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Climate and Human Health: A Literature Review

Attachment A

February 2024

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San Luis Valley
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West Denver
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This research was supported by the National Institutes of Health under award number OT2HL158287.The contents of this report are solely the responsibility of the authors and do not represent the official views of the National Institutes of Health.

Introduction

Climate change is a significant and increasing threat to human health, around the world, and in the United States (U.S.).[1] There are risks to physical, mental, and community health and while everyone is at risk, some people and communities are more vulnerable. There are many conceptual diagrams that illustrate the connections between individual and community factors and climate change exposures.[1,2] Common elements of these conceptual models include direct climate drivers or exposures, such as extreme heat and extreme precipitation, as well as the indirect proximal exposures, including drought, wildfires, and vector borne diseases. There are also varied health outcomes that are represented in the models, including heat-related illnesses, cardiovascular and respiratory diseases, physical injury, and mental health and well-being, among others. Social and behavioral contextual systems include individual demographic factors, such as age, gender, race, ethnicity, socioeconomic status, education, health care access, pre-existing medical conditions, and housing and infrastructure. Jerrett and colleagues also outline adaptive measures in their conceptual model, which includes community infrastructure such as building design, stormwater management, green spaces, wildland fuel management, early warning systems, and surveillance.[2]

Determinants of vulnerability to climate stressors includes: 1) exposure – the contact between a person and a stressor; 2) sensitivity – degree to which people or communities are affected; and 3) adaptive capacity – the ability of people or communities to adjust to potential climate stressors.

Risks to climate stressors vary by geographic locale. In the western U.S., major climate stressors include extreme heat, wildfires, drought, and poor air quality. These events do not occur in silos. Extreme heat and low precipitation lead to drought conditions, increase the risk of wildfires, all of which lead to worsening air quality. Often, communities are exposed to multiple stressors, compounding their impact on health.

The purpose of this literature review is to: 1) provide an overview of what is known about the impacts of climate stressors on human health, including physical and mental health outcomes and 2) provide an overview of current community adaptive actions and interventions to address these hazards. The scope of this literature reviews includes scientific publications from a 10-year period (2014-2024) based on work in the western U.S.

Climate Stressors and Health Impacts

Extreme Heat

There exists an increase in both average and extreme temperatures in the U.S. The average temperature in the U.S. has increased by nearly 2 degrees Fahrenheit over the past century and projections for the rest of this century are that average U.S. temperatures will increase by another 3 to 10 degrees Fahrenheit.[1] Heat waves have also become more frequent and intense during this time. Complicating matters, there is not a standard definition for what a heat wave entails, which leads to inconsistencies when comparing studies.

A complex relationship exists between extreme heat and health. Extreme heat can raise body temperature, result in increased breathing rates and elevated heart rates.[2] Studies examining the impacts of extreme heat on health outcomes have found a number of connections. In the ten-year period 2004-2013, heat was responsible for more estimated deaths than any other extreme event.[1] Extreme heat has been associated with increased mortality across numerous studies.[2-6] For example, Baker and Sturm found that compared to days with no heat risk, days with heat risks were associated with increased deaths of 6.7% (moderate heat risk), 15.3% (major heat risk), and 65.5% (extreme heat risk).[4] Similarly, Joe and colleagues examined excess mortality associated with a 2006 heat wave in California and found 582 excess deaths occurred, a 5% increase over expected deaths.[5]

Sharpe and colleagues looked broadly at excess deaths associated with natural disasters and found that deaths associated with heat were the largest proportion of excess deaths, with 7,884 excess deaths reported over a 20 year period (1999-2018).[6] Increased mortality does not impact all people equally. Individuals who were experiencing homelessness faced a 59.3% increase across heat risk days and those in elder care facilities faced a 91.4% increase in mortality on major or extreme heat days.[4] Heat impacts were more pronounced for individuals who were ages 35-44 years and over 65 years old, and higher for Hispanic individuals, compared to white individuals.[5]

In addition to excess mortality, there is a link between extreme heat and multiple health conditions, including Alzheimer's disease,[7] renal outcomes,[8] cardiovascular,[2] respiratory outcomes,[9] pregnancy-related comlications,[10] and mental health outcomes.[2] These findings emerge from both hospitalization data and self-reported data. These health outcomes were more concentrated among certain populations, including the older adults,[2,10] children, pregnant women,[2,10] people with pre-existing health conditions, certain racial and ethnic groups,[6] and outdoor workers.[2] Further, many of the social and behavioral systems outlined in the introduction are important to consider, such as housing and neighborhood supports. Many people have economic barriers to installing or running an air conditioner and certain census tracts are less likely to be protected by urban green space cooling.[2,9]

Wildfires

Increased wildfire activity in the western U.S. in recent years has led to significant property loss, as well as loss of lives and exacerbations of health outcomes.[11] Recent estimates state that nearly 50 million homes are in the wildland-urban interface (WUI), a number that is increasing every year.[12] Smoke from wildfires carries long distances, making wildfires an environmental health hazard that is widespread. This is often reported as exposure to particulate matter of less than 2.5 microns ($PM_{2.5}$) which is a size that can cause adverse health problems. Burke and colleagues estimated that wildfires accounted for 25% of $PM_{2.5}$ across the U.S., and up to 50% of $PM_{2.5}$ in some parts of the western U.S.[12] There are a number of methods that researchers use to connect health outcomes to $PM_{2.5}$ levels related to wildfire smoke, including utilizing municipal and regional air monitoring,[13] modeling of large spatiotemporal datasets,[14-16] public health data,[17] self-reported community survey responses,[18] and hospital utilization data.[14,19-21]

Multiple studies have shown a clear relationship between exposure to wildfire smoke and poor respiratory outcomes.[13-15,18-23] In Albuquerque, there was an increased risk of emergency department (ED) visits for some respiratory and cardiovascular conditions during the heavy smoke conditions experienced during the 2011 Wallow fire.[13] Similarly, researchers studying the impact of the 2008 wildfires in Northern California reported increases in asthma hospitalizations, asthma-related ED visits, as well as ED visits for chronic obstructive pulmonary disease (COPD).[14] The 2017 Lilac fire in Southern California resulted in an increase in pediatric respiratory ED visits from an average of 55.0 daily visits prior to the fire to 75.1 average daily visits during the fire, with children under the age of five showing the largest relative increase in visits.[20]

Others reported that while total ED visits were no different than reference periods, those for respiratory diagnoses increased by 34% and those for asthma increased by 112%.[19] Maya and colleagues also examined the impact of wildfire smoke on asthma control and found that in the absence of wildfire smoke, 48% of their cohort had complete or well controlled asthma, a number that fell to 27% after two weeks of wildfire smoke exposure.[18] They also found an 4% increase in acute healthcare utilization during this period. Complicating this picture, severe wildfires can impact residents' ability to obtain even routine healthcare.[24]

Masri established that there has been a doubling of census tracts affected by major wildfires and a doubling of the number of people residing in those tracts.[25] This increase in who is exposed does not impact all individuals equally. Traditionally, wildfires impacted residents who were more likely to be white, high-income, and older.[11] However, as wildfires are impacting larger proportions of the population, certain vulnerable groups of people are more likely to live in areas prone to wildfire smoke exposures and be more susceptible to the health impacts of wildfire smoke.[26,27] These vulnerable groups include people older than 65 years of age,[13,23,25] children younger than 5 years old,[20,21] low-income residents,[25] Native American populations,[25] and Black and Pacific Islander residents.[15,21] Communities in the western U.S. have the highest vulnerability. Communities with higher exposures to $PM_{2.5}$ often have higher vulnerability and lower adaptive capacity.[28]

In addition to well-documented cases of respiratory and asthma-related health outcomes, other researchers have demonstrated relationships between exposure to wildfire smoke and conditions such as cardiovascular disease,[13,21] cardiac arrest,[29] and pregnancy related conditions.[30] An interaction between heat and wildfire smoke days for CV disease has also been established, demonstrating that climate stressors do not act in isolation of one another and can compound the health impacts that individuals experience.[21]

Further, a growing line of research has examined the impacts of wildfires on mental health-related outcomes including depression, post-traumatic stress disorder (PTSD), and anxiety.[2,31-34] Six months after the 2018 Camp wildfire in California, Silveira and colleagues collected information about wildfire exposures and mental health outcomes.[32] They found that direct exposure to wildfires increased risk for depression and PTSD, risks that were exacerbated by pre-existing stressful life events.[32] Zhu and colleagues found that ED visits for anxiety disorders increased significantly during major wildfire events. Individual resilience can positively impact mental health outcomes,[32] which will be discussed later in the overview of community-based programs.

Drought

While extreme heat and lack of precipitation are the direct climate change exposures, drought is an indirect proximal effect caused by those changes.[2] Parts of the western U.S. are experiencing severe and prolonged drought, caused by increased temperatures and decreased precipitation. Droughts impact rural and agricultural communities, as well as urban communities.[35] The impacts of droughts on community and individual health are complicated and include downstream impacts on food insecurity, water availability, and environmental degradation, and economic effects.[2,36] The health effects due to drought are less well studied than for other climate hazards due to their complicated nature. Many studies focus on forest health, water quantity and quality, as well as impacts to agriculture.[36]

Researchers have examined the impact of drought on community water sources and found that droughts show higher water nitrate levels, as well as arsenic concentrations.[37] Similar to other climate hazards, the impacts are not felt equally. Community water systems for majority Latino/a communities are more affected. Others reported that vegetation in more disadvantaged communities is less drought-resistant, requiring more water and being less likely to survive, reducing the benefits of green spaces in urban environments.[2]

Increasingly, studies are looking at both the physical and mental health outcomes of persons exposed to drought conditions. Like with other climate hazards, it is important to note that for drought, both risk of drought and the vulnerability to drought must be considered. Vulnerabilities include age. Those ages 65 and older and ages 5 and younger are at increased risk to physical health impacts, adolescents have increased risks for adverse mental health effects, as do some agricultural workers.[36,38] In addition to understanding the mental health effects, researchers are seeking solutions to build resiliency in communities of agricultural producers, building upon existing social networks and community connections.[38]

Air Quality

Air quality is typically reported as $PM_{2.5}$ in the air, with higher amounts of $PM_{2.5}$ in the air equating to poorer air quality. Poor air quality can be caused by multiple sources, including wildfire smoke, traffic pollution, dust storms caused by droughts, or other industrial sources, demonstrating the interconnectedness of some climate stressors.[39] There is also a strong connection between outdoor air quality and indoor air quality and both are important exposures.[1,40,41] Poor air quality can lead to excess mortality,[42,43] ED visits,[44,45] respiratory conditions,[17,44,46] adverse pregnancy-related outcomes,[47,48] metabolic disorders,[49] and adverse mental health outcomes.[50-52] Bennett and colleagues found that $PM_{2.5}$ contribute to excess mortality, lowering the overall life expectancy for men and women.[42] Others similarly modeled the effects of improving $PM_{2.5}$ concentrations and found health benefits and fewer premature deaths each year.[43] These projected improvements were more likely to benefit disadvantaged communities.[42,43]

Respiratory outcomes are the most common health effects studied in conjunction with poor air quality. Between 2004 and 2024, there were over 2,000 published studies that focused on air quality and respiratory health.[53] Researchers reported that in three California regions, between 2012 and 2014, there were over 1.3 million ED visits for respiratory diseases and those ED visits corresponded to underlying outdoor pollutant levels for $PM_{2.5}$ and NO_2.[54] Mehta and colleagues also reported a positive association between $PM_{2.5}$ and increased respiratory hospital admissions.[44] Adults with chronic pulmonary disease (COPD) were found to have increased mortality due to cardiovascular outcomes when exposed to long-term $PM_{2.5}$.[17]

As with the other climate stressors discussed, the impacts of poor air quality are not experienced equally among all residents. Mehta reported the strongest respiratory impacts were experienced by Black residents.[44] Residents from more vulnerable communities, as defined by demographic and socioeconomic characteristics, have higher rates of ED visits for asthma and cardiovascular disease, correlating with their increased exposures to ambient air pollution.[45] Hispanic and Latino/a residents also have greater exposure to $PM_{2.5}$, resulting in increased insulin resistance, cholesterol levels, and metabolic syndrome.[49] Birth rate also has been shown to decrease, corresponding to increases in poor air quality, with larger impacts among less educated women[55] and black women.[48] Similar findings exist for indoor air quality. When examining indoor air quality during a wildfire event, researchers reported that indoor $PM_{2.5}$ increased substantially, and that values varied based on characteristics such as income, age of home, presence of air conditioning, and use of air cleaners.[41]

Environmental and Social Vulnerability

A portion of environmental researchers seek to address and correct the disproportionate burdens of environmental hazards that impact health and well-being, which are borne by more vulnerable communities, including those that are low-income and Black, Indigenous, and people of color (BIPOC).[56] Tools have been developed that help policymakers, researchers, and community organizations better understand the environmental needs of communities. Examples include the National Risk Index developed by the Federal Emergency Management Agency (FEMA),[57] the Social Vulnerability Index developed by the Centers for Disease Control and Prevention (CDC) Agency for Toxic Substances and Disease Registry (ATSDR),[58] and CalEnviroScreen, developed by the California Environmental Protection Agency.[2,59] Turek-Hankins and colleagues raised important issues about differences in various social vulnerability indices and the need to identify and select an index based on benefits and trade-offs of each.[60]

Increasingly, analyzing risk and vulnerability is taking a more holistic approach to exposures and outcomes. One example is the use of the CalEnviroScreen to identify the contributions of 12 environmental hazard indicators, 5 socioeconomic indicators, and 3 health outcomes.[59] Additionally, the researchers created an “overall disease burden” based on total hospitalization from 14 diagnostic categories. Two environmental factors explained 43% of the variance – 1) industrial activity and air pollution and 2) ground level ozone, drinking water, and $PM_{2.5}$ levels. Notably, of the socioeconomic factors, socioeconomic hardship explained 66% of the variance of disease burden, supporting the conclusion that socioeconomic status had a greater impact on disease burden than environmental hazards.[59] Overall, their analysis supported the use of the CalEnviroScreen tool as a measure of census tract vulnerability.

Other states, including Colorado, have developed similar tools such as the Colorado EnviroScreen 2.0.[61,62] Puskar and colleagues found county level evidence for a 3% increase in all-cause mortality associated with a 10% increase in an “environmental exposure” component from the Colorado EnviroScreen.[62] Others used latent profile analysis to identify neighborhood subtypes based on social and environmental factors such as race and ethnicity, crime rates, traffic-related air pollution, and green spaces.[63] They found four distinct neighborhood types, as well as associations between more disadvantaged neighborhoods and lung function. Also in Colorado, the City and County of Denver initiated a neighborhood climate and health vulnerability project, linking public health data and climate science data into a mapping tool, allowing for greater insights into the planning processes used by the local government.[64] Vulnerability indices are important tools to develop broader understanding of community-level needs related to environmental hazards.

State and Local Government Initiatives

State and local governments have primary responsibility for identifying, planning for, and responding to the health challenges caused by climate hazards.[65,66] Adaptation at the municipal level can reduce vulnerability to climate hazards.[35] To support state and local government efforts, the CDC developed the Climate-Ready States and Cities Initiative (CRSCI) in 2009. This initiative provides funding to state and local health departments to support their work responding to health impacts from climate change.[65] CRSCI-funded projects included the development of online toolkits, risk reduction policies for schools, communication strategies, surveys to identify service gaps for vulnerable populations, and providing climate equity training.[65]

State and local initiatives also occur because of higher order mandates, such as in California which has a 2018 mandate to address environmental needs. Brinkley and Wagner conducted an analysis of 461city plans across the state of California and reported that equity principles were found in "all required elements of general plans" including housing, circulation, land use, health, safety, open space, air quality, and noise.[56] They concluded that the mandate had been operationalized as health equity, with a focus on vulnerable populations and places, less so on race and racism. Another study that examined 14 local health department plans in California found that all 14 focused on vulnerability indices, 12 focused on strengthening collaborations, and 11 included a communications or public awareness campaign.[66] In contrast, only one local health department included a comprehensive adaptation plan.

Another study that examined the city plans from five cities across the world found that they included fairly generic plans for hazards, such as heat management.[35] There is a real opportunity for cities, as well as smaller towns and rural communities to make more specific plans to address climate hazards and environmental needs, taking into account local contexts. Three identified themes for building greater community resilience include: 1) preparing for greater intensity events; 2) understanding the compound effects from multiple climate stressors on vulnerable populations; and 3) identifying appropriate tools and strategies.[67]

Many factors support and hinder state and local climate change and health outcomes work. Challenges included limited subject matter expertise, competing demands, staff and leadership turnover, the complexity and uncertainty of the work, and limited resources.[35,65] Conversely, facilitators to conducting this work at the state and local level included partnering with other organizations, leadership support, hiring people with specific expertise in addressing climate and health, and taking advantage of opportunities to redirect focus and resources.[65]

Community-Based Adaptation and Resiliency

Environmental health research driven by academics and policymakers can overlook important contributions from community members, who have valuable insights and strong relationships with community leaders.[53,68,69] This oversight can result in inadequate solutions and less community ownership of generated products. Increasingly, academic researchers are engaging with communities to identify the major environmental health issues and co-develop solutions that address adaptation and resillience.[53,68-71] Nearly half (47%) of community members indicated they would be willing to participate in community resilience planning.[69] Community adaptation and resiliency projects include a wide variety of activities, such as changes to infrastructure and outdoor spaces,[15,35,72] air quality monitoring,[27,39,70,71,73,74] case study exercises,[75] stress and mental health programming,[38] communications,[35,76] and emergency alerts.[77] Communities are also working with researchers to develop and implement individual level adaptations, which include behavior changes,[52] environmental health literacy,[78] diary studies,[68] and online and phone-based apps.[31,79,80]

Changes to Infrastructure and Outdoor Spaces

Changes to community infrastructure include increasing community green spaces,[35] tree canopies such as the Million Trees Initiative in Los Angeles,[35] and capture and reuse of storm water.[35] These adaptations can be highly effective. Tayyebi and Jenerette found that vegetation increased cooling effectiveness between 6.1 and 31.7 degrees in the greater Los Angeles area.[72] Others reported that increased tree canopies attenuated the effects of $PM_{2.5}$ from wildfire smoke.[15] However, inverse relationships exist between increased vulnerabilities and decreased green spaces and tree canopies.[15] It is important that these initiatives take into account the communities with the greatest burden and need and aim for a more equitable distribution of climate adaptive infrastructure.[35] Other community infrastructure initiatives include reducing emissions from transportation, water conservation and recycling, including the capture and reuse of stormwater as well as reduced water usage.[35]

Air Monitoring

One of the most common climate-related interventions in the research literature centers around low-cost air monitoring sensors.[27,39,70,71,73,74] These networks often supplement governmental air monitoring networks which tend to be sparsely located.[73] More expansive, low-cost networks can provide data at a more localized scale, leading to more relevant and actionable data for communities.[73] After a network was installed in the Imperial Valley of California, researchers validated the data against the regulatory air monitoring system. They found that the community air monitoring system identified 10 times as many episodes of poor air quality, as compared to the regulatory air monitoring system.[73] Others have reported that the air quality index (AQI) is an effective risk communication tool if the air mixture is simple and corresponds to $PM_{2.5}$ levels, primarily in the cooler months, but is less predictive in the warmer months, when air quality tends to be worse.[54] During those time periods, other measures may more accurately reflect risk.

Researchers have used data from low-cost air monitoring networks to estimate $PM_{2.5}$ concentrations and examine those levels in relationship to both health outcomes, such as respiratory and cardiovascular ED visits,[27] as well as equity-related outcomes, including socioeconomic status, housing inequities, and health dispartities.[27,39] It is not enough to install low-cost air monitors within communities. There must be engagement with the communities to facilitate their usability and the utilization of data.[70,73] In one study in the Coachella Valley of California, 400 air quality sensors were placed across 14 communities and researchers assessed their use and community feedback.[74] To support installation, communities were provided with a series of workshops prior to, during, and after the sensor deployment and on-demand technical assistance was provided throughout the process. There was a wide variability in the installation of sensors, the time to installation, and maintenance of sensors. Notably, once sensors were installed in a community, most participants were willing to maintain their sensors, though factors such as higher asthma rates, unemployment, and lower socioeconomic status are associated with lower installation rates.[74] Further highlighting that these low-cost sensor networks can exacerbate differences based on community differences, Sun and colleagues reported that while the coverage of low-cost sensors increased significantly across California, they were less like to be found in communities with lower socioeconomic status, higher rates of $PM_{2.5}$, and higher proportions of residents who were in a racial or ethnic minority group.[39] Low-cost sensors also tend to be located in communities with higher socioeconomic status and who residents are more likely to be white.[81]

Communication and Education

Many climate hazard interventions focus on communication methods and education. Risk communication was flagged as a recommendation for cities to incorporate into their climate plans. This is an opportunity for cities to raise awareness about health risks and to increase understanding of climate risks among the public, but also among politicians, government employees, and schools.[35] Most of the published climate intervention research focuses on environmental health literacy[78,82,83] and alerts and warnings.[52,84,85]

Environmental health literacy is based on understanding the link between environmental hazards and health outcomes and combines key concepts from fields including risk communication, health literacy, environmental health sciences, communications research, and safety culture.[86] Communication can help achieve environmental health literacy at both the individual and community level.[35,83] However, there needs to be a greater understanding of what effective communication entails and how to move people to take action. Rosen and colleagues studied different visual designs to communicate about poor air quality.[80] They found that participants exposed to the visual message design displayed greater message comprehension, as opposed to the text-based message, although this did not translate to increased protective behaviors. High efficacy messages, those that drew upon the person's ability to view themselves acting in a certain way, were shown to increase protective behaviors, but not comprehension.[80] These findings support the call for additional work to better understand how to best communicate complex environmental health information to the public, ensuring that it is actionable.

Ramirez and colleagues evaluated available air quality communications and solicited expert stakeholder input, as well as community input to better understand the effectiveness of communication.[83] They found that there were primarily two types of information sources – those used by experts and those for use by the general public and the general public was generally unaware of all available sources of air quality information. Issues identified with air quality messaging was that the messaging did not explicitly tie air quality to either short- or long-term health outcomes,[83] which residents have indicated they want.[85] Others reported that the most common sources of air quality information residents report using were looking outside, followed by the TV, while the most highly recommended methods for assessing air quality were the least utilized.[76] Top communication priorities by community residents included improving emergency alert systems, improve warning systems for high heat and poor air quality, and quickly providing information to allow people to take care of their health and safety during extreme weather.[77] Similar systems have been developed for water quality – the online Drinking Water Tool was developed in 2017 to help California residents understand water sources and water challenges.[79] They found that the development through an academic-community partnership facilitated acceptance and usability. While they tool was not ultimately used by all stakeholders, the community engagement process had many positive outcomes, including the acceleration of parallel efforts undertaken by others.[87]

Palinkas and colleagues[52,84] found that residents did receive and respond to warnings about both air quality and heat waves. In one small study in Los Angeles, they reported that all residents who participated in an interview reported experiencing the negative impacts of poor air quality and 60% reported that they received advanced warnings about the hazard from newscasts or cell phone apps. Further, they adapted their behavior by staying indoors, recirculating indoor air, or wearing masks when outside.[52] They found similar results from a study examining extreme heat communications, where 80% of participants reported receiving advanced warning about heat waves from newscasts or social media.[84] Adaptations included staying hydrated, remaining indoors or going to a cooler location. While air conditioning was the most common adaptation, they noted that one third of participants either did not have air conditioning or could not afford to use their air conditioning. Electric fans are another lower cost option to help people stay cool, but there are temperatures at which the use of an electric fan is unsafe due to increasing the amount of heat spread across the skin.[88] These findings highlight that even with knowledge about a climate hazard, not all residents are able to most effectively counter it.[84]

Multiple studies also focused on communication and education for youth residents.[78,82] Examples of this work include developing an internship program aimed at increasing environmental health literacy among high school students. The students participated in activities such as learning about air quality and health, explaining the benefits of air monitoring stations to community residents, and speaking about environmental hazards with state government officials.[78] Participation in the 10 week internship led to increases across the board in attitudes and behaviors that reflect environmental health literacy concepts.[78] Working to increase environmental health literacy doesn’t start in high school. Another study described a summer camp that was developed for Native American elementary school children to better understand the importance of water quality, utilizing a community-based participatory research process.[82] The children learned about respecting water, the connection between water and health, water contamination, and water conservation. The summer camp curriculum underwent multiple iterations as community members and university educators engaged in a multiyear process to develop a curriculum that was accurate, engaging, and met the needs of the community.[82] Both teams noted the importance of engaging young people to address the increasing threats that climate change has for human health.[78,82]

Conclusions

The impacts of climate change on human health are increasingly recognized as a hazard in the U.S. Researchers have established connections between a changing climate in the western U.S. and environmental hazards such as extreme heat, drought, wildfires, and poor air quality.[1] Those environmental hazards impact health in numerous ways, including through increased mortality and morbidity due primarily to respiratory diseases and cardiovascular disease, though research has established these connections to many other physical conditions. An increasing amount of research has also highlighted the connections between climate hazards and mental health conditions, including anxiety, depression, and PTSD. Evident in the literature is the notion that these outcomes impact vulnerable populations in disproportionate ways.

Communities are not passive bystanders to environmental challenges. Resilience is important and there is evidence that communities are facing these challenges head on through a number of different mitigation and adaptation strategies. Common strategies are to increase community access to knowledge through increased communication and education so that residents know when to take action and can identify actions to take. Successful capacity building includes not only researchers and state and local government officials, but also community residents who are most attuned to the hazards they face and the actions that are supported within their communities, including a recognition of available resources to implement adaptive strategies.

The existing literature provides many examples of successful community-based interventions. The knowledge gained from these studies can be expanded to other climate hazards and applied to other communities. A vast majority of the published research takes place in California, but the lessons learned are applicable across other western states that face the same climate hazards.

Despite the increase in publications focusing on community-level climate adaptations, many gaps persist. Noted gaps include the lack of surveillance and data across more disadvantaged communities, lack of understanding of community members about what actions to take to protect their health and safety, and lack of resources at both the community and individual level to implement evidence-based adaptations. It is imperative that academic researchers, state and local policymakers, and community members work together to identify the most pertinent climate-related hazards and co-design and evaluation effective solutions.

References

1. Crimmins A, Balbus J, Gamble JL, et al., eds. *USGCRP, 2016: The Impacts of Climate Change on Human Health in the United States: A Scientific Assessment.* Washington, DC: U.S. Global Change Research Program; 2016.
2. Jerrett M, Connolly R, Garcia-Gonzales DA, et al. Climate change and public health in California: A structured review of exposures, vulnerable populations, and adaptation measures. *Proceedings of the National Academy of Sciences of the United States of America.* 2024;121(32):e2310081121.
3. Azzouz M, Hasan Z, Rahman MM, et al. Does socioeconomic and environmental burden affect vulnerability to extreme air pollution and heat? A case-crossover study of mortality in California. *Journal of Exposure Science & Environmental Epidemiology.* 2024;07:07.
4. Baker L, Sturm R. Mortality in extreme heat events: an analysis of Los Angeles County Medical Examiner data. *Public Health.* 2024;236:290-296.
5. Joe L, Hoshiko S, Dobraca D, et al. Mortality during a Large-Scale Heat Wave by Place, Demographic Group, Internal and External Causes of Death, and Building Climate Zone. *International Journal of Environmental Research & Public Health [Electronic Resource].* 2016;13(3):09.
6. Sharpe JD, Wolkin AF. The Epidemiology and Geographic Patterns of Natural Disaster and Extreme Weather Mortality by Race and Ethnicity, United States, 1999-2018. *Public Health Reports.* 2022;137(6):1118-1125.
7. Zhang Y, Ebelt ST, Shi L, et al. Short-term associations between warm-season ambient temperature and emergency department visits for Alzheimer's disease and related dementia in five US states. *Environmental Research.* 2023;220:115176.
8. Baraghoshi D, Niswander C, Strand M, et al. Exacerbation of Renal, Cardiovascular, and Respiratory Outcomes Associated with Changes in Climate. *Yale Journal of Biology & Medicine.* 2023;96(2):159-169.
9. Crank PJ, O'Lenick CR, Baniassadi A, Sailor DJ, Wilhelmi O, Hayden M. Sociodemographic Determinants of Extreme Heat and Ozone Risk Among Older Adults in 3 Sun Belt Cities. *Journals of Gerontology Series A Biological Sciences & Medical Sciences.* 2024;79(8):01.
10. Rogne T, Wang R, Wang P, et al. High ambient temperature in pregnancy and risk of childhood acute lymphoblastic leukaemia: an observational study. *The lancet Planetary Health.* 2024;8(7):e506-e514.
11. Wibbenmeyer M, Robertson M. The distributional incidence of wildfire hazard in the western United States. *Environmental Research Letters.* 2022;17(6):064031.
12. Burke M, Driscoll A, Heft-Neal S, Xue J, Burney J, Wara M. The changing risk and burden of wildfire in the United States. *Proceedings of the National Academy of Sciences of the United States of America.* 2021;118(2):e2011048118.
13. Resnick A, Woods B, Krapfl H, Toth B. Health outcomes associated with smoke exposure in Albuquerque, New Mexico, during the 2011 Wallow fire. *Journal of Public Health Management & Practice.* 2015;21 Suppl 2:S55-61.
14. Reid CE, Jerrett M, Tager IB, Petersen ML, Mann JK, Balmes JR. Differential respiratory health effects from the 2008 northern California wildfires: A spatiotemporal approach. *Environmental Research.* 2016;150:227-235.

15. Do V, Chen C, Benmarhnia T, Casey JA. Spatial Heterogeneity of the Respiratory Health Impacts of Wildfire Smoke PM_{2.5} in California. *GeoHealth.* 2024;8(4):e2023GH000997.

16. Stewart DR, Saunders E, Perea RA, Fitzgerald R, Campbell DE, Stockwell WR. Linking Air Quality and Human Health Effects Models: An Application to the Los Angeles Air Basin. *Environmental health insights.* 2017;11:1178630217737551.

17. Alexeeff SE, Deosaransingh K, Liao NS, Van Den Eeden SK, Schwartz J, Sidney S. Particulate Matter and Cardiovascular Risk in Adults with Chronic Obstructive Pulmonary Disease. *American Journal of Respiratory & Critical Care Medicine.* 2021;204(2):159-167.

18. Maya S, Thakur N, Benmarhnia T, Weiser SD, Kahn JG. The Impact of Wildfire Smoke on Asthma Control in California: A Microsimulation Approach. *GeoHealth.* 2024;8(10):e2024GH001037.

19. Hutchinson JA, Vargo J, Milet M, et al. The San Diego 2007 wildfires and Medi-Cal emergency department presentations, inpatient hospitalizations, and outpatient visits: An observational study of smoke exposure periods and a bidirectional case-crossover analysis. *PLoS Medicine / Public Library of Science.* 2018;15(7):e1002601.

20. Leibel S, Nguyen M, Brick W, et al. Increase in Pediatric Respiratory Visits Associated with Santa Ana Wind-Driven Wildfire Smoke and PM_{2.5} Levels in San Diego County. *Annals of the American Thoracic Society.* 2020;17(3):313-320.

21. Heaney A, Stowell JD, Liu JC, Basu R, Marlier M, Kinney P. Impacts of Fine Particulate Matter From Wildfire Smoke on Respiratory and Cardiovascular Health in California. *GeoHealth.* 2022;6(6):e2021GH000578.

22. Cascio WE. Wildland fire smoke and human health. *Sci Total Environ.* 2018;624:586-595.

23. Liu JC, Wilson A, Mickley LJ, et al. Who Among the Elderly Is Most Vulnerable to Exposure to and Health Risks of Fine Particulate Matter From Wildfire Smoke? *American Journal of Epidemiology.* 2017;186(6):730-735.

24. Saberi P, Ming K, Arnold EA, Leddy AM, Weiser SD. Extreme weather events and HIV: development of a conceptual framework through qualitative interviews with people with HIV impacted by the California wildfires and their clinicians. *BMC Public Health.* 2023;23(1):950.

25. Masri S, Scaduto E, Jin Y, Wu J. Disproportionate Impacts of Wildfires among Elderly and Low-Income Communities in California from 2000-2020. *International Journal of Environmental Research & Public Health [Electronic Resource].* 2021;18(8):08.

26. Modaresi Rad A, Abatzoglou JT, Fleishman E, et al. Social vulnerability of the people exposed to wildfires in U.S. West Coast states. *Science Advances.* 2023;9(38):eadh4615.

27. Kramer AL, Liu J, Li L, Connolly R, Barbato M, Zhu Y. Environmental justice analysis of wildfire-related PM_{2.5} exposure using low-cost sensors in California. *Science of the Total Environment.* 2023;856(Pt 2):159218.

28. Jung J, Wilkins JL, Schollaert CL, et al. Advancing the community health vulnerability index for wildland fire smoke exposure. *Science of the Total Environment.* 2024;906:167834.

29. Jones CG, Rappold AG, Vargo J, et al. Out-of-Hospital Cardiac Arrests and Wildfire-Related Particulate Matter During 2015-2017 California Wildfires. *Journal of the American Heart Association.* 2020;9(8):e014125.

30. Fernandez ACG, Basilio E, Benmarhnia T, et al. Retrospective analysis of wildfire smoke exposure and birth weight outcomes in the San Francisco Bay Area of California. *Environmental Research, Health : ERH.* 2023;1(2):025009.

31. Heinz AJ, Wiltsey-Stirman S, Jaworski BK, et al. Feasibility and preliminary efficacy of a public mobile app to reduce symptoms of postdisaster distress in adolescent wildfire survivors: Sonoma rises. *Psychological Services.* 2021;15:15.

32. Silveira S, Kornbluh M, Withers MC, Grennan G, Ramanathan V, Mishra J. Chronic Mental Health Sequelae of Climate Change Extremes: A Case Study of the Deadliest Californian Wildfire. *International Journal of Environmental Research & Public Health [Electronic Resource].* 2021;18(4):04.

33. Zhu Q, Zhang D, Wang W, et al. Wildfires are associated with increased emergency department visits for anxiety disorders in the western United States. *Nature Mental Health.* 2024;2(4):379-387.

34. Humphreys A, Walker EG, Bratman GN, Errett NA. What can we do when the smoke rolls in? An exploratory qualitative analysis of the impacts of rural wildfire smoke on mental health and wellbeing, and opportunities for adaptation. *BMC Public Health.* 2022;22(1):41.

35. Paz S, Negev M, Clermont A, Green MS. Health Aspects of Climate Change in Cities with Mediterranean Climate, and Local Adaptation Plans. *International Journal of Environmental Research & Public Health [Electronic Resource].* 2016;13(4):438.

36. Jalalzadeh Fard B, Puvvula J, Bell JE. Evaluating Changes in Health Risk from Drought over the Contiguous United States. *Int J Environ Res Public Health.* 2022;19(8).

37. Sum S. Impact of Droughts on Served Drinking Water Disparities in California, 2007-2020. *American Journal of Public Health.* 2024;114(9):935-945.

38. Freeman B, Grocke-Dewey MU, Chichester L, Breeding K, Stallones L, Minter M. "Death by a Thousand Cuts": Agriculture Producer Resiliency in the Western United States. *Journal of Agromedicine.* 2024;29(1):66-79.

39. Sun Y, Mousavi A, Masri S, Wu J. Socioeconomic Disparities of Low-Cost Air Quality Sensors in California, 2017-2020. *American Journal of Public Health.* 2022;112(3):434-442.

40. Shu X, Cao J, Liu Q, et al. Global Trends and Hotspots in the Research of the Effects of PM2.5 on Asthma: A Bibliometric and Visualized Analysis. *Journal of Epidemiology and Global Health.* 2024;14(4):1720-1736.

41. Walker ES, Stewart T, Jones D. Fine particulate matter infiltration at Western Montana residences during wildfire season. *Science of the Total Environment.* 2023;896:165238.

42. Bennett JE, Tamura-Wicks H, Parks RM, et al. Particulate matter air pollution and national and county life expectancy loss in the USA: A spatiotemporal analysis. *PLoS Medicine / Public Library of Science.* 2019;16(7):e1002856.

43. Martenies SE, Akherati A, Jathar S, Magzamen S. Health and Environmental Justice Implications of Retiring Two Coal-Fired Power Plants in the Southern Front Range Region of Colorado. *GeoHealth.* 2019;3(9):266-283.

44. Mehta S, Vashishtha D, Schwarz L, et al. Racial/ethnic disparities in the association between fine particles and respiratory hospital admissions in San Diego county, CA. *Journal of Environmental Science & Health Part A-Toxic/Hazardous Substances & Environmental Engineering.* 2021;56(4):473-480.

45. Miao Y, Porter WC, Schwabe K, LeComte-Hinely J. Evaluating health outcome metrics and their connections to air pollution and vulnerability in Southern California's Coachella Valley. *Science of the Total Environment.* 2022;821:153255.

46. Farzan SF, Kamai E, Duenas Barahona D, et al. Cohort profile: The Assessing Imperial Valley Respiratory Health and the Environment (AIRE) study. *Paediatric and Perinatal Epidemiology.* 2024;38(4):359-369.

47. Lee J, Costello S, Balmes JR, Holm SM. The Association between Ambient PM_{2.5} and Low Birth Weight in California. *International Journal of Environmental Research & Public Health [Electronic Resource].* 2022;19(20):19.

48. Schwarz L, Bruckner T, Ilango SD, Sheridan P, Basu R, Benmarhnia T. A quantile regression approach to examine fine particles, term low birth weight, and racial/ethnic disparities. *Environmental Epidemiology.* 2019;3(4):e060.

49. Letellier N, Zamora S, Spoon C, et al. Air pollution and metabolic disorders: Dynamic versus static measures of exposure among Hispanics/Latinos and non-Hispanics. *Environmental Research.* 2022;209:112846.

50. Nguyen AM, Malig BJ, Basu R. The association between ozone and fine particles and mental health-related emergency department visits in California, 2005-2013. *PLoS ONE [Electronic Resource].* 2021;16(4):e0249675.

51. Thilakaratne RA, Malig BJ, Basu R. Examining the relationship between ambient carbon monoxide, nitrogen dioxide, and mental health-related emergency department visits in California, USA. *Science of the Total Environment.* 2020;746:140915.

52. Palinkas LA, De Leon J, Yu K, et al. Adaptation Resources and Responses to Wildfire Smoke and Other Forms of Air Pollution in Low-Income Urban Settings: A Mixed-Methods Study. *International Journal of Environmental Research & Public Health [Electronic Resource].* 2023;20(7):04.

53. Aranda AA, Kelty JS, Manukian S, et al. Environmental Health Assessment by Local Environmental Justice Experts for Evidence-based Decision-making in an Agricultural Community of Northern California. *Community Science.* 2024;3(3).

54. Cromar KR, Ghazipura M, Gladson LA, Perlmutt L. Evaluating the U.S. Air Quality Index as a risk communication tool: Comparing associations of index values with respiratory morbidity among adults in California. *PLoS ONE [Electronic Resource].* 2020;15(11):e0242031.

55. Ng C, Malig B, Hasheminassab S, Sioutas C, Basu R, Ebisu K. Source apportionment of fine particulate matter and risk of term low birth weight in California: Exploring modification by region and maternal characteristics. *Science of the Total Environment.* 2017;605-606:647-654.

56. Brinkley C, Wagner J. Who is Planning for Environmental Justice, And How. *Journal of the American Planning Association.* 2022;90:63-76.

57. FEMA. Federal Emergency Management Agency (FEMA) National Risk Index for Natural Hazards. 2024; https://www.fema.gov/flood-maps/products-tools/national-risk-index. Accessed 2/17/2025.

58. CDC/ASTDR. Centers for Disease Control and Prevention Agency for Toxic Substances and Disease Registry Social Vulnerability Index. 2024; https://www.atsdr.cdc.gov/place-health/php/svi/index.html. Accessed 2/17/2025.
59. Greenfield BK, Rajan J, McKone TE. A multivariate analysis of CalEnviroScreen: comparing environmental and socioeconomic stressors versus chronic disease. *Environmental Health: A Global Access Science Source.* 2017;16(1):131.
60. Turek-Hankins LL, Hino M, Mach KJ. Risk screening methods for extreme heat: Implications for equity-oriented adaptation. *PLoS ONE [Electronic Resource].* 2020;15(11):e0240841.
61. CDPHE. Colorado Department of Public Health and Environment Colorado EnviroScreen 2.0. 2025; https://cdphe.colorado.gov/enviroscreen. Accessed 2/17/2025.
62. Puskar S, DeBie K, Clark M, et al. Environmental Justice and Sustainable Development: Cumulative Environmental Exposures and All-Cause Mortality in Colorado Counties. *Sustainability.* 2024;16(21):9147.
63. Humphrey JL, Lindstrom M, Barton KE, et al. Social and Environmental Neighborhood Typologies and Lung Function in a Low-Income, Urban Population. *International Journal of Environmental Research & Public Health [Electronic Resource].* 2019;16(7):29.
64. Rudolph L, Maizlish N, North S, Dervin K. A Public Health Learning Collaborative on Climate Change for Urban Health Departments, 2016-2018. *Public Health Reports®.* 2020;135(2):189-201.
65. Mallen E, Joseph HA, McLaughlin M, et al. Overcoming Barriers to Successful Climate and Health Adaptation Practice: Notes from the Field. *International Journal of Environmental Research & Public Health [Electronic Resource].* 2022;19(12):11.
66. Holmes TJ, Holt A, English DQ. Progress of Local Health Department Planning Actions for Climate Change: Perspectives from California, USA. *International Journal of Environmental Research & Public Health [Electronic Resource].* 2022;19(13):29.
67. Sheehan MC. Climate Change and Human Well-Being in the 2020s: Lessons From 2020. *International Journal of Health Services.* 2021;51(3):281-286.
68. Shamasunder B, Chan M, Navarro S, Eckel S, Johnston JE. Mobile daily diaries to characterize stressors and acute health symptoms in an environmental justice neighborhood. *Health & Place.* 2022;76:102849.
69. Lovell S, Vickery J, Lopez P, et al. Evaluating an equity-focused approach to assess climate resilience and disaster priorities through a community survey. *PLoS ONE [Electronic Resource].* 2024;19(6):e0302106.
70. Wong M, Bejarano E, Carvlin G, et al. Combining Community Engagement and Scientific Approaches in Next-Generation Monitor Siting: The Case of the Imperial County Community Air Network. *International Journal of Environmental Research & Public Health [Electronic Resource].* 2018;15(3):15.
71. Wong M, Wilkie A, Garzon-Galvis C, et al. Community-Engaged Air Monitoring to Build Resilience Near the US-Mexico Border. *International Journal of Environmental Research & Public Health [Electronic Resource].* 2020;17(3):09.
72. Tayyebi A, Darrel Jenerette G. Increases in the climate change adaption effectiveness and availability of vegetation across a coastal to desert climate gradient in metropolitan Los Angeles, CA, USA. *Science of the Total Environment.* 2016;548-549:60-71.

73. Seto E, Carvlin G, Austin E, et al. Next-Generation Community Air Quality Sensors for Identifying Air Pollution Episodes. *International Journal of Environmental Research & Public Health [Electronic Resource].* 2019;16(18):05.

74. Collier-Oxandale A, Papapostolou V, Feenstra B, Der Boghossian B, Polidori A. Towards the Development of a Sensor Educational Toolkit to Support Community and Citizen Science. *Sensors.* 2022;22(7):26.

75. Chandra A, Williams MV, Lopez C, Tang J, Eisenman D, Magana A. Developing a Tabletop Exercise to Test Community Resilience: Lessons from the Los Angeles County Community Disaster Resilience Project. *Disaster Medicine & Public Health Preparedness.* 2015;9(5):484-488.

76. Brown P, Cameron L, Cisneros R, et al. Latino and Non-Latino Perceptions of the Air Quality in California's San Joaquin Valley. *International Journal of Environmental Research & Public Health [Electronic Resource].* 2016;13(12):15.

77. Kreslake JM. Perceived Importance of Climate Change Adaptation and Mitigation According to Social and Medical Factors Among Residents of Impacted Communities in the United States. *Health Equity.* 2019;3(1):124-133.

78. Madrigal D, Claustro M, Wong M, Bejarano E, Olmedo L, English P. Developing Youth Environmental Health Literacy and Civic Leadership through Community Air Monitoring in Imperial County, California. *International Journal of Environmental Research & Public Health [Electronic Resource].* 2020;17(5):27.

79. Pace C, Fencl A, Baehner L, Lukacs H, Cushing LJ, Morello-Frosch R. The Drinking Water Tool: A Community-Driven Data Visualization Tool for Policy Implementation. *International Journal of Environmental Research & Public Health [Electronic Resource].* 2022;19(3):27.

80. Rosen Z, Bice C, Scott S. Visualizing the Invisible: Visual-Based Design and Efficacy in Air Quality Messaging. *International Journal of Environmental Research & Public Health [Electronic Resource].* 2021;18(20):16.

81. deSouza P, Kinney PL. On the distribution of low-cost PM_{2.5} sensors in the US: demographic and air quality associations. *Journal of Exposure Science & Environmental Epidemiology.* 2021;31(3):514-524.

82. LaVeaux D, Simonds VW, Picket V, Cummins J, Calkins E. Developing a Curriculum for Change: Water and Environmental Health Literacy in a Native American Community. *Progress in Community Health Partnerships.* 2018;12(4):441-449.

83. Ramirez AS, Ramondt S, Van Bogart K, Perez-Zuniga R. Public Awareness of Air Pollution and Health Threats: Challenges and Opportunities for Communication Strategies To Improve Environmental Health Literacy. *Journal of Health Communication.* 2019;24(1):75-83.

84. Palinkas LA, Hurlburt MS, Fernandez C, et al. Vulnerable, Resilient, or Both? A Qualitative Study of Adaptation Resources and Behaviors to Heat Waves and Health Outcomes of Low-Income Residents of Urban Heat Islands. *International Journal of Environmental Research & Public Health [Electronic Resource].* 2022;19(17):04.

85. Hoshiko S, Buckman JR, Jones CG, et al. Responses to Wildfire and Prescribed Fire Smoke: A Survey of a Medically Vulnerable Adult Population in the Wildland-Urban Interface, Mariposa County, California. *International Journal of Environmental Research & Public Health [Electronic Resource].* 2023;20(2):10.

86. Finn S, O'Fallan. The Emergence of Environmental Health Literacy - From Its Roots to Its Future Potential. *Environmental Health Perspectives.* 2017;125(4):495-501.

87. Balmes JR, Hicks A, Johnson MM, Nadeau KC. The Effect of Wildfires on Asthma and Allergies. *The Journal of Allergy & Clinical Immunology in Practice.* 2024;11:11.

88. Parsons LA, Lo F, Ward A, Shindell D, Raman SR. Higher Temperatures in Socially Vulnerable US Communities Increasingly Limit Safe Use of Electric Fans for Cooling. *GeoHealth.* 2023;7(8):e2023GH000809.