Curr Envir Health Rpt (2016) 3:99–105
DOI 10.1007/s40572-016-0077-0

Using Uncertain Climate and Development Information in Health Adaptation Planning

Kristie L. Ebi[1] **· Jeremy J. Hess**[1,2] **· Tania Busch Isaksen**[3]

Published online: 27 January 2016

Abstract To aid health adaptation decision-making, there are increasing efforts to provide climate projections at finer temporal and spatial scales. Relying solely on projected climate changes for longer-term decisions makes the implicit assumption that sources of vulnerability other than climate change will remain the same, which is not very probable. Over longer time horizons, this approach likely over estimates the extent to which climate change could alter the magnitude and pattern of health outcomes, introducing systematic bias into health management decisions. To balance this potential bias, decision-makers also need projections of other drivers of health outcomes that are, like climate change, recognized determinants of some disease burdens. Incorporating projections via an iterative process that allows for regular updates based on new knowledge and experience has the potential to improve the utility of fine-scale climate projections in health system adaptation to climate change.

This article is part of the Topical Collection on *Climate Change and Health*

✉ Kristie L. Ebi
krisebi@uw.edu

Jeremy J. Hess
jjhess@uw.edu

Tania Busch Isaksen
tania@uw.edu

[1] School of Public Health, University of Washington, 4225 Roosevelt Way NE #100, Seattle, WA 98105, USA

[2] School of Medicine, University of Washington, Seattle, WA, USA

[3] School of Public Health, University of Washington, Seattle, WA 98195, USA

Keywords Climate change · Health risks · Adaptation · Risk management · Uncertainty

Introduction

The overall goal of health system adaptation to climate change is to bring sustained improvements in population health in an unstable climate. This goal can be achieved by developing climate-resilient health systems with the capacity to anticipate, respond to, cope with, and recover from climate-related shocks and stresses [1••]. Integrating climate change into health system planning and other activities is challenging, as future climate and other factors affecting health systems are inherently uncertain [2]. Nevertheless, waiting for more certainty to implement adaptation interventions needed to manage the risks associated with a changing climate will unnecessarily put individuals and communities at risk.

One building block of a resilient health system is service delivery designed to integrate climate change into programs for controlling climate-sensitive health outcomes, to improve management of the social and environmental determinants of health, and to enhance disaster risk management for extreme weather and climate events [1••, 3]. Ministries and departments of health are beginning to incorporate climate variability and change into their policies, programs, and plans [4, 5]. These efforts are being made to better manage current burdens of weather-sensitive health outcomes and to prepare for future shifts in the magnitude and pattern of health burdens as climate continues to change [6••]. Doing so requires understanding the magnitude and pattern of uncertainties not just only about weather and climate information but also about how development pathways (this includes demographic and socioeconomic change, urbanization, land use, investments in new technologies, governance, the degree to which equity issues are addressed, and other factors) could alter future vulnerability to the risks posed by a changing climate [7].

The following sections review the uncertainties in climate and development predictions and projections, discuss temporal and spatial scales for climate and development information, provide examples of early warning systems and strategic planning, and discuss the importance of iterative risk management approaches to effectively handle the uncertainties inherent when looking to the future.

Decision-Making and Uncertainties About Future Climate

Health decision-makers face multi-dimensional uncertainty when using models to modify existing and implement new policies and programs [8]. These uncertainties pertain to choices regarding management of today's risks of climate variability and change and, even more demonstrably, to preparations for a future with further, and potentially more dramatic, departures from historical weather patterns [9]. Clarifying the temporal and spatial scales of data and projections needed to help inform these decisions can help identify key uncertainties. This information can be used, in turn, to consider which decisions need to be taken now and which could be postponed until uncertainties are reduced [10]. Such an approach can also inform when decisions should be reconsidered in the future to evaluate whether new knowledge alters the decision calculus significantly.

In assessing the uncertainty accompanying inputs into decision-making processes, decision-makers need to understand the extent to which the scale of current knowledge matches the information needed for a particular decision, what is known about the certainty of that knowledge, and the extent to which the uncertainty may resolve over time [11]. Uncertainty related to some systems is quite distinct to uncertainty from others, and uncertainty related to adaptation decisions may be less likely to resolve with time than other types [11].

These issues have implications for public health adaptation in the near and longer terms. For instance, public health organizations and agencies are increasingly utilizing seasonal and medium-term (several year) weather and climate variability outlooks to inform their short-term planning and relying on quantitative climate change health risk projections for longer-term planning efforts [6••]. Providing products with reasonable skill to serve these needs at appropriate spatial and temporal scales is challenging; low skill (and other factors) currently limits widespread use. However, there are indications that skill is gradually increasing [12] and that further improvements are within reach [13]. Even as skill improves, however, predictions and projections will be less useful for certain types of planning because they are outside the temporal scale of the decision or because skill improvements will not be uniform across hazards. Globally and increasingly regionally, projections of changes in surface temperature over land and in changes in precipitation patterns are skilled and robust, while projections of changes in other relevant variables such as drought, hurricanes, and cloud cover, are more uncertain [14]. There also is evidence that increases in skill will vary by geographic region [15•].

Decision-Making and Uncertainties About Future Development

Adding to the complexity, weather and climate are not the sole determinants of climate-sensitive health outcomes. Environmental factors, of which climate is just one, are estimated to be responsible for 25–33 % of the global burden of disease, although climate instability was not a factor in previous assessments [16]. Despite this multifactorial causal pathway and the dominance of other factors, health impact projections often ignore these other considerations. When they are considered, they are often reduced to the proxy measure of economic development as expressed by projections of gross domestic product (GDP) and even then considering only a limited range of possible futures [17]. Considering only population and GDP when projecting risks makes the implicit assumption that other sources of vulnerability will remain the same, an unlikely possibility [18], particularly over longer temporal scales. Including a broader range of uncertainties in these projections is important given that these uncertainties may be much larger than those related to climate projections.

Recent work extends projections of socioeconomic development based on the shared socioeconomic pathways [19]. As the authors recognize, these projections are subject to significant uncertainty and should not be viewed as predictions. Incorporating not only socioeconomic development trajectories but also other determinants of health could significantly strengthen adaptation planning efforts [20]. The new climate change research and assessment scenarios are designed to facilitate estimating the extent to which plausible development pathways could increase or decrease future risks [21].

For example, investments in health services are not perfectly correlated with economic development [22]. Thus, it may not be adequate to use GDP as a proxy for health service activities that are relevant to climate change health impacts. Further, some advances in public health may not be well represented even by projections in health service spending. Take, for instance, the proposition that a highly effective malaria vaccine would significantly reduce concerns about climate change possibly affecting the geographic range, seasonality, and incidence of malaria in a warmer climate. But what is the likelihood of such a technology breakthrough over the next few years and how long would it take to be deployed at scale? Will climate change affect the likelihood of such a development or the timeline from vaccine development to widespread distribution?

Illustrating the challenge is the relative tractability of the problem of predicting the extent to which malaria prevention and control activities can be maintained going forward until and when a vaccine exists and the impacts they are likely to have. Experts conjecture that, with investments of US$ 6–8 billion per year, malaria could be eradicated in 35 countries and incidence reduced to below 90 % of 2015 levels by 2030, without considering the possible impacts of climate change [23].

Temporal and Spatial Scales of Information Needed for Health Adaptation Decisions

Health adaptation decisions cross a range of temporal and spatial scales, from reducing the current adaptation deficit (e.g., unmanaged vulnerability) by implementing an early warning system to incorporating projections of sea level rise and storm surges into planning for infrastructure that will exist for 50 or more years. The information needed for these decisions varies by health outcome and decision, but in general, factors of importance include trends and projections of demographics and GDP, quality and accessibility of public health and health care systems, infrastructure planning, land use change, and the extent to which adaptation could reduce the burden of climate-sensitive health outcomes. Decisions focused on the next few years can use information on recent trends to inform early warning systems, including trends in weather variables, and use information on modifications planned to increase the resilience of health systems. The short time frame and extent of information will lead to greater certainty that the decisions taken will remain effective over the next few years. In contrast, the further into the future the focus of the decision, in general, the more uncertain the information related to climate and to how health systems could evolve.

Some decisions taken over the short-term can create path dependencies that may constrain future options. These longer-term consequences should be explicitly considered; doing so may narrow the uncertainty to a degree, although it will not reduce it to the level expected in the shorter term.

Weather and climate models produce outputs at specified temporal and spatial scales, whether weather forecasts, medium-term predictions related to seasonal weather trends informed by climate variability, general circulation models projecting climate at a decadal scale, or integrated assessment models projecting economic growth over decades. Climate change projections, in particular, are typically spatially resolved at pixels of roughly 50 km^2 and temporally with outputs averaged over decades. For certain climate-sensitive health outcomes, this coarse spatial and temporal resolution ignores relevant variations in exposure dynamics over space and time, thus increasing uncertainty in the projected magnitude and pattern of health risks. To facilitate quantitative projections at finer spatial scales, climate scientists are working to furnish downscaled climate change projections for use in multiple sectors, including public health, although fine-scale projections are not always necessary to facilitate decision making: matching the scale of decision-making inputs with the geographic and temporal scale of the decisions being taken is most important.

Table 1 shows some health adaptation decisions and the temporal and spatial scales of information that would be helpful to inform the decisions. The following sections explore these dynamics in relation to two health systems adaptation activities, early warning systems, and national adaptation plans.

Early Warning Systems

Early warning systems allow for early recognition of weather-related hazards so messages can be conveyed to vulnerable populations and vulnerable infrastructure can be protected. Early warning systems need information on more than just the climate-related hazard; other drivers include the location of vulnerable populations, the status of health systems, the pattern of urbanization, and other factors. The Global Framework on Climate Services (GFCS) is a worldwide mechanism for coordinated actions to enhance the quality, quantity, and application of climate services (https://gfcs.wmo.int), including early warning systems. Health is a priority area, where GFCS will foster access to reliable health and climate-related data, tools, and services to support developing early warning systems, augmenting disease surveillance programs, and other activities. Under the GFCS and other programs, countries and regions are developing early warning systems to warn of conditions that could lead to an outbreak of an infectious disease, such as malaria, dengue fever, and cholera. There are a growing number of early warning systems with the potential to reduce current morbidity and mortality from climate-sensitive health outcomes.

For example, Hii and colleagues showed the feasibility of using weekly mean temperature and cumulative rainfall to forecast dengue cases in Singapore up to 16 weeks in advance, with high sensitivity to distinguishing between outbreak and non-outbreak periods [24]. Another example is a heatwave early warning system for Ahmedabad, India, wherein probabilistic temperature forecasts are used to scale up public health and health care activities protective of public health [25]. The system achieved early success and is being scaled to other regions in India with similar high seasonal heat exposure. A third example is that of Washington State's *Vibrio parahaemolyticus* control policy that incorporates forecasted weather specific to shellfish bed locations with annual risk

Table 1 Health adaptation decisions and the temporal and spatial scales of information to inform them

	Climate data	Socioeconomic data		Comments
Adaptation	*Timeframe*	*Spatial scale*	*At scale of climate data*	
Ministry/department of health strategic plans	Expected trends over next 5 years and projected changes in weather patterns to 2030–2040 (15–25 years)	Depends on the health outcomes of concern	Current trends and projections of changes in population, economic growth, urbanization, and other relevant variables, and storylines of how other variables could evolve under different development pathways	Considering a longer time frame than 5 years is important for planning for adaptation needs likely to arise over the next few decades
Vulnerability and adaptation assessments	Expected trends over next 5 years and projected changes in weather patterns to 2030–2040 (15–25 years); longer may be appropriate depending focus of assessment	Depends on the health outcomes of concern, generally national, sub-national, community levels	Current trends and projections of changes in population, economic growth, urbanization, and other relevant variables, and storylines of how other variables could evolve under different development pathways	
Early warning systems	Daily to seasonal forecasts	Matched to the scale of vulnerability factors for deploying effective response systems	Needed to identify most vulnerable populations and how to appropriately target messages	Early warning systems are developed based on relationships between the hazard and health outcomes, should evaluate the skill between forecast and observed weather variables
Disaster risk management	Daily to seasonal forecasts	Matched to the scale of vulnerability factors for deploying effective response systems	Needed to identify most vulnerable populations and how to appropriately target messages; also need to collect data on factors that can monitor long-term health consequences	
Integrated surveillance & monitoring programs	Daily to seasonal forecasts to next 5–10 years	As fine a scale as possible to ensure data are being collected to inform early warning systems and other activities	Factors required for analysis of surveillance and monitoring programs	Coordination with national/state meteorological services so that weather and health data are collected in the same locations
Enhancing supply chains	Next 5 years and projected changes in weather patterns to 2030–2040 (15–25 years)	Depends on the key components of the supply chain and their associated weather risks	Projections of population, economic growth and other variables that could inform estimates of how the supply chain could evolve under different development pathways	
Infrastructure and technologies	Projected changes in weather patterns to 2040+ to account for the long lifetime of infrastructure	Fine enough scale to determine risks of, for example, extreme weather and climate events, to infrastructure	Projections of population, economic growth, urbanization and other variables that could inform estimates of use of the infrastructure/technology	

characterization derived from historical illness burden to regulate shellfish bed closure parameters [26].

Developing longer lead times for these and other warning systems would mean providing more time for educating populations of the risks and appropriate actions to take to decrease vulnerability. In the case of dengue early warning, optimal lead times—and thus optimal forecast periods—are at least 3 months prior to an outbreak [27]. Lag times for heatwave early warnings such as the system developed for Ahmedabad are shorter [28]. For some hazards, longer lag times are more useful, particularly those that require evacuation, efforts to harden or relocate critical infrastructure and capital, ecological interventions such as vector control, or large-scale resource mobilization.

A caveat about early warning systems is that these systems are based on observations of environmental exposures, such as temperature and precipitation and human morbidity and mortality, but warnings are based on forecasts of the key exposure variables. In Stockholm, the weather forecasts of hot temperatures are consistently lower than observed hot temperatures [29]. Given uncertainties in forecast models, validation is an important component of any early warning system.

Effective early warning systems also need other information, such as socioeconomic and underlying health data, to design interventions to protect particularly vulnerable populations [30]. Flood early warning systems need information on urbanization choices, such as where critical infrastructure (and access to it) is located. Which individuals are particularly vulnerable and where they live is important for developing response plans once a warning is called. Vulnerability mapping and identification of climate-sensitive disease hotspots are important adjuncts that can help target early warning messages and other interventions [31]. The Ahmedabad heat early warning system mentioned above incorporated a vulnerability assessment of heat exposure and health impacts in slums prior to its initiation [25], and its managers closely track urban planning and construction activities because outdoor construction workers are particularly vulnerable to extreme heat.

One challenge is that many of these early warning systems do not consider how climate change and adaptation of health systems could alter their effectiveness over the next decade. For example, summer is longer by days to weeks than it was just a few decades ago, depending on the region [14]. Yet, heatwave early warning systems were often established as static programs, without provisions for modifying the start/stop dates of the systems. Further, there is growing evidence that people are acclimatizing over time to warmer summers [32, 33]. Early warning systems will themselves need to be adjusted as weather patterns continue to change if they are to maintain their effectiveness, and to effect these changes, decision-makers will need information at appropriate spatial and temporal scales to modify interventions over time.

National Adaptation and Other Strategic Plans

Many countries are evaluating their health system strategic plans as part of a process initiated under the United Nations Framework Convention on Climate Change [34] (UNFCCC). Countries are developing National Adaptation Plans to complement their National Communications required under the UNFCCC [35]. WHO issued guidance for countries to develop the health component of a country's National Adaptation Plan [36••]. Doing so requires evaluating the wide range of policies and programs designed to prevent and manage the health risks of climate variability and change, including water, sanitation, and hygiene (WASH), surveillance programs for a range of infectious diseases, maternal and child health, air quality, and disaster risk management.

The Millennium Development Goals highlighted the importance for health and well-being of access to safe water and improved sanitation, resulting in significant investments in development assistance for WASH. However, climate change was not taken into consideration when these interventions were designed and deployed. Changes in precipitation patterns, particularly extreme rainfall events, flooding, storm surges, and sea level rise could put these investments at risk. Research is ongoing to understand how climate change could manifest itself at the local level through changing rainfall, runoff, and groundwater recharge [37].

Information required for making new infrastructure investment decisions includes how the mean and variability of temperature, precipitation, and other weather variables could change over the coming decades at a scale relevant to the decision being taken. Input from health planners is critical to ensuring health considerations are adequately addressed in infrastructure decisions. Such information and interdisciplinary coordination would allow for better understanding of how infrastructure plans could be modified to account for risks arising later in the century. Climate projections should be at a fine-enough spatial and temporal scale to determine the risks of, for example, extreme weather and climate events to infrastructure. In addition, it would be helpful to also have projections of factors such as projected population growth in the region the infrastructure will serve, economic growth, urbanization, and other variables that could inform estimates of the design and use of the infrastructure.

Uncertainties Reinforce the Need for Iterative Adaptive Management

Making public health decisions based on predictions and projections should be done within an iterative risk management framework that acknowledges decisions will need re-evaluation as more information becomes available [38, 39••, 40••]. Iterative adaptive management is a structured process for decision-making when key information is uncertain. While decision-makers routinely make decisions under uncertainty, the breadth and depth of the uncertainties with climate change are often larger than for other decisions. Because uncertainty will continue to be a feature of managing the risks of climate change, adapting to uncertainty is a key feature of adapting to climate change. Adopting decision-making processes that recognize and integrate the stressors associated with climate change, the large uncertainties related to a changing climate, and the likelihood those uncertainties will be reduced over the time frame of relevant planning processes are key features of adapting to climate change.

Adaptive management in health systems is a process to facilitate effective use of system-based approaches when modifying current or implementing new interventions, based on projections of future vulnerabilities and risks. Adaptive management is intended to increase the effectiveness of interventions by designing decision-making processes so they explicitly take into account new information, environmental changes, and shifting social and political conditions [38, 39••, 40••]. Learning is a key component [40••]. This perspective is consistent with adaptation in other sectors, because climate change-related uncertainties pertain to all sectors [9].

Conclusions

Public health agencies are increasingly relying on short-term predictions and longer-term projections to incorporate climate variability and change into their planning and decision-making activities. Careful consideration is needed of the uncertainties associated with different predictions and projections used in decision-making processes. A particular challenge is that there is frequently a mismatch between the temporal and spatial scales of climate change projections and the availability of predictions and projections of trends in other drivers of population health that are relevant for the decision being taken. Particularly, over longer time horizons, this mismatch has the potential to introduce a systematic bias that can overestimate the impact of climate change and underestimate the role of other drivers of population health. No matter the skill of predictions and projections, the future is inherently uncertain, so adopting an iterative approach to decision making and continually revising adaptation policies, programs, and plans as new knowledge is gained would be prudent.

Compliance with Ethical Standards

Conflict of Interest Kristie L. Ebi reports consultation fees from Stratus Consulting (now Abt Consulting), World Health Organization, including its regional offices, Health Canada, Sanofi Pasteur, and Chemonics International Inc.

Jeremy J. Hess reports consultation fees from Stratus Consulting and the Natural Resources Defense Council for scientific consulting and research activities.

Tania Busch Isaksen declares that she has no conflict of interest.

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.•• World Health Organization. Operational framework for building climate resilient health systems. Geneva: United Nations 2015. This guidance document outlines the components of a climate-resilient health system and the approaches and tools available to promote resilience.
2. Moser SC, Ekstrom JA. A framework to diagnose barriers to climate change adaptation. Proc Natl Acad Sci. 2010;107(51):22026–31.
3. Frumkin H, Hess J, Luber G, et al. Climate change: the public health response. Am J Public Health. 2008;98(3):435–45.
4. Bierbaum R, Smith JB, Lee A, et al. A comprehensive review of climate adaptation in the United States: more than before, but less than needed. Mitig Adapt Strat Glob Chang. 2013;18(3):361–406.
5. Paterson JA, Ford JD, Ford LB, et al. Adaptation to climate change in the Ontario public health sector. BMC Public Health. 2012;12(1):452.
6.•• Marinucci GD, Luber G, Uejio CK, et al. Building resilience against climate effects—a novel framework to facilitate climate readiness in public health agencies. Int J Env Res Publ Health. 2014;11(6):6433–58. **This publication outlines the approach used by the US Centers for Disease Control and Prevention for promoting adaptation in departments of health**.
7. Haines A, Kovats RS, Campbell-Lendrum D, et al. Climate change and human health: impacts, vulnerability, and mitigation. Lancet. 2006;367(9528):2101–9.
8. Van Kerkhove MD, Ferguson NM. Epidemic and intervention modelling: a scientific rationale for policy decisions? Lessons from the 2009 influenza pandemic. Bull World Health Organ. 2012;90(4):306–10.
9. Wise R, Fazey I, Smith MS, et al. Reconceptualising adaptation to climate change as part of pathways of change and response. Glob Env Chang. 2014;28:325–36.
10. Linkov I, Satterstrom FK, Kiker G, et al. From comparative risk assessment to multi-criteria decision analysis and adaptive management: Recent developments and applications. Env Int. 2006;32(8):1072–93. doi:10.1016/j.envint.2006.06.013.
11. Refsgaard JC, Arnbjerg-Nielsen K, Drews M, et al. The role of uncertainty in climate change adaptation strategies—a Danish water

management example. Mitig Adapt Strat Glob Chang. 2013;18(3): 337–59. doi:10.1007/s11027-012-9366-6.

12. Hoskins B. The potential for skill across the range of the seamless weather-climate prediction problem: a stimulus for our science. Q J R Meteorol Soc. 2013;139(672):573–84.
13. Palmer T. Towards the probabilistic Earth-system simulator: a vision for the future of climate and weather prediction. Q J R Meteorol Soc. 2012;138(665):841–61.
14. Stocker TF, Qin D, Plattner G-K, et al. Technical Summary. In: Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Stocker TF, Qin D, Plattner G-K, et al. (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA. 84 pp.
15.• Meehl GA, Goddard L, Boer G, et al. Decadal climate prediction: an update from the trenches. Bull Am Meteorol Soc. 2014;95(2): 243–67. **This paper summarizes progress on achieving decadal climate predictions**.
16. Smith KR, Corvalán CF, Kjellstrom T. How much global ill health is attributable to environmental factors? Epidemiol-Baltimore. 1999;10(5):573–84.
17. Ebi KL. Health in the new scenarios for climate change research. Int J Environ Res Public Health. 2014;10:1. doi:10.3390/ijerph100x000x.
18. Ebi KL, Rocklöv J. Climate change and health modeling: horses for courses. Global Health Action. 2014;7:24154. doi:10.3402/gha.v7.24154.
19. Dellink R, Chateau J, Lanzi E, et al. Long-term economic growth projections in the shared socioeconomic pathways. Global Env Chang. 2015. doi:10.1016/j.gloenvcha.2015.06.004.
20. Bowen KJ, Ebi KL. Governing the health risks of climate change: towards multi-sector responses. Curr Opin Environ Sustain. 2015;12:80–5.
21. Van Vuuren DP, Kriegler E, O'Neill BC, et al. A new scenario framework for climate change research: scenario matrix architecture. Clim Chang. 2014;122(3):373–86.
22. Farag M, NandaKumar AK, Wallack S, et al. The income elasticity of health care spending in developing and developed countries. Int J Health Care Finance Econ. 2012;12(2):145–62. doi:10.1007/s10754-012-9108-z.
23. Tanner M, Greenwood B, Whitty CJ, et al. Malaria eradication and elimination: views on how to translate a vision into reality. BMC Med. 2015;13(1):167.
24. Hii YL, Zhu H, Ng N, et al. Forecast of dengue incidence using temperature and rainfall. PLoS Negl Trop Dis. 2012;6:1908. doi:10.1371/journal.pntd.0001908.
25. Knowlton K, Kulkarni SP, Azhar GS, et al. Development and implementation of South Asia's first heat-health action plan in Ahmedabad (Gujarat, India). Int J Environ Res Publ Health. 2014;11(4):3473–92.
26. Washington state Vibrio parahaemolyticus control plan., WAC 246-282-006 2015.
27. Hii YL, Rocklöv J, Wall S, et al. Optimal lead time for dengue forecast. PLoS Negl Trop Dis. 2012;6, e1848. doi:10.1371/journal.pntd.0001848.
28. Tran K, Azhar G, Nair R, et al. A cross-sectional, randomized cluster sample survey of household vulnerability to extreme heat among slum dwellers in Ahmedabad, India. Int J Environ Res Publ Health. 2013;10(6):2515–43.
29. Astrom C, Ebi KL, Langner J, et al. Developing a heatwave early warning system for Sweden: evaluating sensitivity of different epidemiological modelling approaches to forecast temperatures. Int J Environ Res Publ Health. 2015;12:254–67.
30. O'Brien K, Leichenko R, Kelkar U, et al. Mapping vulnerability to multiple stressors: climate change and globalization in India. Glob Environ Chang Human Policy Dimens. 2004;14(4):303–13. doi:10.1016/j.gloenvcha.2004.01.001.
31. English PB, Richardson MJ: Components of population vulnerability and their relationship with climate-sensitive health threats. Current Environmental Health Report 2016, in press.
32. Hondula DM, Balling Jr RC, Vanos JK, et al. Rising temperatures, human health, and the role of adaptation. Curr Clim Chang Reports. 2015;1(3):144–54.
33. Lee M, Nordio F, Zanobetti A, et al. Acclimatization across space and time in the effects of temperature on mortality: a time-series analysis. Environ Health. 2014;13(1):89.
34. UNFCCC, United Nations Framework Convention on Climate Change. Bonn, Germany. 1992. 33 pp. http://unfccc.int/files/essential_background/background_publications_htmlpdf/application/pdf/conveng.pdf.
35. UNFCCC Least Developed Country Expert Group (LEG). National Adaptation Plans: Technical guidelines for the national adaptation plan process. Bonn, Germany. 2012. 152 pp. https://unfccc.int/files/adaptation/cancun_adaptation_framework/application/pdf/naptechguidelines_eng_high__res.pdf.
36.•• World Health Organization. WHO Guidance to protect health from climate change through health adaptation planning. Geneva: United Nations 2014. This guidance document outlines the process for conducting the health component of a national adaptation plan.
37. Oates N, Ross I, Calow R, et al. Adaptation to climate change in water, sanitation and hygiene: assessing risks, appraising options in Africa. London: Overseas Development Institute; 2014. **98 pp**.
38. Ebi K. Adaptive management to the health risks of climate change. In: Ford J, Berrang-Ford L, editors. Climate change adaptation in developed nations. New York: Springer; 2011.
39.•• Hess J, McDowell J, Luber G. Integrating climate change adaptation into public health practice: using adaptive management to increase adaptive capacity and build resilience. Environ Health Perspect. 2012;120(2):171–9. doi:10.1289/ehp.110351. **This paper outlines how iterative adaptive managementcan be implemented by health systems**.
40.•• Ebi K. Climate change and health risks: assessing and responding to them through 'adaptive management'. Health Affairs. 2011;30: 924–30. **This paper outlines how iterative adaptive managementcan be implemented by health systems**.