Constraints and Barriers to Public Health Adaptation to Climate Change

A Review of the Literature

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Abstract: Public health adaptation to climate change is an important issue and inevitably is needed to address the adverse health impacts of climate change over the next few decades. This paper provides an overview of the constraints and barriers to public health adaptation and explores future research directions in this emerging field. An extensive literature review was conducted in 2010 and published literature from 2000 to 2010 was retrieved. This review shows that public health adaptation essentially can operate at two levels, namely, adaptive-capacity building and implementation of adaptation actions. However, there are constraints and barriers to public health adaptation arising from uncertainties of future climate and socioeconomic conditions, as well as financial, technologic, institutional, social capital, and individual cognitive limits. The opportunities for planning and implementing public health adaptation are reliant on effective strategies to overcome these constraints and barriers. It is proposed here that high research priority should be given to multidisciplinary research on the assessment of potential health impacts of climate change, projections of health impacts under different climate and socioeconomic scenarios, identification of health co-benefits of mitigation strategies, and evaluation of cost-effective public health adaptation options.
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Introduction

There is widespread scientific consensus that the world's climate is changing because of greenhouse gas (GHG) emissions caused by human activity.[1] In 1990, 1995, 2001, and 2007, the Intergovernmental Panel on Climate Change (IPCC) released four assessment reports, which concluded that warming of the climate system is unequivocal.[2] Observational evidence[3] from around the world shows that many systems are already being affected by recent climate changes, particularly temperature increases.

Climate change also poses a critical challenge to the health sector.[4] An increase in the frequency and magnitude of extreme events, along with reduced water and food security as well as degrading ecosystems, will have a great impact on human health.[5–7] The health impacts of climate change range from direct to indirect effects, such as extra deaths due to heatwaves, increases in the transmission of climate-sensitive infectious diseases, and mental health problems caused by income loss resulting from a reduction in agricultural productivity associated with floods, droughts, and other extremes.[8–13]

All people will be exposed to the potential impacts of climate change, but some populations may be more vulnerable.[5] The vulnerability depends on the level of exposure, population sensitivity, and adaptive capacity.[3,14] The health impacts will depend on the rate and magnitude of changes in climate; on the social, economic, demographic, infrastructural, and other factors that can influence the sensitivity of populations to climate change; and on the adaptive capacity to manage the health effects of climate change.[7,15–18]

Exposure may further be exacerbated by the increasing GHG emissions. Even if rapid and sustained reductions in emissions are achieved, climate change still is projected to continue.[3] In the future, more frequent and intense extreme events and their associated impacts over most areas are expected.[2] There are two main elements in climate change response policy: mitigation and adaptation. Mitigation means implementing policies to reduce GHG emissions and enhance carbon sinks.[2] The health sector also can play an important role in mitigating climate change by reducing its own emissions while at the same time saving money and generating substantial health, environmental, and social co-benefits.[19] *Adaptation* re-

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fers to "adjustment in natural or human systems in response to actual or expected climatic stimuli or their effects, which moderates harm or exploits beneficial opportunities."[20] Although mitigation endeavors to avoid the unmanageable, adaptation endeavors to manage the unavoidable.[3] Therefore, public health adaptation has become an important issue on the climate change agenda, and it is necessary to address the adverse health impacts of climate change over the next few decades.[21–25]

To date, however, few studies have evaluated the constraints and barriers to public health adaptation. Based on a review of literature, this paper aims to provide an overview of the constraints and barriers to public health adaptation. It also explores future research needs in this emerging field. An extensive literature review was conducted in 2010 using electronic databases PubMed, Scopus, ProQuest, ScienceDirect, and Web of Science. Additionally, relevant websites, such as IPCC and WHO, also were searched. Published literature from 2000 to 2010 was retrieved using a standard search strategy based on the key words *climate change*, *adaptation*, *vulnerability*, *public health*, *constraint*, and *barrier*.

Public Health Adaptation

Generally, public health adaptation is considered as any short- or long-term strategies that can reduce adverse health impacts or enhance resilience in response to observed or expected changes in climate and associated extremes.[26–30] Considering the likelihood that the frequency, variability, and characteristics of climate will change relatively faster, the current public health practices, policies, strategies, and infrastructure will become increasingly inappropriate and maladapted.[30,31] Thus, public health adaptation to climate change has become necessary.

See related Commentary by Frumkin in this issue.

Many adaptations can be taken automatically in a reactive manner. This is known as autonomous adaptation,[32] such as changes in farm practice.[3] By contrast, planned adaptation requires conscious intervention.[33] It means that actions are taken by using information on observed and anticipated climate change and by reviewing the suitability of current and planned practices, policies, and strategies.[34,35] An example of planned adaptation is the development of an early warning system. Overall, the health sector needs to go beyond simply reacting to a changing climate. It is important to integrate planned adaptations into existing health promotion and protection activities to reduce the health risks posed by climate change.[6,26,29]

Public health adaptation can operate at two levels, including building adaptive capacity and implementing adaptation actions. Adaptive capacity represents the set of resources available for adaptation, as well as the ability to utilize these resources effectively and efficiently.[35,36] Although all societies have inherent abilities to deal with certain changes in climate, adaptive capacities may become unequally distributed across countries or within societies.[3,5] Populations in small islands and developing countries are particularly vulnerable to death and injury from increasingly extreme events.[37–39] People of lowest SES are often the most vulnerable to climate change, as are the elderly.[40–42] Therefore, access to resources can be influenced by a range of social, economic, and institutional factors. For example, Alberini et al.[43] reported results of their survey of public health and climate change experts, which showed that per capita income, universal healthcare coverage, and high levels of access to information were the most important determinants of adaptive capacity related to the health risks of climate change.

To some extent, adaptive capacity is a prerequisite for the design and implementation of effective adaptation actions. Public health adaptation also comprises a wide range of actions by households, businesses, communities, and governments.[4,26,27] Thus, a mix of policies and measures for adaptation is necessary to address the health impacts of climate change at different levels. Policies refer to objectives and means of implementation.[36] For example, the WHO Regional Office for Europe published *Heat–Health Action Plans: Guidance* in 2008.[44] It describes the general principles and core elements of national or regional heat–health action plans and gives options and models for intervention. Measures are considered as focused actions aimed at specific issues, such as implementing a heat watch/warning system. In some cases, public health adaptation also can be undertaken as part of broader social and development initiatives, rather than actions to address the health risks only. For instance, some actions are usually implemented to cope with climate change as part of disaster preparedness, land use planning, or initiatives linked to sustainable development.[45–48] They are rooted in areas such as housing, agriculture, transport, and development; however, these actions also could have substantial health co-benefits.[15]

Constraints and Barriers to Public Health Adaptation

Although public health adaptation is regarded increasingly as an inevitable part of the response to climate change, a number of studies show that there are constraints and barriers to adaptation. Despite substantial investment in adaptive capacity and increased attention to adaptation actions, extreme events continue to result

in many deaths and injuries due to practical constraints and barriers.[49,50] For example, as a result of the 2009 Melbourne Bushfires, 172 civilians died. Although the bushfire safety policies had appeared sound on paper, implementation presented major challenges. A large proportion of the victims were taken by surprise and many falsely assumed that they would receive a specific warning from the public authorities. This bushfire example highlights the challenges facing successful adaptation, as even good preparedness at the householder level may not be enough to prevent fatalities.[51]

Generally speaking, constraints are limitations that may lie outside, but have a direct impact on the adaptation process. Barriers refer to any condition that makes it difficult to achieve progress toward adaptation. Furthering the understanding of these constraints and barriers may considerably improve the planning and implementation of strategies and policies for better public health adaptation.

Uncertainties of Future Climate and Socioeconomic Conditions

Public health adaptation decisions are made in a context of uncertain and dynamic environments.[31] Although it is very likely that the global climate will change, there are still uncertainties about how it will change and how fast.[52] In order to address the climate change due to increasing GHG emissions, the IPCC defined a set of 40 scenarios.[1] Each scenario makes different assumptions for future GHG emissions, land use, and other driving forces. To project spatially dependent climates in the future under various emissions scenarios, various General Circulation Models have been developed based on physical principles at the continental scale.[1] However, because different models use different plausible representations of the climate system, climate projections for a single scenario can differ, creating more uncertainties.

In addition to the uncertainties in climate projections, difficulties also rise from uncertainties of future demographic, socioeconomic, and technologic conditions that will change the exposure, sensitivity, and adaptive capacity of populations.[53,54] For example, there are uncertainties regarding the future populations at risk and future sensitivity to climate change.[55,56] Even though the future population stratified by age could be estimated reasonably, trends in education levels, financial situation, and levels of racial diversity and acclimatization within each age group are very hard to predict.[57] Thus, an inherent challenge for public health adaptation is the handling of uncertainties about the future health impacts of climate change.[58–61]

Financial Challenges

Managing the health effects of climate change can be costly. Billions of dollars are likely to be required every year to meet the challenges in the near future.[62–64] However, the countries that are most severely affected by climate change are often those most under-resourced.[65,66] Furthermore, within each country, the poorest groups in a society have the least capacity to adapt.[3] The distribution of adaptive capacity within and across societies represents a major barrier to the effectiveness of any adaptation strategy.[67] This barrier will likely exacerbate existing health inequalities as well as the underlying social determinants of illness and premature death, which largely limits the ability of disadvantaged people to take actions to adapt to climate change.[6]

In the developed countries, there is also a problem of funding insufficiency to address the health impacts of climate change. For example, Ebi et al.[68] argued that the NIH and other government agencies need to have robust programs to meet the challenges in the U.S., with annual funding of more than $200 million per year. However, the funding assigned to directly addressing the health impacts of climate change has been less than $3 million, creating a large financial gap. Bedsworth[69] conducted a survey to examine how local health agencies in California are prepared for dealing with the potential risks of climate change. Most local health officers responded that they have inadequate resources. Likewise, Olaris[70] suggested that funding was the main barrier for the health sector to tackle climate change in Victoria, Australia. Hence, in the absence of governmental prioritization of climate change impacts on health, financial resources are likely to remain a substantial barrier to public health adaptation.

Technologic Limits

Technology potentially can play an important role in adapting to climate change.[71] Access to, and use of, technology usually is regarded as an important determinant of adaptive capacity.[72] There have been successful applications of new technologies in the public health area to adapt to observed and anticipated climate change. GISs and remote-sensing data are becoming useful assessment tools, and such technologies can help health professionals to reallocate resources and reduce risks.[73,74]

However, conditions for the creation of new technology require access to expertise, knowledge, and funding. Even though some technologies already exist, it is also a challenge to make those technologies accessible to populations who will be most affected by climate change.[6] For example, the Internet is a powerful communication tool and is an important source of information to address the health impacts of climate change. Nevertheless, studies show that substantial disparities exist in Internet adop-

tion within and among countries, with these disparities linked to income, education, age, and ethnicity.[75] Because of major affordability and skill limitations, it is difficult to bring the Internet to rural and remote areas, particularly in developing countries.[76]

Institutional Arrangements

Institutions refer to the formal and informal rules as well as organizational arrangements governing human interactions.[77] Public health adaptation to climate change demands political action and social mobilization, so there is an important role for institutions in facilitating adaptation. However, the current institutional arrangements seem unlikely to ensure an effective, efficient and equitable adaptation strategy. Governments are typically organized in specialized policy domains. Fragmentation and policy contradictions are often a serious problem at all levels of government.[6] Given the complexity of health impacts of climate change, it is difficult to catalog all adaptations taking place. This is complicated particularly by the fact that, currently, in many countries there is no lead agency responsible for public health adaptation.[27]

In addition, knowledge about what adaptation actions to take, coupled with a high degree of adaptive capacity, may not automatically translate into successful adaptations.[67] Climate change may be perceived as posing little risk compared with other health hazards and therefore be given low priority by decision makers. In 2007, Maibach et al.[78] conducted a telephone survey with 133 randomly selected local health department directors in the U.S. The results suggested that a majority of respondents felt that climate change was likely to become an increasing problem in the coming decades in their jurisdiction; however, only a few had made climate change one of the priorities of their departments.

Moreover, effective adaptation requires information about what actions are possible to address the impacts. Yet there is a paucity of knowledge about the potential effectiveness of different adaptation options and their costs.[66,79] Typically, evaluation of particular adaptation options should compare the benefits with the costs, and the options that are chosen should be the ones that yield the highest net benefit. Otherwise, if information on adaptation options is inadequate or their expected costs go beyond the expected benefits, decision makers may decide not to adapt, or to delay their adaptation actions.[31]

Social Capital

It has been claimed that the theoretic underpinning of public health adaptation lies in the concept of social capital, which enables residents to coordinate community actions to achieve shared goals.[80] A high level of social capital will support collective initiatives of adaptation and also enhance resilience.[81,82] Research in Chicago suggests that belonging to a social network can have a protective effect against heat-related illness.[83] By contrast, a low level of social capital is regarded as shaping the vulnerability of population groups who are excluded from access to resources or decision making in the adaptation process.[84]

However, Wolf et al.[85] indicate that strong bonding networks also could exacerbate rather than reduce vulnerability to the effects of climate change. The authors suggested that misperceptions by the elderly and their social contacts about the health risks from heatwaves were an example of a barrier to proactive adaptation. Accordingly, public health adaptation may not always be able to rely on efficacy in existing social networks in response to climate change. Because social capital barriers to public health adaptation have not been well researched so far, it is still unclear in which conditions social capital may be counterproductive and even increase vulnerability.[86]

Individual Cognition

Finally, public health adaptation to climate change can be limited by human cognition.[87] An individual's knowledge of climate change is necessary but insufficient for adaptation. Perceptions of risk, vulnerability, and adaptive capacity will also affect decision making or behavioral change.[67] For example, the public may know when a heatwave will occur, but they may not think they are vulnerable to the impacts.[88] Higher-income earners may perceive a lower risk from climate change because they have the financial means to cope with the threats.[89]

Individual interpretation of information can be influenced by personal experience, values, priorities, and other contextual factors. Sheridan[90] conducted a telephone survey of public perception and response to heat warnings across four North American cities during the summers of 2004 and 2005. Among respondents with advanced age or chronic illness, 60% of them reported that they did not perceive themselves to be at risk from the health effects of heat. Further, relatively few respondents reported taking preventive actions because of the heat event. An interview-based study of older people in London and Norwich also confirmed these similar findings.[91] Hence, even with the most sophisticated warning system available, the system will be less effective if the public are not motivated to respond.[92]

Discussion

Addressing the impacts of climate change on health is becoming more important and urgent.[79] In order to respond to the challenges, it is necessary for the research community to continually collect evidence on health effects, through innovative and interdisciplinary study, to improve our understanding of the complex linkages be-

tween climate change and health.[6,93,94] So far, research on vulnerability and adaptation to climate change from the social sciences has not been applied widely in terms of health. Together with a need for greater understanding of epidemiologic studies of the health impacts of climate change, there is also a need for better understanding of the social processes that shape vulnerability to the impacts and the means by which individuals and institutions can manage the impacts.[82]

In addition, decision making about public health adaptation needs to address uncertainties. Given climate change projections, identifying current adaptation deficits is not sufficient to address the projected health impacts. Consideration is required of future climate and socioeconomic changes and how they will influence the health risks.[27] Projecting health impacts under various climate and socioeconomic scenarios can provide important insights to assist decision makers in planning adaptations and communicating the health risks to the public and politicians.[55,95,96]

Moreover, climate change is prompting a rethinking of consumption patterns, energy choices, and lifestyles. This presents an important opportunity for public health, as many actions to combat climate change also could bring substantial health co-benefits.[97] For example, appropriate GHG mitigation strategies in transport,[98] household energy,[99] food and agriculture,[100] and power generation[48] all can have substantial net benefits for health.[101] The public health research community needs to be aware of these opportunities, and endeavor to optimize their health co-benefits.[102]

Attention should also be paid to evaluating specific adaptation options.[28] For informed decision making, it is necessary to know what risks could be reduced through adaptation, and the likely costs of the proposed programs. Cost–benefit and cost-effectiveness analyses therefore can be used to judge whether these expenditures are reasonable and whether the programs are justified.[66,103] In addition, public health adaptation strategies should focus not only on the pre-decision stages of the process but also on monitoring and evaluation in the implementation and post-implementation stages. Careful monitoring and evaluation of implemented adaptation actions would be helpful to assess what is working, what is not working, and why.[36] This information will allow policymakers to set priorities and to select the most appropriate strategy, so that adaptation can be sustained and improved over time.

Further, as part of society's efforts to address and prepare for climate change, the health sector should add its voice to the growing climate change concern and demonstrate a substantive leadership role.[104] Climate change no longer can be considered simply as an environmental or a developmental issue and already is affecting human health and well-being. There is a need to assess health vulnerabilities and identify adaptation strategies in all sectors. The Health Impact Assessment framework comprehensively can serve as a decision support tool for practitioners who may take into account the full set of implications of any policy options on climate change that could affect health.[94] Human health should be a central concern for policymakers when they consider how best to adapt to climate change; therefore, funding mechanisms for public health adaptation should be established in a systematic and timely way.[97]

To strengthen institutional capacity and facilitate public health adaptation, there is also a need to identify a lead agency that can coordinate effectively multiple organizations.[27] This lead agency should thereby involve the public health research community in adapting to climate change. Its key roles will include identifying knowledge gaps in the information available to decision makers, synthesizing existing and emerging research on climate change impacts and adaptation, and developing targeted communication products for the general public and politicians.

Conclusion

Climate is changing rapidly and the health impacts of climate change command increasing policy and public attention. As stated by Bo Lim, "adaptation is no longer tomorrow's choice, but today's imperative."[105] Public health adaptation requires multisectoral and multidisciplinary responses in which individuals, communities, governments, international organizations, and the research community collaborate closely to address the adverse health impacts of climate change.[106]

Collaborative multidisciplinary research on the assessment of the potential health impacts of climate change, projections of health impacts under various climate and socioeconomic scenarios, identification of health co-benefits of GHG mitigation strategies, and evaluation of cost-effective adaptation options should be given highest research priority. Such research agenda has the potential to contribute greatly to both managing the health impacts of climate change and strengthening alliances for sustainable development.

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References

1. IPCC. Climate change 2007: the physical science basis. Contribution of Working Group I to the fourth assessment report of the Intergovernmental Panel on Climate Change. Cambridge, UK: Cambridge University Press, 2007.
2. IPCC. Climate change 2007: synthesis report. Contribution of Working Groups I, II and III to the fourth assessment report of the Intergovernmental Panel on Climate Change. Geneva, Switzerland: IPCC, 2007.
3. IPCC. Climate change 2007: impacts, adaptation and vulnerability. Contribution of Working Group II to the fourth assessment report of the Intergovernmental Panel on Climate Change. Cambridge, UK: Cambridge University Press, 2007.
4. Confalonieri U, Menne B, Akhtar R, et al. Human health. In: Parry ML, Canziani OF, Palutikof JP, van der Linden PJ, Hanson CE, eds. Climate change 2007: impacts, adaptation and vulnerability. Cambridge, UK: Cambridge University Press, 2007:391–431.
5. WHO. Protecting health from climate change: World Health Day 2008. Geneva: WHO, 2008.
6. Costello A, Abbas M, Allen A, et al. Managing the health effects of climate change: Lancet and University College London Institute for Global Health Commission. Lancet 2009;373(9676):1693–733.
7. Haines A, Kovats R, Campbell-Lendrum D, Corvalan C. Climate change and human health: impacts, vulnerability, and mitigation. Lancet 2006;367(9528):2101–9.
8. Patz JA, Campbell-Lendrum D, Holloway T, Foley JA. Impact of regional climate change on human health. Nature 2005;438(7066):310–7.
9. McMichael AJ, Woodruff RE, Hales S. Climate change and human health: present and future risks. Lancet 2006;367(9513):859–69.
10. Ebi KL, Mills DM, Smith JB, Grambsch A. Climate change and human health impacts in the U.S.: an update on the results of the U.S. national assessment. Environ Health Perspect 2006;114(9):1318–24.
11. Luber G, McGeehin M. Climate change and extreme heat events. Am J Prev Med 2008;35(5):429–35.
12. Semenza J, Menne B. Climate change and infectious diseases in Europe. Lancet Infect Dis 2009;9(6):365–75.
13. Qi X, Tong S, Hu W. Preliminary spatiotemporal analysis of the association between socio-environmental factors and suicide. Environ Health 2009;8:46.
14. Adger WN. Vulnerability. Glob Environ Change 2006;16(3):268–81.
15. Ebi KL, Kovats RS, Menne B. An approach for assessing human health vulnerability and public health interventions to adapt to climate change. Environ Health Perspect 2006;114(12):1930–4.
16. Rey G, Fouillet A, Bessemoulin P, et al. Heat exposure and socioeconomic vulnerability as synergistic factors in heatwave-related mortality. Eur J Epidemiol 2009;24(9):495–502.
17. Reid C, O'Neill M, Gronlund C, et al. Mapping community determinants of heat vulnerability. Environ Health Perspect 2009;117(11):1730–6.
18. Kovats RS, Hajat S. Heat stress and public health: a critical review. Annu Rev Public Health 2008;29:41–55.
19. WHO and Health Care Without Harm. Healthy hospitals, healthy planet, healthy people: addressing climate change in health care settings. Geneva: WHO, 2009.
20. IPCC. Climate change 2001: impacts, adaptation, and vulnerability: contribution of Working Group II to the third assessment report of the Intergovernmental Panel on Climate Change. Cambridge, UK: Cambridge University Press, 2001.
21. McMichael AJ, Neira M, Bertollini R, Campbell-Lendrum D, Hales S. Climate change: a time of need and opportunity for the health sector. Lancet 2009;374(9707):2123–5.
22. Campbell-Lendrum D, Corvalán C, Neira M. Global climate change: implications for international public health policy. Bull World Health Organ 2007;85(3):235–7.
23. Campbell-Lendrum D. How much does the health community care about global environmental change? Glob Environ Change 2005;15(4):296–8.
24. Mills DM. Climate change, extreme weather events, and U.S. health impacts: what can we say? J Occup Environ Med 2009;51(1):26–32.
25. Tong S, Soskolne CL. Global environmental change and population health: progress and challenges. Eco Health 2007;4:352–62.
26. Frumkin H, Hess J, Luber G, Malilay J, McGeehin M. Climate change: the public health response. Am J Public Health 2008;98(3):435–45.
27. Ebi K. Public health responses to the risks of climate variability and change in the U.S. J Occup Environ Med 2009;51(1):4–12.
28. Ebi KL, Burton I. Identifying practical adaptation options: an approach to address climate change-related health risks. Environ Sci Policy 2008;11:359–369.
29. Menne B, Ebi KL. Climate change and adaptation strategies for human health. Darmstadt: Steinkopff, 2006.
30. McMichael AJ, Campbell-Lendrum D, Corvalan C, et al. Climate change and human health: risk and responses. Geneva: WHO, 2003.
31. Leary N, Adejuwon J, Barros V, Burton I, Kulkarni J, Lasco R. Climate change and adaptation. London: Earthscan, 2008.
32. Smit B, Burton I, Klein RJT, Wandel J. An anatomy of adaptation to climate change and variability. Clim Change 2000;45(1):223–51.
33. Fankhauser S, Smith JB, Tol RSJ. Weathering climate change: some simple rules to guide adaptation decisions. Ecol Econ 1999;30(1):67–78.
34. Fussel HM. Adaptation planning for climate change: concepts, assessment approaches, and key lessons. Sustainability Sci 2007;2(2):265–75.
35. Smit B, Wandel J. Adaptation, adaptive capacity and vulnerability. Glob Environ Change 2006;16(3):282–92.
36. Lim B, Spanger-Siegfried E, Burton I, Malone EL, Huq S. Adaptation policy frameworks for climate change: developing strategies, policies and measures. Cambridge, UK: Cambridge University Press, 2005.
37. Hess JJ, Malilay JN, Parkinson AJ. Climate change: the importance of place. Am J Prev Med 2008;35(5):468–78.
38. Mirza MMQ. Climate change and extreme weather events: can developing countries adapt? Clim Policy 2003;3(3):233–48.
39. Mertz O, Halsnaes K, Olesen JE, Rasmussen K. Adaptation to climate change in developing countries. Environ Manage 2009;43(5):743–52.
40. Balbus JM, Malina C. Identifying vulnerable subpopulations for climate change health effects in the U.S. J Occup Environ Med 2009;51(1):33–7.
41. St Louis ME, Hess JJ. Climate change: impacts on and implications for global health. Am J Prev Med 2008;35(5):527–38.
42. Vaneckova P, Beggs PJ, Jacobson CR. Spatial analysis of heat-related mortality among the elderly between 1993 and 2004 in Sydney, Australia. Soc Sci Med 2010;70(2):293–304.
43. Alberini A, Chiabai A, Muehlenbachs L. Using expert judgment to assess adaptive capacity to climate change: evidence from a conjoint choice survey. Glob Environ Change 2006;16(2):123–44.
44. Matthies F, Bickler G, Marín NC, Hales S, eds. Heat–health action plans: guidance. Copenhagen, Denmark: WHO, 2008.
45. Keim ME. Building human resilience: the role of public health preparedness and response as an adaptation to climate change. Am J Prev Med 2008;35(5):508–16.
46. Allen KM. Community-based disaster preparedness and climate adaptation: local capacity-building in the Philippines. Disasters 2006;30(1):81–101.
47. Smith KR, Jerrett M, Anderson HR, et al. Public health benefits of strategies to reduce greenhouse-gas emissions: health implications of short-lived greenhouse pollutants. Lancet 2009;374(9707):2091–103.
48. Markandya A, Armstrong BG, Hales S, et al. Public health benefits of strategies to reduce greenhouse-gas emissions: low-carbon electricity generation. Lancet 2009;374(9706):2006–15.
49. Meusel D, Menne B, Kirch W, Bertollini R. Public health responses to extreme weather and climate events—a brief summary of the WHO meeting on this topic in Bratislava on 9–10 February 2004. J Public Health 2004;12(6):371–81.
50. Elder K, Xirasagar S, Miller N, Bowen S, Glover S, Piper C. African Americans' decisions not to evacuate New Orleans before Hurricane Katrina: a qualitative study. Am J Public Health 2007;97(1S):S124–9.

51. Handmer J, O'Neil S, Killalea D. Review of fatalities in the February 7, 2009, bushfires. Melbourne: Bushfire CRC and Centre for Risk and Community Safety RMIT University, 2010.
52. Stainforth DA, Aina T, Christensen C, et al. Uncertainty in predictions of the climate response to rising levels of greenhouse gases. Nature 2005;433(7024):403–6.
53. Adger WN, Vincent K. Uncertainty in adaptive capacity. Comptes Rendus Geosciences 2005;337(4):399–410.
54. Vincent K. Uncertainty in adaptive capacity and the importance of scale. Glob Environ Change 2007;17(1):12–24.
55. Kinney PL, O'Neill MS, Bell ML, Schwartz J. Approaches for estimating effects of climate change on heat-related deaths: challenges and opportunities. Environ Sci Policy 2008;11(1):87–96.
56. Gosling SN, Lowe JA, McGregor GR, Pelling M, Malamud BD. Associations between elevated atmospheric temperature and human mortality: a critical review of the literature. Clim Change 2009;92(3):299–341.
57. O'Neill MS, Ebi KL. Temperature extremes and health: impacts of climate variability and change in the U.S. J Occup Environ Med 2009;51(1):13–25.
58. Ebi KL. Using health models to prepare for and cope with climate change. Clim Change 2008;88(1):1–3.
59. Knowlton K, Lynn B, Goldberg RA, et al. Projecting heat-related mortality impacts under a changing climate in the New York City region. Am J Public Health 2007;97(11):2028–34.
60. van Lieshout M, Kovats RS, Livermore MTJ, Martens P. Climate change and malaria: analysis of the SRES climate and socio-economic scenarios. Glob Environ Change 2004;14(1):87–99.
61. Hales S, de Wet N, Maindonald J, Woodward A. Potential effect of population and climate changes on global distribution of dengue fever: an empirical model. Lancet 2002;360(9336):830–4.
62. Ebi KL. Adaptation costs for climate change-related cases of diarrhoeal disease, malnutrition, and malaria in 2030. Global Health 2008;4:9.
63. Stern N. The economics of climate change: the Stern Review. Cambridge, UK: Cambridge University Press, 2007.
64. Bouwer LM, Aerts JC. Financing climate change adaptation. Disasters 2006;30(1):49–63.
65. Burton I, Diringer E, Smith J. Adaptation to climate change: international policy options. Arlington VA: The Pew Center on Global Climate Change, 2006.
66. Agrawala S, Fankhauser S. Economic aspects of adaptation to climate change: costs, benefits and policy instruments. Paris: Organization for Economic Co-operation and Development, 2008.
67. Adger WN, Agrawala S, Mirza M, et al. Assessment of adaptation practices, options, constraints and capacity. In: Parry ML, Canziani OF, Palutikof JP, van der Linden PJ, Hanson CE, eds. Climate change 2007: impacts, adaptation and vulnerability. Cambridge, UK: Cambridge University Press, 2007:717–43.
68. Ebi KL, Balbus J, Kinney PL, et al. U.S. Funding is insufficient to address the human health impacts of and public health responses to climate variability and change. Environ Health Perspect 2009;117(6):857–62.
69. Bedsworth L. Preparing for climate change: a perspective from local public health officers in California. Environ Health Perspect 2009;117(4):617–23.
70. Olaris K. Community health services and climate change: exploring the sector's capacity to respond. Environ Health 2008;8(2):28–41.
71. Grubb M. Technology innovation and climate change policy: an overview of issues and options. Keio Econ Stud 2004;41(2):1–37.
72. Yohe G, Tol RSJ. Indicators for social and economic coping capacity: moving toward a working definition of adaptive capacity. Glob Environ Change 2002;12(1):25–40.
73. Estrada-Pena A, Venzal JM. A GIS framework for the assessment of tick impact on human health in a changing climate. Geospat Health 2007;1(2):157–68.
74. Johnson DP, Wilson JS, Luber GC. Socioeconomic indicators of heat-related health risk supplemented with remotely sensed data. Int J Health Geogr 2009;8:57.
75. Gilmour JA. Reducing disparities in the access and use of Internet health information. A discussion paper. Int J Nurs Stud 2007;44(7):1270–8.
76. James J. Mechanisms of access to the Internet in rural areas of developing countries. Telematics and Informatics 2010;27:370–6.
77. Agrawal A. The role of local institutions in adaptation to climate change. Paper prepared for the Social Dimensions of Climate Change, Social Development Department, The World Bank; 2008 Mar 5–6; Washington DC.
78. Maibach EW, Chadwick A, McBride D, Chuk M, Ebi KL, Balbus J. Climate change and local public health in the U.S.: preparedness, programs and perceptions of local public health department directors. PLoS One 2008;3(7):e2838.
79. WHO. Protecting health from climate change: global research priorities. Geneva: WHO, 2009.
80. Ebi KL, Semenza JC. Community-based adaptation to the health impacts of climate change. Am J Prev Med 2008;35(5):501–7.
81. Adger WN. Social capital, collective action, and adaptation to climate change. Econ Geogr 2003;79(4):387–404.
82. Few R. Health and climatic hazards: framing social research on vulnerability, response and adaptation. Glob Environ Change 2007;17(2):281–95.
83. Naughton MP, Henderson A, Mirabelli MC, et al. Heat-related mortality during a 1999 heat wave in Chicago. Am J Prev Med 2002;22(4):221–7.
84. Cutter SL, Boruff BJ, Shirley WL. Social vulnerability to environmental hazards. Soc Sci Q 2003;84(2):242–61.
85. Wolf J, Adger WN, Lorenzoni I, Abrahamson V, Raine R. Social capital, individual responses to heat waves and climate change adaptation: an empirical study of two UK cities. Glob Environ Change 2010;20:44–52.
86. Pelling M, High C. Understanding adaptation: what can social capital offer assessments of adaptive capacity? Glob Environ Change 2005;15(4):308–19.
87. Grothmann T, Patt A. Adaptive capacity and human cognition: the process of individual adaptation to climate change. Glob Environ Change 2005;15(3):199–213.
88. Kalkstein AJ, Sheridan SC. The social impacts of the heat–health watch/warning system in Phoenix, Arizona: assessing the perceived risk and response of the public. Int J Biometeorol 2007;52(1):43–55.
89. Semenza JC, Hall DE, Wilson DJ, Bontempo BD, Sailor DJ, George LA. Public perception of climate change: voluntary mitigation and barriers to behavior change. Am J Prev Med 2008;35(5):479–87.
90. Sheridan SC. A survey of public perception and response to heat warnings across four North American cities: an evaluation of municipal effectiveness. Int J Biometeorol 2007;52(1):3–15.
91. Abrahamson V, Wolf J, Lorenzoni I, et al. Perceptions of heatwave risks to health: interview-based study of older people in London and Norwich, UK. J Public Health 2009;31(1):119–26.
92. Kalkstein LS, Sheridan SC, Kalkstein AJ. Heat health warning systems: development, implemetation, and intervention activities. In: Ebi KL, Burton I, McGregor GR, eds. Biometeorology for adaptation to climate variability and change. Dordrecht: Springer, 2008:33–48.
93. Haines A. Climate change and health: strengthening the evidence base for policy. Am J Prev Med 2008;35(5):411–3.
94. Patz J, Campbell-Lendrum D, Gibbs H, Woodruff R. Health impact assessment of global climate change: expanding on comparative risk assessment approaches for policy making. Annu Rev Public Health 2008;29:27–39.
95. Martens P, Lorenzoni I, Menne B. Implications of the SRES scenarios for human health in Europe. In: Menne B, Ebi KL, eds. Climate change and adaptation strategies for human health. Darmstadt: Steinkopff, 2006:395–407.
96. Berkhout F, Hertin J, Jordan A. Socio-economic futures in climate change impact assessment: using scenarios as "learning machines." Glob Environ Change 2002;12(2):83–95.
97. Neira M, Bertollini R, Campbell-Lendrum D, Heymann DL. The Year 2008: a breakthrough year for health protection from climate change? Am J Prev Med 2008;35(5):424–5.

98. Woodcock J, Edwards P, Tonne C, et al. Public health benefits of strategies to reduce greenhouse-gas emissions: urban land transport. Lancet 2009;374(9705):1930–43.
99. Wilkinson P, Smith KR, Davies M, et al. Public health benefits of strategies to reduce greenhouse-gas emissions: household energy. Lancet 2009;374(9705):1917–29.
100. Friel S, Dangour AD, Garnett T, et al. Public health benefits of strategies to reduce greenhouse-gas emissions: food and agriculture. Lancet 2009;374(9706):2016–25.
101. Haines A, McMichael AJ, Smith KR, et al. Public health benefits of strategies to reduce greenhouse-gas emissions: overview and implications for policymakers. Lancet 2009;374(9707):2104–14.
102. Frumkin H, McMichael AJ. Climate change and public health: thinking, communicating, acting. Am J Prev Med 2008;35(5):403–10.
103. Markandya A, Chiabai A. Valuing climate change impacts on human health: empirical evidence from the literature. Int J Environ Res Public Health 2009;6(2):759–86.
104. Jackson R, Shields KN. Preparing the U.S. health community for climate change. Annu Rev Public Health 2008;29:57–73.
105. Schmidt CW. Beyond mitigation: planning for climate change adaptation. Environ Health Perspect 2009;117(7):307–9.
106. Costello A, Grant M, Horton R. The Lancet-UCL Commission: health effects of climate change. Lancet 2008;371(9619):1145–7.