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Components of Population Vulnerability and Their Relationship With Climate-Sensitive Health Threats

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Abstract Climate change is increasingly being framed as risks that will impact the poorest and most vulnerable communities among us. This has led to more efforts to estimate climate change risks across populations and in the context of human health and health equity. We describe the public health dimensions of climate vulnerability—exposure, population sensitivity, and adaptive capacity—and explore how these dimensions can modify population health impacts and their distribution. An overview of health disparities associated with specific climate risks is presented, and we offer potential solutions grounded in equitable urban development and improved characterization of climate vulnerabilities.

Keywords Vulnerability · Climate change · Sensitivity · Adaptive capacity · Exposure · Urbanization · Migration

Introduction

With the publication of the Laudato Si' Encyclical (Praise be to you—On Care For Our Common Home) by Pope Francis in June 2015, the world heard, perhaps never so strongly, the risks that climate change are posing to the poorest among us [1••]. As Pope Francis quoted succinctly, "everyday experience and scientific research show that the gravest effects of all attacks on the environment are suffered by the poorest." The World Health Organization has estimated that climate change was already contributing 150,000 deaths annually across the globe as of the year 2000 when considering a conservative range of health outcomes, with the largest impacts among the world's poor [2]. Though the poor generate the fewest greenhouse gas emissions, they will continue to face the greatest burden from climate change, underlining climate change's social and environmental equity dimensions, and driving a moral need for action.

The Papal Encyclical is a call to action that cites the particular challenges and environmental disparities facing the poor and the vulnerable. Poverty is an important component of public health "vulnerability" to climate change, but vulnerability is more complex than poverty alone. Despite its frequent use in the scientific literature, vulnerability has been difficult to operationalize into policy action.

A common public health understanding of vulnerability to climate change is needed to craft equitable climate policies and to devote limited resources to populations with the greatest need, in order to generate the highest potential for positive impacts. In a limited way, California has begun doing just that, with a portion of revenues from California's cap and trade program being invested in the most vulnerable communities identified as communities "disproportionately affected by environmental pollution", and measured by various environmental hazards, health, and demographic data [3]. As more local, national, and international governments adapt to climate change, it will be essential to better assess the identified components of climate vulnerability (exposure, sensitivity, and adaptive capacity); understand how these components interact

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with each other to lessen or enhance population vulnerabilities; and predict how specific climate hazards will differentially impact vulnerable populations based on data from past events.

Definition of Vulnerability

The Intergovernmental Panel on Climate Change (IPCC) has defined vulnerability to climate change as "the degree to which geophysical, biological, and socio-economic systems are susceptible to, and unable to cope with, adverse impacts of climate change" [4]. The breadth of this definition may partially reflect that the term 'vulnerability' is common across many disciplines and circumstances, and it will manifest itself in myriad ways across various climate hazards and geographical regions. Adger [5] conducted an overview on the evolution of the term vulnerability in the social and natural sciences, where he has concluded that vulnerability is best measured by assessing a community's (1) *exposure* to external stress; (2) *sensitivity* to the perturbation; and (3) *adaptive capacity.*

In characterizing vulnerability to climate change in a public health context, exposure is the human contact with various hazards that are likely to result from climate change (e.g., heat waves, flooding, sea level rise, increase in infectious disease vectors, forced migrations, etc.).

Sensitivity, or the degree to which humans are affected by the climate hazards in a positive or negative fashion, is impacted by underlying individual and community characteristics, such as age, income, existing co-morbidities, and political empowerment. Existing cumulative exposures, such as the exposure to multiple pollutants or other environmental hazards, may also increase or synergistically modify a community's sensitivity to climate hazards.

Adaptive capacity is "the ability of a system to adjust to climate change to moderate potential damages, to take advantage of opportunities, or to cope with the consequences" [6]. Dimensions of vulnerability may include economic resources, knowledge, infrastructure, institutions, and technology [7]. A community or institution with high levels of adaptive capacity will be able to respond to, cope with, and recover from exposures to climate disaster hazards. Adaptive capacity can occur at an institutional level (e.g., provision of government services) or a community level (e.g., neighborhood cohesiveness), or at the household and individual level (e.g., household emergency preparedness).

Communities with the greatest adaptive capacity to withstand climate hazards are often considered "resilient". In that way, community resiliency can be viewed as a counterweight to vulnerability. Ultimately, these various components of vulnerability will need to be assessed within the context of specific climate hazards to help communities and policy makers understand how they can best build community resiliency by reducing exposures, minimizing sensitivities, and enhancing adaptive capacity.

Exposure Vulnerability, Population Sensitivity, and Adaptive Capacity

Exposure Vulnerability

Exposure vulnerabilities to climate change will vary by global region. Any climate hazard's ultimate health impact will reflect a community's underlying sensitivity and adaptive capacities. Some regions may simply be overwhelmed by climate exposures, such as areas most susceptible to sea level rise or storm surges, including low lying island states, the Philippines, and Bangladesh. In general, exposures to climate change hazards are expected to have greater impact in the global South, where other vulnerability components compound the effect [8].

Climate exposures remain global in every sense of the word and are already being felt. The Artic, for example, is facing risks from loss of sea ice and the Greenland ice sheet, resulting in dramatic environmental changes affecting the ecology, human health, and long-held social practices in Aboriginal communities with a reliance on local foods [9–11]. Warmer temperatures may also increase the bioavailability of persistent organic pollutants that have been previously locked in permafrost, risking the health of indigenous diets [9]. Conversely, a community's traditional knowledge and skills, social networks, and adaptive flexibility with the natural world may offer resiliency to many exposures related to climate change by decreasing population sensitivity and increasing adaptive capacity [12].

When assessing a region's overall vulnerability, the impact of various climate exposures will vary by both the specific hazard and population sensitivities. For example, though heat waves kill more individuals in the USA than all other natural hazards combined, certain segments of the population, such as the elderly and the poor, will be far more vulnerable than others [13]. Likewise, heat waves will carry the potential for high mortality in other regions of the world, such as India, where a recent heat wave cost the lives of at least 2500 individuals [14]. But in terms of population exposure vulnerability and health risks, severe storms may be far more deadly for India, where farming is very sensitive to monsoon variability and 350 million people are dependent on rain-fed agriculture [15]. These examples do not negate vulnerabilities in the US food system nor nullify heat health risks in India, but rather indicate the wide variation in risks and vulnerabilities in various regions of the world.

Population Sensitivity

Population sensitivity is a combination of community characteristics that can increase or decrease an individual or community's susceptibility to the harmful effects of climate change hazards. Sensitivity indicators often include age (the elderly and children being the most vulnerable), race/ethnicity, income, occupation, mental and physical disabilities, and existing comorbidities [16]. Children are generally more susceptible to environmental hazards than adults because of modified exposure routes such as playing on the ground and frequent hand-mouth contact; eating, drinking, and breathing more than adults relative to their body size; and due to a child's complex and precisely choreographed neurological development [17]. The elderly often have limited mobility, are more likely to have comorbidities, and may be taking medications that may make them more prone to dehydration and have a reduced thirst sensation, leaving them more susceptible to adverse outcomes during heat waves and other emergencies [18]. Specific race/ethnicities may be more prone to climate-related hazards because of a pervasive lack of political empowerment that impacts their proximity to exposures, poverty status, and access to health care and other adaptive resources [19, 20•]. Many outdoor laborers, including farm and construction workers, will have higher exposure risks to heat and storm events [16]. People with mental and/or physical disabilities fare worse than their nondisabled counterparts across many health indicators and are more vulnerable during emergency situations [21]; during Hurricane Katrina, nearly 40 % of residents who did not evacuate had a disability or were caring for an individual with a disability [22].

Climate change will also create new sensitive subpopulations, including immigrants and refugees from other impacted areas. Although forced migration may be an effective method of adaptation that results in improved health status for those fleeing climate disasters, these migrants will face sociocultural challenges of integration as they leave their homes and move from rural areas into cities and towns [23].

Adaptive Capacity

Individuals and societies have been adapting to a constantly changing climate over the entire course of human history; in that way, vulnerability to a changing climate has always acted as a catalyst for collective action [24]. However, impending climatic changes are expected to be greater in variability and magnitude compared to historic changes. In recent years, there has been greater insistence on the production of decision-oriented research as priorities shift from quantifying and mitigating climate impacts and vulnerabilities to enabling action and adaptation planning to prepare for its inevitable impacts. Effective adaptation planning will necessitate both incremental and transformative actions, targeting proximate causes of vulnerability while also undergoing broader social and political change [25]. Fundamental to this process will be addressing systemic drivers of vulnerability that inhibit adaptive processes, rather than solely focusing on risk reduction.

Ultimately, a community's adaptive capacity will be measured by its social capital; strength of and opportunity for civic participation; economic equality; and equitable housing, transportation, and parks and other constructed infrastructure. At the institutional level, government capacity for emergency preparedness and response and its basic public health systems should draw upon broader democratic participation to improve the equity and responsiveness of these services.

Urban areas will be at the core of much of our adaptation planning. Cities are home to the majority of the world's population, as well as a major source of greenhouse gas emissions. By 2050, the United Nations estimates that two-thirds of the world will live in urban areas [26]. Cities facing the greatest climate hazards, particularly in rapidly urbanizing low- and middle-income countries, often have the fewest resources to adapt to these hazards [27]. However, urbanization itself, coupled with strong environmental policies, can be an effective strategy for reducing greenhouse gas emissions [28, 29•]. Climate vulnerability, adaptive capacity, and emissions mitigation can be influenced based on how we plan and build equitable environments.

Sea-rise will create higher storm surges and, in some cases, inundate or erode entire communities. Extreme weather events will strain emergency services and damage core infrastructure. Flooding will displace residents and erode water quality. Changes in precipitation will, in some regions, constrain fresh drinking water supplies. An increase in the intensity and frequency of heat waves will be compounded by "heat island" effects created in urbanized areas. In order to both reduce exposure and adapt to these hazards, cities can anticipate the need to focus on high quality and affordable housing; robust infrastructure for water systems, transit, and other municipal services; and the protection and restoration of environmental resources essential to human settlements, such as coastal resources, green spaces, and water sources.

Governments have become increasingly interested in development strategies that promote the capacity for individuals, communities, and institutions to respond to climate health hazards. Yet planning efforts are still far behind the need. A recent review of 200 European cities found that 35 % of cities did not have a climate mitigation plan, and 72 % did not have an adaptation plan [30].

The failures of municipalities to provide core infrastructure and resources are often even more pronounced in lower- and middle-income countries where climate hazards and vulnerabilities are expected to be greatest. For example, informal or illegal settlements, arising from an essential need for low-income residents to secure access to shelter, will be among the most vulnerable communities [27, 31]. Globally, the World Health Organization has estimated that over

one-third of global urban residents reside in slums [32]. That number can be as high as 70–80 % in some African cities prone to multiple climate hazards [31]. These communities often have little to no public services, including basic waste management and potable water supplies.

Cities throughout the world should collect data on existing climate risks, perform vulnerability assessments at the most refined geographic scale possible, and incorporate this data into existing planning processes to sustainably develop for adaptive capacity [27, 33]. This will add to existing knowledge of public health climate risks and improve population resiliency.

Vulnerability in Relation to Specific Climate Threats

Researching historic climate-related events allows us to better understand hazard and population-specific vulnerabilities and improves our ability to plan and adapt accordingly. Below, we examine notable climate-related hazards and summarize what has been learned in Table 1.

Heat

The vulnerability of certain subpopulations to heat has been the most researched of all climate-related health hazards. Analyses of past heat events have found that children, the elderly, and pregnant women are more prone to poor health effects from heat [34, 35]. Socioeconomic factors, such as poverty level and living in isolation, also elevate an individual's risk [34, 36]. Military personnel and outdoor laborers are at greater risk for heat stroke [37]. While socioeconomic disparities, linguistic isolation, living conditions, and occupation have been recognized as contributors to poorer heat-health outcomes among minority ethnic groups in the USA, more research is needed globally [38].

Extreme Weather Events and Man-Made Disasters

Extreme weather events, such as heavy precipitation, flash flooding, mudslides, and natural and man-made disasters (such as wildfires) are expected to increase in frequency with climate change. These events often have impacts on other aspects of an economy, such as tourism and agriculture. The

Table 1 Climate hazards, public health impacts, sensitive populations, and regional exposure risks

Climate hazard	Public health impacts	Sensitive populations	Regional exposure risks
Heat	Heat-related illnesses and mortality	Children, the elderly, pregnant women, individuals living alone, the poor, and military personnel and outdoor laborers	Increases in heat stress in many regions, especially in continental areas
Extreme weather events and man-made disasters	Injury, infection, mortality, mass displacement and homelessness, nutrition, respiratory impacts, and economic disruptions	Children, the elderly, women, transient populations, ethnic minorities, recent migrants, the poor, and the disabled and their caretakers	Increases in extreme weather events and wildfires in many regions, exacerbated by drought and sea-level rise in coastal regions
Vector-borne and infectious diseases	Vector-borne diseases such as West Nile virus, Lyme disease, chikungunya, dengue, and viral encephalitis, and water-related diseases such as salmonella, cryptosporidium, and cyanobacteria	Children, the elderly, migrants, the poor, malnourished, and immunocompromised individuals	Various regions globally based on changes in habitat suitability, often as a result of changes in temperature and precipitation
Sea level rise	Displacement, mental health impacts, and water and nutritional insecurity from salt water intrusion	Populations in low-lying areas, the poor, and household with the fewest resources to adapt	Coastal areas globally, especially low-lying islands
Drought	Malnutrition, water-related illness, displacement, respiratory illnesses, vector-borne diseases, infectious disease, mental health, and wildfires	Children, the elderly, the poor, individuals with existing health issues, and agrarian and subsistence populations and cultures	Various regions globally, with pronounced impacts in mid-latitude continental areas
Ocean ecosystems	Collapsed fisheries, economies	Indigenous, poor, and subsistence communities	Various regions globally

most vulnerable populations to the effects of extreme weather events include residents of group living facilities; ethnic minorities (by language); recent migrants (including immigrants); tourists and transients; physically or mentally disabled; large households; renters; places with large concentrations of children; poor households; the homeless; and women-headed households [39–42].

During floods, children are at a higher risk for infection and transmitting fecal-oral diseases, and those who are physically and/or mentally disabled may be at an increased risk for mortality or injuries [43]. Low-income households are less likely to be insured for protection against weather disasters and may be more susceptible to lasting damage to their dwellings [44]. During drought or other events that result in food scarcity, nutritional needs of women and girls suffer more compared to males [45]. Other extreme events such as wildfires, wind, and dust storms lead to increases in respiratory ailments [46, 47].

Vector-Borne and Other Infectious Diseases

The incidence of vector-borne diseases (such as West Nile virus, Lyme disease, chikungunya, dengue, and viral encephalitis) and food- and water-related diseases (such as salmonella, cryptosporidium, and cyanobacteria) has been linked to changes in the climate [48–50]. Models to predict vulnerability to climate-sensitive infectious disease in Europe have found that the Iberian Peninsula, the UK and Ireland, and southern France rank high [51]. Generally, children, the elderly, migrants, the poor, and those already suffering from malnutrition will be most vulnerable to infectious diseases [48].

Sea Level Rise

The largest hazard presented from sea level rise will be the erosion and inundation of coastal lands. And coastal populations are growing more rapidly than the global average. It has been estimated that a 2-m rise in sea level could lead to the displacement of 187 million people over the course of the coming century [52]. Migration itself can lead to many serious health impacts, including mental health problems, infectious disease, and greater morbidity from chronic conditions [53]. Yet migration will also be an essential process of adaptation and should be accommodated by local and national institutions [54]. Sea level rise will also contribute to salt water intrusion of drinking water supplies, changes in infectious disease patterns, and other effects from a variety of ecological changes [55]. Populations in low-lying areas, and especially the poor in those regions with the fewest resources to adapt, will be the most vulnerable to the direct impacts of rising seas [56].

Drought

Drought can lead to malnutrition, water-related illness, respiratory illnesses related to dust and/or infectious diseases (such as coccidioidomycosis), food/water insecurity, vector-borne diseases, mental health, and other health impacts related to wildfires, migrations, and other distal impacts [57, 58]. The extent of these impacts will greatly vary based on a population's underlying sensitivities, existing infrastructure, and their political and socioeconomic environment. The impacts of famine, for example, largely depend on social and political factors and can occur even while a country's food exports reach all-time highs [59].

Ocean Ecosystems

Climate-driven changes in ocean ecosystems include warmer ocean temperatures, acidification, depletion of oxygen, and loss of productivity that impacts fisheries, tourism, subsistence populations, and tropical coastal communities. An estimated 470–870 million of the world's poor rely on the ocean for employment, food, and other resources [60]. Ocean acidification has already been blamed for millions of dollars of losses in the US oyster fisheries, and the United Nations has estimated that acidification could cost the global economy $1 trillion per year by the end of the century. However, studies of climate-related risks have been recognized as needing more accurate methods to fully better project climatic impacts on ocean ecosystems [61].

Discussion

The 2015 Lancet Commission on Climate Change and Health has recommended that by 2020 governments "invest in climate change and public health research, monitoring, and surveillance to ensure a better understanding of the adaptation needs and the potential health co-benefits of climate mitigation at the local and national level" [45]. To invest in community adaptation and climate resiliency, a proper understanding of which populations are vulnerable and where they are located is essential. As we have outlined in this paper, each of the components of public health vulnerability to climate change —exposure, population sensitivity, and adaptive capacity— will vary geographically and continue to change over time. For example, population sensitivity to climate impacts will increase with the graying of the population and increases in chronic comorbidities.

Towards Equitable Development and the Greater Characterization of Population Vulnerabilities

Global urbanization and population density have the potential to magnify health disparities without an implicit focus on equitable development. According to the United Nations, by

2030 about five billion of the world's population will live in urban areas, and the majority of this growth will occur in Asia and Africa [25]. Sustainable and equitable approaches to land use and planning—such as affordable and high-quality housing and transportation, heat island reduction, and access to green spaces—will be important in mitigating health risks associated with rapid urbanization. These strategies, properly employed, can also improve climate adaptation and reduce overall climate vulnerability.

For some climate risks, such as heat, there is the potential for modest physiological adaptation. Recent studies have debated whether the effect of temperature on heat deaths has been decreasing over time [62, 63], but there are likely physiological limits to acclimatization and thermoregulation [64]. In the case of rising temperatures, it is likely that urban design, equitable development, and behavior changes will be more important than individual acclimatization.

There are many aspects of climate change which are still not well-characterized with respect to human health and vulnerability. For example, little is known about specific vulnerabilities related to long-term versus short-term drought [58]. More research is needed on the human health effects that may result from the disruption of ocean food chains. And in freshwater ecosystems, more investigation is needed on who is most vulnerable to the neurotoxic effects from harmful algal blooms and subsequent health impacts [65].

Conclusions

Exposure, population sensitivity, and adaptive capacity are all essential for assessing public health vulnerabilities to climate change. How these components of vulnerability interact with each other drives the human-related dimensions of climate change. For example, the USA may have lower risks of climate-induced risks than other areas of the world, but increasing rates of chronic diseases such as diabetes and obesity increases subpopulation vulnerabilities in the USA. Countries which have high exposure potential, adverse population sensitivity, and low adaptive capacity include low-lying island nations, South Asia, and parts of Africa. Different climate risks, such as drought, heat, and ocean ecosystem changes, will create unique population vulnerability profiles. Certain global trends, such as forced migration and urbanization, may augment the burden of climate-related illness, injury, and disease worldwide, but these trends also present an opportunity to promote adaptive capacity. For example, fostering equitable urban landscapes that build community resiliency would be an appropriate core governmental response to climate change threats. Regions and communities with the greatest vulnerability may need more resources for adaptation planning and exposure mitigation to reduce global climate health burdens.

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Compliance with Ethical Standards

Conflict of Interest The authors declare that they have no competing interests.

Human and Animal Rights and Informed Consent This article does not contain any studies with human or animal subjects performed by any of the authors.

References

Papers of particular interest, published recently, have been highlighted as:
- • Of importance
- •• Of major importance

1.•• Pope Francis. Laudato si' (Praise be to you—On Care For Our Common Home. May 24, 2015. Encyclical Letter of the Holy Father. Pope Francis' second Encyclical provides a scientific and moral rationale for an immediate and global move to action to prevent and adapt to climate change.
2. McMichael AJ, Campbell-Lendrum D, Kovats RS, et al. 2004. Global climate change. Chapter 20. In: Ezzati M, Lopez AD, Rodgers A, et al., Eds. Comparative quantification of health risks: global and regional burden of disease due to selected major risk factors. Vol. 2. Geneva: World Health Organization.
3. Senate Bill 535, De León. Chapter 830. California Global Warming Solutions Act of 2006: Greenhouse Gas Reduction Fund. 2012; leginfo.legislature.ca.gov/faces/billNavClient.xhtml?bill_id=201120120SB535.
4. Schneider SH, Semenov S, Patwardhan A, et al. Assessing key vulnerabilities and the risk from climate change. Climate Change 2007: Impacts, Adaptation and Vulnerability. A Report of Working Group II to of the Intergovernmental Panel on Climate Change, Parry ML, Canziani OF, Palutikof JP, et al., Eds. Cambridge University Press, Cambridge, UK, 779–810.
5. Adger WN. Vulnerability. Glob Environ Chang. 2006;16(3):268–81.
6. Gallopin GC. Linkages between vulnerability, resilience, and adaptive capacity. Glob Environ Chang. 2006;16:293–303.
7. Climate ESPON. Climate change and territorial effects on regions and local economies in europe. Dortmund, Germany: Technical University of Dortmund; 2011.
8. Anguelovski I, Chu E, Carmin J. Variations in approaches to urban climate adaptation: experiences and experimentation from the global South. Glob Environ Chang. 2014;27:156–67.
9. Donaldson SG, Van Oostdam J, Tikhonov C, et al. Environmental contaminants and human health in the Canadian Arctic. Sci Total Environ. 2010;408(22):5165–234.
10. Letcher RJ, Bustnes JO, Dietz R, et al. Exposure and effects assessment of persistent organohalogen contaminants in arctic wildlife and fish. Science of the Total Environment. 2010;408(15):2995–3043.
11. Ford JD, Willox AC, Chatwood S, et al. Adapting to the effects of climate change on Inuit health. Am J Public Health. 2014;104 Suppl 3:e9–17.

12. Ford JD, Smit B, Wandel J. Vulnerability to climate change in the Arctic: a cast study from Arctic Bay. Canada Global Environmental Change. 2006;16:145–60.
13. U.S. EPA. Climate change indicators in the United States: heat-related deaths. May 2014. http://www3.epa.gov/climatechange/pdfs/print_heat-deaths-2014.pdf.
14. Samenow J. 'India's hellish heat wave, in hindsight." Washington Post. June 10, 2015. http://www.washingtonpost.com/blogs/capital-weather-gang/wp/2015/06/10/indias-hellish-heat-wave-in-hindsight/.
15. Senapati MR, Behera B, Mishra SR. Impact of climate change on Indian agriculture & its mitigating priorities. American J Environ Protection. 2013;1(4):109–11.
16. Balbus JM, Malina C. Identifying vulnerable subpopulations for climate change health effects in the United States. J Occup Environ Med. 2009;51(1):33–7.
17. United States Environmental Protection Agency. America's Children and the Environment. 3rd Edition. 2013; http://www.epa.gov/envirohealth/children/
18. Hutton D. Older people in emergencies: considerations for action and policy development. World Health Organization. 2008; http://cdrwww.who.int/ageing/publications/Hutton_report_small.pdf.
19. Shonkoff S, Morello-Frosch R, Pastor M, et al. The climate gap: environmental health and equity implications of climate change and mitigation policies in California—a review of the literature. Clim Change. 2011;109(1):485–503.
20.• Cushing L, Morello-Frosch R, Wander M. The haves, the have-nots, and the health of everyone: the relationship between social inequality and environmental quality. Annual Review of Public Health. 2015;36:193–209. **This article outlines how inequality can lead to environmental degradation, and how environmental degradation most greatly impacts the poor**.
21. Krahn GL, Walker DK, Correa-De-Araujo R. Persons with disabilities as an unrecognized health disparity population. Am J Public Health. 2015;105 Suppl 2:S198–206.
22. Kaiser Family Foundation. Survey of Hurricane Katrina Evacuees. 2005;http://www.kff.org/newsmedia/7401.cfm.
23. McMichael C, Barnett J, McMichael AJ. An ill wind? Climate change, migration, and health. Environ Health Perspect. 2012;120(5):646–54.
24. Adger WN, Huq S, Brown K, et al. Adaptation to climate change in the developing world. Progress in Development Studies. 2003;3(3):179–95.
25. Wise RM, Fazey I, Stafford Smith M, et al. Reconceptualising adaptation to climate change as part of pathways of change and response. Glob Environ Chang. 2014;28:325–36.
26. United Nations, Department of Economic and Social Affairs, Population Division. 2014. World Urbanization Prospects: The 2014 Revision, Highlights. (ST/ESA/SER.A/352).
27. Satterthwaite D. Climate Change and Urbanization: Effects and Implications for Urban Governance. In, "United Nations Expert Group Meeting on Population Distribution, Urbanization, Internal Migration and Development." United Nations. New York, 21 – 23 January 2008.
28. Martínez-Zarzoso I, Maruotti A. The impact of urbanization on CO2 emissions: evidence from developing countries. Ecol Econ. 2011;70(1):1344–53.
29.• Ponce de Leon Barido D, Marshall JD. Relationship between urbanization and CO2 emissions depends on income level and policy. Environ Sci Technol. 2014;48:3632–9. **This research demonstrates that urbanization alone may be an inadequate strategy to lower GHG emissions, and that it must occur within the context of directed environmental policies**.
30. Reckien D, Flacke J, Dawson J, et al. Climate change response in Europe: what's the reality? Analysis of adaptation and mitigation plans from 200 urban areas in 11 countries. Clim Change. 2014;122(1–2):331–40.
31. Dodman D, Soltesova K, Satterthwaite D, et al. Understanding the assessment and reduction of vulnerability to climate change in African cities: a focus on low-income and informal settlements. 2015; l'Agence Française de Développement.
32. World Health Organization. Hidden cities: unmasking and overcoming health inequities in urban settings. 2010; http://www.who.int/kobe_centre/publications/hidden_cities2010/en/.
33. Houghton A, English PB. An approach to developing local climate change environmental public health indicators, vulnerability assessments, and projections of future impacts. J Environ Public Health. 2014; doi:10.1155/2014/132057.
34. McGeehin MA, Mirabelli M. The potential impacts of climate variability and change on temperature-related morbidity and mortality in the United States. Environ Health Perspect. 2001;109 Suppl 2:185–9.
35. Xu Z, Sheffield PE, Su H, et al. The impact of heat waves on children's health: a systematic review. Int J Biometeorol. 2014;58(2):239–47.
36. Semenza JC, Rubin CH, Falter KH, et al. Heat-related deaths during the July 1995 heat wave in Chicago. N Engl J Med. 1996;335(2):84–90.
37. Gubernot DM, Anderson GB, Hunting KL. The epidemiology of occupational heat exposure in the United States: a review of the literature and assessment of research needs in a changing climate. Int J Biometeorol. 2014;58(8):1779–88.
38. Hansen A, Bi L, Saniotis A, et al. Vulnerability to extreme heat and climate change: is ethnicity a factor? Global Health Action. 2013; 6: 10.3402/gha.v6i0.21364. doi:10.3402/gha.v6i0.21364.
39. Wisner B. Marginality and vulnerability: why the homeless of Tokyo don't 'count' in disaster preparations. Applied Geography. 1998;18(1):25–33.
40. McGuire LC, Ford ES, Okoro CA. Natural disasters and older US adults with disabilities: implications for evacuation. Disasters. 2007;31(1):49–56.
41. Peek L, Stough LM. Children with disabilities in the context of disaster: a social vulnerability perspective. Child Dev. 2010;81(4):1260–70.
42. Intergovernmental Panel on Climate Change. 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. Field CB, Barros V, Stocker TF, et al., Eds. 2012; Cambridge University Press, Cambridge, UK and New York, NY, USA.
43. Ahern M, Kovats RS, Wilkinson P, Few R, Matthies F. Global health impacts of floods: epidemiologic evidence. Epidemiol Rev. 2005;27(1):36–46.
44. Marmot M. The Marmot Review: Fair Society Healthy Lives. 2010; UCL Institute of Health Equity. University College London, London, UK. http://www.instituteofhealthequity.org/projects/fair-society-healthy-lives-the-marmot-review.
45. Watts N, Adger WN, Agnolucci P, et al. Health and climate change: policy responses to protect public health. Lancet. 2015;S0140–6736(15):60854–6.
46. Dohrenwend PB, Le MV, Bush JA, Thomas CF. The impact on emergency department visits for respiratory illness during the Southern California Wildfires. West J Emerg Med. 2013;14(2):79–84.
47. Yu HL, Yang CH, Chien LC. Spatial vulnerability under extreme events: a case of Asian dust storm's effects on children's respiratory health. Environ Int. 2013;54:35–44.
48. Patz JA, Epstein PR, Burke TA, et al. Global climate change and emerging infectious diseases. JAMA. 1996;275(3):217–23.
49. Lafferty KD. The ecology of climate change and infectious diseases. Ecology. 2009;90(4):888–900.

50. Semenza JC, Menne B. Climate change and infectious diseases in Europe. The Lancet. 2009;9(6):365–75.
51. Suk JE, Ebi KL, Vose D, et al. Indicators for tracking European vulnerabilities to the risks of infectious disease transmission due to climate change. Int J Environ Res Public Health. 2014;11(2):2218–35.
52. Nicholls RJ, Marinova N, Lowe JA, et al. Sea-level rise and its possible impacts given a 'beyond 4°C world' in the twenty-first century. Philosophical Transactions A. 2011;369(1934):161–81.
53. Kristiansen M, Mygind A, Krasnik A. Health effects of migration. Dan Med Bull. 2007;54(1):46–7.
54. Tocali C. Crisis or adaptation? Migration and climate change in a context of high mobility. Environment and Urbanization. 2009;21(2):513–25.
55. Craig RK. A public health perspective on sea-level rise: starting points for climate change adaptation. Widener Law Review. 2010;15(2):521–40.
56. Frumkin H, Hess J, Luber G, et al. Climate change: the public health response. Am J Public Health. 2008;98(3):435–45.
57. Stanke C, Kerac M, Prudhomme C, et al. Heath effect of drought: a systematic review of the evidence. PLOS Current Disasters. 2013; doi: 10.1371/currents.dis.7a2cee9e980f91ad7697b570bcc4b004.
58. Yusa A, Berry P, Cheng JJ, et al. Climate change, drought and human health in Canada. Int J Environ Res Public Health. 2015;12(7):8359–412.
59. World Health Organization. Climate change and human health: risks and responses. 2003; www.who.int/globalchange/publications/climchange.pdf.
60. Mora C, Wei CL, Rollo A, et al. Biotic and human vulnerability to projected changes in ocean biogeochemistry over the 21st century. PLoS Biol. 2013;11(10), e1001682.
61. Cressey D. "Crucial ocean-acidification models come up short.". Nature News. 2015;524(7563):18–9.
62. Bobb JF, Peng RD, Bell ML, et al. Heat-related mortality and adaptation to heat in the United States. Environ Health Perspect. 2014;122(8):811–6.
63. Kim H, Heo J, Kim H, et al. Has the impact of temperature on mortality really decreased over time? Sci Total Environ. 2015;512–513:74–81.
64. Hanna EG, Tait PW. Limitations to thermoregulation and acclimatization challenge human adaptation to global warming. Int J Environ Res Public Health. 2015;12(7):8034–74.
65. Weirich CA, Miller TR. Freshwater harmful algal blooms: toxins and children's health. Curr Probl Pediatr Adolesc Health Care. 2014;44(1):2–24.