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Review

Identifying practical adaptation options: an approach to address climate change-related health risks

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ABSTRACT

There is little guidance for the health sector on identifying and prioritizing practical adaptation options to reduce current and projected burdens of climate-sensitive health determinants and outcomes at local and regional levels. An approach is outlined that identifies all theoretically possible adaptation options to reduce adverse climate change-related health outcomes through a search of current practice and experience and through expert solicitation. This theoretical range of choices can then be screened to generate a list of measures that are practical for implementation in a particular population and region. This approach is applied to a theoretical country facing a projected increase in malaria due to climate change. Prioritizing the options should take into consideration technical viability, human and financial resource capacity, compatibility with current policies, and other constraints. Policy makers can combine the information generated with other considerations to select measures for implementation.

1. Introduction

The evidence for anthropogenic climate change is clear and convincing. The Earths' surface warmed nearly 0.8 °C over the past century, with most of the warming occurring in the past three decades (Solomon et al., 2007). The global surface temperature is projected to increase 1.1–6.4 °C over the 21st century. Climate change will be characterized by increasing temperatures, changes in the hydrologic cycle, sea level rise, and increased climate variability, particularly more frequent and intense heatwaves, droughts, windstorms, and floods (Solomon et al., 2007). All of these changes will affect human health.

Weather and climate are among the factors that determine the geographic range and incidence of several major causes of ill health, including morbidity and mortality due to temperature extremes, other extreme weather events, under-nutrition, poor air quality, water- and foodborne diseases, and vector-, rodent- and tick-borne diseases (Confalonieri et al., 2007). These health outcomes are current problems; under-nutrition affects 17% of the world's population in developing countries (FAO, 2005); diarrheal diseases and other conditions due to unsafe water and lack of basic sanitation cause 2 million deaths annually, mostly in young children (Kosek et al., 2003); and malaria causes more than a million childhood deaths annually (WHO, 2004a). The risks are higher in lower-income populations, predominantly within tropical/subtropical countries, because the current burdens of climate-sensitive health outcomes are high and because public health systems that could substantially reduce health risks tend to be relatively weak.

Reducing current and projected health risks attributable to climate change is a risk management issue, with adaptation

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and mitigation the primary responses. Mitigation and adaptation are not mutually exclusive; co-benefits to human health can result concurrently with implementation of mitigation actions, and adaptation measures can reduce greenhouse gas emissions. Because inherent characteristics of the climate system mean that the world is committed to at least as much additional climate change as has already occurred (Solomon et al., 2007), the extent to which populations will experience climate change-related health impacts over the next few decades will largely depend on the effectiveness of adaptation. Without implementation of effective and timely implementation options, the burden of climate-sensitive health outcomes is expected to increase with increasing climate change (Confalonieri et al., 2007).

The ability of a nation or community to identify and implement timely and effective adaptation options depends on the range of available options; the availability of resources and their distribution across the population; the structure of critical institutions, including the allocation of decision-making authority; the stock of human and social capital; the ability of decision-makers to manage information; and the public's perception of the significance of exposure (Smit et al., 2001). Thus, local policy-making processes, institutions, and resources will influence which adaptation options are practical to implement. It is important to note that effective and timely adaptation policies and measures can reduce, but not eliminate, all health impacts.

Because climate change is one of many public health issues that need to be addressed, adaptations need to ensure that actions to reduce climate-related health risks support current programs to address health burdens (win-win interventions) and explicitly consider uncertainties in the rate and extent of climate change (no regrets strategies).

General adaptation recommendations are available for the health sector, but there is little guidance on developing a list of specific adaptation options that may be suitable for a particular location. This paper first reviews the steps in an adaptation assessment; reviews actors and their roles and responsibilities for adaptation; reviews possible health policy responses to address climate variability and change; develops a framework that can be used to identify and prioritize practical adaptation policies and measures for a particular health issue in a particular population, and applies that framework to a theoretical country facing a projected increase in malaria due to climate change; and finally discusses conclusions for climate change and health policy.

2. Steps in an adaptation assessment

An adaptation assessment aims to identify specific strategies, policies, and measures that can be implemented to reduce current and future vulnerability to climate variability and change, as well as the resources needed (financial, technological and human capital) to implement them. The information can be combined with a cost–benefit or other economic analysis to inform priority setting by policymakers. A variety of frameworks have been developed for conducting an adaptation assessment (e.g. Ebi et al., 2006a). In general, Ministries of Health are aware of their current vulnerability to climate variability. A key need is to determine modifications to current and planned programs and activities to reduce projected burdens of climate-sensitive health determinants and outcomes. An adaptation assessment should address the following questions:

- *What are the most important climate-sensitive health determinants and outcomes, nationally, regionally, and locally?* Importance can be defined using mortality, disability-adjusted life years lost, or another metric.
- *What current programs and measures address these health outcomes?* This should include consideration of activities that affect the distal and proximal drivers of each outcome, both in health and other sectors. What modifications would increase their effectiveness to address current climate variability?
- *How might climate change alter current health patterns?* This involves developing qualitative or quantitative projections of how key drivers may change over time, including population and economic growth, evolution of public health interventions, etc. The projections should be at a scale of relevance for public health decision-makers. Uncertainties should be explicitly considered.
- *What options are available to reduce the projected health burden due to climate change?* Where and when will modifications likely be needed in current programs and activities? What new programs may need to be implemented?
- *Which of these adaptation options are the highest priorities?* Priorities can be established using burden of disease, cost-benefit, or another approach.
- *How can the constraints to implementation be addressed?*

Monitoring and evaluation programs for existing and planned interventions should be modified to ensure they are generating evidence to (1) look for health impacts of climate change; and (2) determine whether the interventions are timely and effective.

The design and implementation of interventions for a health outcome in a specific region take place within the context of slowly-changing factors that are partial determinants of the extent of impacts experienced and that are specific to a region or population, including population and regional vulnerabilities, social and cultural factors, the built and natural environment, the status of the public health infrastructure, and health and social services. Other factors that set the context include the degree of risk perceived, the human and financial resources available for adaptation, the available technological options, and the political will to undertake adaptation. The context for adaptation varies across geographic and temporal scales. In some situations, the most effective interventions may be to change some aspect of the context instead of directly focusing on the projected health impact.

3. Actors and their roles and responsibilities for adaptation

Responsibility for the management of climate-sensitive health risks rests with individuals, community and state governments, national agencies, and others. The roles and responsibilities vary by health outcome and political context. For example, individuals can undertake some adaptation activities with little external assistance, such as controlling vectors by clearing bush and draining stagnant water around homes (Mutero et al., 2004). Other adaptation options, such as forecasting and early warning systems, require external assistance. National and international agencies and organizations fund research and development to increase the options available for adaptation, implement programs and activities to reduce population vulnerability, and allocate human and financial resources to address the health impacts of climate change. Medical and nursing schools are responsible for ensuring that health professionals are trained in the identification and treatment of climate-sensitive diseases. The Red Cross and other nongovernmental organizations (NGOs) play critical roles in disaster response.

Table 1 provides examples of the roles and responsibilities of various actors for adapting to climate change. Note that viewing adaptation from a public health perspective results in similar activities being classified as primary (reduce exposure) vs. secondary (reduce disease onset) prevention under different health outcomes. It is not possible to prevent the occurrence of a heatwave, so primary prevention focuses on actions such as developing and enforcing appropriate infrastructure standards, while secondary prevention focuses on implementing early warning systems and other activities. For vectorborne diseases, primary prevention refers to preventing exposure to infected vectors; in this case, early warning systems can be considered primary prevention. For most vectorborne diseases, there are few options, other than seeking appropriate medical treatment, for preventing disease onset once an individual has been exposed.

4. Policy responses to address climate variability and change

The strategies, policies, and measures implemented by public health authorities to manage health risks depend on the factors that increase the risk, the health outcome, and the enabling conditions. Policy responses range from deploying successful measures used by other countries/regions to developing new policies for addressing emerging health threats. The degree to which programs and measures will need to be augmented to address the additional pressures due to climate change will depend on factors such as the current burden of climate-sensitive health outcomes, the effectiveness of current interventions, projections of where, when, and how the health burden could change with changes in climate and climate variability, the feasibility of implementing additional cost-effective interventions, other stressors that could increase or decrease resilience to impacts, and the social, economic, and political context within which interventions are implemented (Ebi et al., 2006b). Adaptation will be a process of continual adjustment to increases in the degree and rate of climate change and other factors.

Most policy responses will likely be incremental changes in current public health programs to address shifts in the incidence and geographic range of diseases. For example, the success of measures designed to prevent foodborne diseases such as salmonella varies across developed countries (Kovats et al., 2004). Because the risk of salmonella may increase with warmer ambient temperatures that favor the growth and spread of the bacteria, enhancing current salmonella control programs and improving measures to encourage more people to follow proper food-handling guidelines can lower current and future disease burdens irrespective of how the climate changes. The design and implementation of incremental policy changes should be grounded in an understanding of the adequacy of existing measures and how the effectiveness of these measures could change under different climate change scenarios. For example, increased frequency of malaria outbreaks in one season leads to increased effectiveness of control measures (when they are implemented) because of the length of time measures are effective (Teklehaimanot et al., 2004). Another example is that because extreme temperatures are projected to become more frequent over the coming decades, early warning systems should be evaluated to consider whether they are likely to be adequate under climate change projections (Meehl and Tebaldi, 2004).

In order to implement effective programs to manage vectorborne and zoonotic diseases, it is necessary to understand the various drivers of disease expansion and retreat. Because climate is one of the constraints on the range of many of these vectors and pathogens, increasing average temperatures and changes in precipitation may foster the spread of climate-sensitive vectors and pathogens into new regions that were previously inhospitable for reproduction and survival, carrying diseases with them (NRC, 2001). A variety of recent modeling efforts have shown that, assuming no future human-imposed constraints on malaria transmission, changes in temperature and precipitation could alter the geographic distribution and intensity of malaria transmission (e.g. Tanser et al., 2003; Van Lieshout et al., 2004; Ebi et al., 2005). Projected changes include an expansion towards higher latitudes and elevations, and, in some regions, a longer season during which malaria may be present. Such changes could increase the number of people at risk for malaria. In some regions, the geographic range may contract if temperatures become too hot. The extent of future changes will depend not only on climate change, but also on changes in other factors that influence the incidence of malaria, including land use change, the prevalence of drug-resistant parasites, and the effectiveness of vector-control programs.

A key approach to the control of infectious diseases is surveillance and response. Surveillance is a critical component of efforts to measure, recognize, evaluate, anticipate, and respond to the effects of climate on health (Wilson and Anker, 2005). Surveillance involves the systematic collection of information on health determinants and outcomes necessary to determine the occurrence and spread of health outcomes, and the analysis, interpretation, and distribution of this information to relevant actors for timely and effective control activities. Surveillance programs provide early intelligence on whether a health outcome is increasing in incidence or geographic range. One adaptation option to address the threat of the spread of vectorborne diseases is to expand current

Table 1 – Actors and example of their roles and responsibilities for adaptation

Actor	Reduce exposures	Prevent disease onset	Reduce morbidity and mortality
Extreme temperature and weather events			
Individuals	Stay informed about impending weather events Follow guidance for emergency preparedness	Follow guidance for conduct during and after an extreme weather event (such as seeking cooling centers during a heatwave or evacuation during a hurricane)	Seek treatment when needed
Community and national agencies	Provide scientific and technical guidance for building and infrastructure standards	Develop scientific and technical guidance and decision support tools for early warning systems and emergency response plans, including appropriate individual behavior	Ensure that emergency preparedness plans include medical services
	Enforce building and infrastructure standards	Implement early warning systems and emergency response plans Conduct tests of early warning systems and response plans before events Conduct education and outreach on emergency preparedness	Monitor the air, water, and soil for hazardous exposures Collect, analyze, and disseminate data on the health consequences of extreme events and heatwaves Monitor and evaluate the effectiveness of systems
NGOs and other actors		NGOs and other actors play critical roles in emergency preparedness and disaster relief	Education and training of health professionals on risks from extreme weather events
Vectorborne and zoonotic diseases			
Individuals	Reduce exposure to infected vectors, including eliminating vector breeding sites around residence	Vaccinate for diseases to which one would likely be exposed	Seek treatment when needed
Community and national agencies	Provide scientific and technical guidance and decision support tools for early warning systems Institute and maintain effective vector (and pathogen) surveillance and control programs Develop early warning systems for disease outbreaks Disseminate information on appropriate individual behavior to avoid exposure to vectors	Sponsor research and development on vaccines and other preventive measures Sponsor research and development on rapid diagnostic tools Provide low-cost vaccinations to those likely to be exposed	Sponsor research and development on treatment options Disseminate information on signs and symptoms of disease to guide individuals on when to seek treatment
Waterborne and foodborne diseases			
Individuals	Follow proper food-handling guidelines Follow guidelines on drinking water from outdoor sources		Seek treatment when needed
Community national agencies	Develop and enforce watershed protection and safe water and food handling regulations	Sponsor research and development on rapid diagnostic tools for food- and waterborne diseases	Sponsor research and development on treatment options Disseminate information on signs and symptoms of disease to guide individuals on when to seek treatment
Diseases related to air pollution			
Individuals	Follow advice on appropriate behavior on high ozone days	For individuals with certain respiratory diseases, follow medical advice during periods of high air pollution	Seek treatment when needed
Community and national agencies	Develop and enforce regulations of air pollutants	Develop scientific and technical guidance and decision support tools for early warning systems Conduct education and outreach on the risks of exposure to air pollutants	Sponsor research and development on treatment options

surveillance programs to regions where changes in weather and climate may facilitate their spread.

Effective surveillance systems are timely, have sufficient coverage, collect good quality data, and have adequate responses to reduce the burdens of health outcomes (Wilson and Anker, 2005). These features require an effective public health infrastructure. The ongoing financial and human capital commitments needed for surveillance programs are difficult for low-income countries to meet. The financial and human capital costs play a key role in determining the type and quantity of data collected. For example, laboratories are required to verify diagnoses, conduct quality assurance, etc. The health and environmental data collected need to match on spatial and temporal scales. Further, surveillance exists within an ethical and legal framework that derives from the broad goal of protecting the health of the public; it needs to balance collecting data for the public good with protecting the privacy and civil liberties of individuals. As a consequence of these and other issues, the extent and effectiveness of surveillance programs vary from one country to another.

For some diseases, surveillance programs may be coupled with an early warning system to provide timely interventions to reduce the magnitude or extent of a disease outbreak (Kuhn et al., 2004). Whereas surveillance systems are designed to detect and investigate adverse disease outbreaks as they occur, early warning systems are designed to alert the population and relevant authorities when an outbreak is expected. Early warning systems can be very effective in preventing deaths, diseases, and injuries. If appropriately designed, early warning systems could be adjusted to incorporate projected increases in climate variability and change, thus preventing increasing burdens of adverse health outcomes.

Another public health management approach is command and control regulation for some environmental exposures, such as air pollutants. This policy process typically evolves in a step-wise function, with periods during which research aims to better understand exposure–response relationships under current regulations, followed by adjustments in local, national, and international regulations to account for changing knowledge of the impacts of individual air pollutants. This process is not designed to respond to rapid increases changes in risk factors, so health burdens managed using this approach may be particularly vulnerable to a changing climate.

The policy process will need to adjust measures to address situations where increases in mean temperature (or other weather factor) could lead to gradual increases in rates of health outcomes, and situations where thresholds could be crossed, leading to large increases in the rates of health outcomes, either because it is close to its boundary conditions or because there is a sudden and/or large change in weather.

Policy responses will need to be developed for new health risks. AIDS, SARS, BSE, and Ebola virus are examples of diseases that were first observed relatively recently in human populations. Although their emergence was not associated with climate variability and change, these diseases are examples of public health risks that had varying degrees of impact and effectiveness of policy response; thus, lessons learned from public health responses to these diseases can be useful in modifying programs to address climate-related health risks. The 2003 European heatwave also could be categorized as a new threat because its strength and duration were outside the range of recent historical experience (Beniston, 2004; Stott et al., 2004).

No matter the approach, management of climate change-related health risks will evolve as the climate changes and as more is understood about the relationships between weather/climate and health determinants and outcomes. Thus, the policy process will require continual learning, recognizing that knowledge will never be sufficient, there will always be uncertainties, and that experience (learning by doing) will inform policy development (Scheraga et al., 2003). Continuing research is needed to understand changing conditions and their implications for management of health outcomes, including the costs of impacts and adaptations. Funding is needed for monitoring and evaluation programs to measure key indicators of disease burdens and the effectiveness of adaptation options. In particular, funding will be needed for low- and middle-income countries to develop and maintain such programs. Flexibility is needed for handling large and/or sudden changes in weather, climate, and other factors. Not only will policy responses change, but the public health institutions themselves will change in response to changes in the social, economic, and political paradigms and power structures that direct and limit the policy context.

5. The theoretical range of adaptation options

Policy objectives can be achieved through many pathways, and should start with evaluation of how climate change could affect national goals and policies. Policy makers need to choose which measures are appropriate for a particular level of government in a particular population. In the process of identifying specific measures to implement, it can be useful to begin by generating a list of all potential measures, without regard to technical feasibility, cost, or other limiting criteria. Such a theoretical range of choice (White, 1961) consists of a comprehensive listing of all available (including currently implemented) measures, new or untried measures, plus other measures that are theoretically possible. The list may be compiled from a canvass of current practice and experience, from a search for measures used in other jurisdictions and in other societies, and from a brain storming session with scientists, practitioners, and affected stakeholders to identify measures that might be an option in the future. Assuming that one policy objective is to increase adaptive capacity to climate variability and change in the health sector, listing the full range of potential adaptation options provides policy makers with a picture of measures that could be implemented to reduce the burden of morbidity and mortality of climate-related risks, and which choices are constrained because of a lack of technology, information or resources, or as a consequence of other policy choices.

For example, Stott et al. (2004) conclude that the frequency and intensity of heatwaves is likely to increase in Europe. Measures suggested to reduce the impacts of heat on human health include development of heatwave early warning systems (including intervention plans) for more cities, particularly those in temperate regions; a requirement to consider climate change projections in the design and construction of new buildings and in the planning of new urban areas, for example by requiring green roofs, more open space, and the planting of more trees; further develop energy efficiency programs to reduce both the urban heat island and the greenhouse effect; reduce the number of motor vehicles to reduce the heat island effect; promote high levels of heat acclimatization via programs that encourage an active lifestyle; and provide cooling centers during days with high ambient temperatures (Koppe et al., 2004). Air conditioning of private and public spaces is a primary measure used in the United States to reduce heat-related morbidity and mortality. However, in Europe, building design makes it difficult to air condition many buildings. Plus, depending on the energy source used to generate electricity, increased use of air conditioning could increase greenhouse gas emissions. Also, air conditioning increases the urban heat island effect and can reduce acclimatization, which creates an additional public health risk when air conditioning is not available due to a brownout.

Using malaria as an example, as shown in Table 2, the theoretical range of adaptation options for a theoretical country in which malaria is projected to increase with climate change could include measures to improve public health infrastructure, source reduction (including larvicide and biological control), insecticide-treated bednets, indoor residual spraying, malaria prophylaxis, development of forecasting and early warning systems, education and awareness programs, a malaria vaccine, and genetic modification of malaria vectors and/or pathogens to prevent pathogen transmission. Integrated vector management programs typically include surveillance along with many of these measures, and are based on knowledge of factors that influence local vector biology, disease transmission, and disease morbidity; use of a range of interventions, often in combination and synergistically; involve collaboration within the health sector and with other public and private sectors; include stakeholder engagement; and are based on a public health regulatory and legislative framework (WHO, 2004b). Public health infrastructure is needed for all phases of malaria prevention, diagnosis, and treatment and is weak in many developing countries (WHO, 2004a).

The next step is to screen the theoretical range of adaptation options to determine which measures are possible for a particular community or country over a particular time period, within existing technological, financial, and human capital constraints, to generate a list of options from which policy makers can choose. Criteria that can be used to determine which choices are practical include:

1. Technical feasibility. Is the choice technically viable or available? Has its effectiveness been demonstrated? For example, integrated vector management is feasible and effective (WHO, 2004b). Another possible option is a vaccine, but is not currently available. Few malaria early warning systems based on weather and environmental variables have been developed, although they have been shown to be reasonably accurate and timely in some regions (Thomson et al., 2005; Teklehaimanot et al., 2004; Abeku et al., 2004).
2. Degree of effectiveness. How effective is the proposed measure in reducing the incidence of the adverse health outcome? Not all malaria prophylactics are effective in all regions because of the development of drug resistance. If a malaria vaccine is developed, then characteristics of the vaccine may be critical to determine effectiveness; some vaccines require a cold-chain that constrain their use in tropical regions. Biological control, including use of predators, such as mosquito fish, that eat larvae and pupae, and insecticide-treated bednets are effective in the control of infected *Anopheles* mosquitoes.
3. Environmental acceptability. Does the proposed measure have environmental consequences that are unacceptable?

Table 2 – Screening the theoretical range of adaptation options—malaria

Theoretical range of choice	Technically feasible?	Effective to address health outcome?	Environmentally acceptable?	Economically feasible?	Socially & legally acceptable?	Closed/open (practical range of choice)
Improve public health infrastructure, including surveillance programs	Yes	Medium	Yes	Sometimes	Yes	Open
Source reduction	Yes	Yes	Spraying may not be acceptable	Yes	Sometimes	Open
Insecticide-treated bednets	Yes	Yes	Yes	Yes	Yes	Open
Indoor residual spraying	Yes	High	Yes if applied correctly	Yes	Yes	Open
Malaria prophylaxis	Yes	Yes	Yes	Only for the few.	Yes	Closed for the many
Weather-based forecasting & early warning systems	Yes	Medium	Yes	Often	Yes	Open
Public information and education/ awareness campaigns	Yes	Low	Yes	Yes	Yes	Open
Vaccination	No					Closed
Genetic modification of mosquitoes and/or parasite	No					Closed

For example, the draining of wetlands may decrease the number of vector breeding sites, but also has adverse ecological consequences. Indoor residual spraying became popular when effective and inexpensive insecticides such as DDT became available in the 1950s. However, vector resistance to some insecticides has resulted from the overuse of insecticides in agriculture and poor management of insecticide use in public health.

4. Economic efficiency. How expensive is the choice in relation to expected benefits? If insecticide-treated bednets are too costly for people in exposed areas to purchase, would it be cost-effective or cost-beneficial to supply bednets free or at a subsidized rate? How much would this cost, and who would pay? Would they in fact be used by those exposed (or sold to neighboring communities to supplement income)? What would the benefits be in terms of the reduced incidence of malaria?
5. Social and legal acceptability. Is the proposed measure in accordance with the laws and social customs and conventions? For example, the spraying of mosquito breeding sites with chemicals may be regulated and/or people may object to spraying.

After this screening process, some measures will remain available or open, and others will be eliminated or blocked in the immediate term. This does not mean that they will be unavailable in the future; the fact that a theoretical option is blocked may be an incentive to find ways of removing the constraint through research, changing laws, or educating the public about the benefits of a practice that is considered culturally unacceptable. Those choices that are open comprise the currently available practical range of adaptation options.

In the case of malaria, neither an effective vaccine nor genetic modification of mosquitoes have been achieved and are blocked as practical choices, but could be possible with additional research funding and are theoretical possibilities. In this example, other choices remain open, with qualifications. Indoor residual spraying and insecticide-treated bednets are cost-effective in some regions but may be ineffective or too costly for the poor. Indoor residual spraying does not work on thatch walls and may be too costly where mosquitoes are resistant to less expensive insecticides. Insecticide-treated bednets are less effective where the principal vector bites outdoors and in the early evening (e.g. *Anopheles arabiensis*) before people are in bed. Larval control (killing larvae with oil or insecticides applied to the water surface of breeding sites) can be effective in arid regions and cities, but is impractical in rural areas where mosquito-breeding sites are small and ubiquitous.

As the example makes clear, local expertise is necessary to evaluate whether particular measures would be appropriate for the region of interest.

6. The practical range of adaptation options

Once the adaptation options have been narrowed to practical choices, additional analysis can identify and prioritize these choices for consideration by policy makers. Because all possible options were listed for the theoretical range of choice exercise, the practical range of options will likely include both new and current measures that analyses recommend be modified or implemented in a particular setting. Analyses can be conducted through quantitative assessment, solicitation of expert judgment and/or stakeholder groups, or another approach. Policy makers will combine the information generated by the assessment with other considerations to determine the final measures for implementation.

Seven additional criteria are suggested to facilitate selection of practical adaptation options and to aid prioritization of likely options. The first, magnitude of the event, or intensity of the exposure, is not shown in Table 3 because it is not relevant to malaria. This criterion refers to estimation of the actual exposure and/or the health outcome of concern. For example, if the concern is related to flooding, what is the projected flood return period? What is the intensity of projected floods? In terms of the health outcome of concern, what is its present and potential future incidence? How serious is the projected health burden? Some proposed measures might be not relevant in the case of a low level of risk (e.g. expensive investments in infrastructure), while others may be inadequate to cope with high levels of risk (e.g. malaria prophylaxis in economically depressed regions with very high disease burdens).

1. Technical viability. This criterion refers to the technical practicality of the proposed measure. For example, can sufficient numbers of insecticide-treated bednets be manufactured and supplied to all exposed regions? Will they be effective for the length of the malaria season?
2. Financial capacity. Are the financial resources available to implement the measure? Even though the benefits of a measure exceed costs, it does not necessarily follow that policy makers can harness the required financial resources. It also is important to consider who bears the costs and how those budgets can be maintained over time. For example, in some communities, fire and rescue personnel are placed on call during a heatwave; the additional operational costs may come from the regular budget, requiring trade-offs with other programs. The total cost over the period of time the measure will remain in operation is an important consideration.
3. Human skills and institutional capacity. Does the country have a sufficient number of trained people and the necessary institutional arrangements to implement the proposed measure? If not, are there non-governmental organizations, international agencies, or others that might be willing to provide skilled personnel and the training necessary to develop local capacity?
4. Compatibility with current policy? Is the proposed measure compatible or in conformity with current policy? Does current policy have to be changed in order for the measure to be deployed? As mentioned earlier, draining wetlands can reduce vector-breeding sites, but may not be compatible with environmental protection policies.
5. Is there a target of opportunity for implementing the policy? (Smith, 1996). For example, tourism is a key economic sector in many countries that could be adversely affected by heatwaves. A target of opportunity for implementing

Table 3 – Analysis of the practical range of adaptation options—malaria

Practical range of choice	Technically viable?	Financial capability?	Human skills and institutional capacity?	Compatible with current policies?	Target of opportunity?	Consequences of option?
Improve public health infrastructure, including surveillance programs	Yes	Low	Low	Yes	Yes	Win/win for public health
Source reduction	Yes	Sometimes	Sometimes	Yes	Yes	Inappropriate application can increase risk of parasite resistance
Insecticide-treated bednets	Yes	Sometimes	Yes	Yes	Yes	If the length of the malaria season increases, bednets may not last an entire season
Indoor residual spraying	Yes	Sometimes	Yes	Sometimes	Yes	Inappropriate application can lead to pesticide exposure and increase risk of parasite resistance
Malaria prophylaxis	Yes	Sometimes	Yes	Yes	Yes	Need to monitor for drug resistance
Weather-based forecasting & early warning systems	Yes	Yes	Yes	Yes	Yes	Consider consequences of false positive and negative warnings
Public information and education/awareness campaigns	Yes	Yes	Sometimes	Yes	Yes	Messages need to be clearly understood

measures to inform tourists of appropriate activities during a heatwave would be while the early warning system is being developed.

6. What are the potential negative consequences of implementing the option? Public health is full of examples of technologies that appeared promising and were implemented widely, only to discover later that key assumptions about how the technology would be used were not met, that there are negative unintended consequences, etc. This criterion calls for thinking about what (and how) implementation could go wrong, and monitoring for and taking appropriate corrective actions early.

Table 3 analyses the practical options for malaria in the theoretical country. The final choice of options does not rest with the analyst; rather it is the task of the analyst to clarify the choices and their implications or consequences (Scheraga et al., 2003). This information will then be used by the responsible authorities and by civil society, particularly those likely to be affected by the policy choice, to make the final determinations.

It can be useful to summarize the state of knowledge that underlies the answer in each cell, including the reasons why particular criteria limit the use of an option. Policy makers can use this information to address the constraints. For example, some vaccines need to remain cold at all times to ensure their effectiveness, so if vaccination is the most effective option to deal with an outbreak, then a cold-chain needs to be established. A longer term solution is development of an alternative vaccine delivery systems that do not require refrigeration.

This list of criteria is not comprehensive. There may be other criteria that policy makers may wish to take into account. For example, river basins often cross national boundaries so land use practices in one country could affect flooding in another. In this case, transboundary cooperation and collaboration may be needed.

7. Prioritization of adaptation options

Because there is no such thing as absolute safety, risk assessors and policy makers seek to understand ''how safe is safe enough?'' The answer is, of course, that it depends upon the risk criteria that have been established and the social norm in a given society or jurisdiction. There are several approaches for evaluating whether the risks associated with an exposure or activity is acceptable, including: (1) an assessment of how much increased (or decreased) health burden will occur; (2) an assessment of comparative risks; (3) a benefit-risk assessment; and (4) a multicriteria assessment (Whyte and Burton, 1980). A comparative risk assessment determines whether alternatives have comparable levels of risk. A benefit-risk assessment determines the costs and benefits of risk reduction. A multicriteria assessment ranks how well each adaptation meets established criteria such as effectiveness, feasibility, and cost. An advantage of this approach is that criteria do not need to be measured in common metrics, and criteria can be weighted to reflect relative importance.

For example, where the risks of foodborne or vectorborne diseases are increasing, policy makers want to understand how much the risks have or are projected to increase, and how much can be attributed to climate change. Because a small elevation in risk may be manageable within existing policies, measures, and settings, decision-makers should focus on approaches to manage larger increases in risk.

Comparative risk refers to the notion that all risks should be approximately equal to each other following risk reduction strategies. However, in practice, risk protection decisions are distorted. For example, much higher standards of safety are required of airplane manufacturers and operators than for automobiles. One assumption underlying this approach is that policy makers should not invest in policies, measures, and settings for risks that are low compared with other risks. The health sector regularly evaluates the risks of various health determinants and outcomes, and makes funding allocations based on which pose larger threats to a community. One problem with this approach is that, over time, successful interventions are at risk of receiving less funding precisely because they are successful in reducing a health burden. An example is the disease prevention and control programs established in the Americas during the first half of the 20th century that effectively controlled arthropod vectors for yellow fever, dengue fever, malaria, and other regionally important diseases (Gubler and Wilson, 2005). These programs relegated the once great plagues of humans to relatively unimportant regional public health problems. Success resulted in complacency, which in turn led to policy changes that resulted in dramatically decreased resources and deterioration in the public health infrastructure needed to deal with vector-borne diseases and in support for research on new and more effective vector control strategies. These public health changes, combined with population growth, modern transportation, increased movement of people, animals, and commodities, and other demographic and societal changes over the past 50 years, have resulted in a global resurgence of a range of diseases.

Benefit–risk assessments compare the benefits to be gained from a particular intervention with the amount of risk reduction to be achieved. One underlying assumption is that society should not invest in policies, measures, and settings for which there will be little gain. This is particularly relevant for risks that have been reduced to a fairly low level. Given that risks cannot be reduced to zero, policy makers need to decide whether the effort required for further reduction in risk is an appropriate allocation of scarce public health resources. Benefit–risk assessments may use cost-effectiveness or benefit–cost analysis. Cost-effectiveness analyses typically involve comparing the relative costs of different options that achieve the same or similar outcomes (http://yosemite.epa.gov/ee/epa/eed.nsf/webpages/Guidelines.html). Benefit–cost analysis requires expression of benefits (e.g., avoided adverse impacts from an adaptation) and costs in a common metric, to allow benefits and costs to be compared to estimate whether the benefits exceed the costs. This is often done by expressing benefits in monetary terms. This is not straightforward for benefits that are not bought and sold in markets, such as illness and human life (http://yosemite.epa.gov/ee/epa/eed.nsf/webpages/Guidelines.html).

8. Discussion

Climate change is projected to have far-reaching effects on human health, with the extent of impacts partially determined by the efficiency and effectiveness of policies and measures implemented to increase the ability of individuals and societies to cope with what the future does bring. Of course, climate is not the sole determinant of the burden of climate-sensitive health determinants and outcomes; other important variables operate at the individual (such as appropriate behavioral responses) to national level (such as the capacity of the public health system to cope with gradual and sudden changes in climate-related diseases). Because public health has experience in coping with climate-sensitive health outcomes, it is likely that few new health management policies will need to be developed (Ebi et al., 2006b). There will be situations where current policies are effective, but will need to be enhanced to address projected climatic changes. For example, although the number of heatwave early warning systems is increasing, few systems use scenarios to project possible temperature anomalies outside the historic range to understand the potential magnitude of future heatwaves. Current adaptation may not be sufficient to cope with the projected health impacts of climate variability and change, including the more frequent re-introduction of vectorborne diseases, increasing food insecurity due to changes in agricultural productivity, etc. Therefore, additional adaptation will be required to cope with climate change, while maintaining or improving current public health standards.

When evaluating all possible adaptation choices, it is important to consider how programs and activities in other sectors could influence either human health vulnerability or public health adaptation to climate variability and change. Irrigation for agriculture, dam construction, deforestation, housing development, and many other factors can influence the range and intensity of climate-related health determinants and outcomes. To protect population health, mechanisms will need to be created to ensure effective and timely cooperation and collaboration across sectors when modifications are made to current activities and when new programs are instituted. For example, implementation of rainwater harvesting programs to increase access to freshwater should be developed in conjunction with public health departments concerned with preventing breeding of mosquito vectors in standing water. Ongoing collaboration can identify potential problems before causing large increases in adverse health outcomes.

To identify and implement effective and efficient adaptation options, policy makers need to understand the potential health impacts of climate change; the effectiveness of current policies in reducing the impacts of weather and climate on health; the range of choices available for enhancement of current or development of new policies, measures, and settings; and the costs and benefits of practical options. Although there is limited research on the degree to which adaptation can reduce the projected health impacts of climate change, the ability of current programs and activities to reduce the burden of climate-sensitive health outcomes indicates that public health adaptations would be effective, if there are sufficient human and financial resources to address additional health burdens.

The approach developed here can be used to summarize theoretical and practical adaptation options in order to identify and prioritize responses. The criteria used to filter the theoretical and practical adaptation options should be based on interactions with policy makers and stakeholders to ensure that the questions of highest concern will be addressed. Ideally, this process would be repeated at regular intervals to ensure that adaptation measures continue to be effective and efficient, and to determine whether new technologies or approaches have arisen that, when implemented, could reduce the risks posed by climate variability and change.

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