, Barlage M, Brunsell N (2014) System for integrated modeling of metropolitan extreme heat risk (SIMMER). Final report to NASA. Online: http://gis.ucar.edu/sites/default/files/uploads/SystemforIntegratedModelingofMetropolitanExtremeheatRisk-projectreport-1.pdf

World Meteorological Organization and World Health Organization (2015) Heatwaves and health: guidance on warning system development. Online: http://www.who.int/globalchange/publications/WMO_WHO_Heat_Health_Guidance_2015.pdf