Improving Public Health Responses to Extreme Weather Events

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Abstract

Recent advances in knowledge about the climate system have increased the ability of meteorologists to forecast extreme weather and climate events, such as floods and heatwaves. Public health agencies and authorities have had limited involvement in the development of early warning systems to take advantage of these forecasts to reduce the burden of disease associated with extreme events. Instead, public health has focused on surveillance and response activities to identify disease outbreaks following an extreme event. Although these systems are critical for detecting and investigating disease outbreaks, they are not designed for identifying and preventing many of the adverse health outcomes associated with extreme events. Designing and implementing effective disease prediction and preventions programs that incorporate advances in weather and climate forecasting have the potential to reduce illness, injury, and death. Critical components of an early warning system include the weather forecast, disease prediction models, and a response plan designed to pro-actively undertake activities to reduce projected adverse health outcomes. Because climate change may increase climate variability, early warning systems can both reduce current vulnerability to extreme events and increase the capacity to cope with a future that may be characterized by more frequent and more intense events.

Introduction

Public health is the science and art of preventing disease, prolonging life, and promoting health through the organized efforts of society (Committee of Inquiry into the Future Development of the Public Health Function 1988). "It is the combination of sciences, skills, and beliefs that is directed to the maintenance and improvement of the health of all people through collective or social actions. The programs, services, and institutions involved emphasize the prevention of disease and the health needs of the population as a whole. Public health activities change with changing technology and social values, but the goals remain the same: to reduce the amount of disease, premature death, and disease-produced discomfort and disability in the population." (Last 2001). Public health has been also defined by the WHO as "the art of applying science in the context of politics so as to reduce inequalities in health while ensuring the best health for the greatest number". (Yach 1996).

Measures to reduce disease and save lives are categorized into primary, secondary, and tertiary prevention. Primary prevention is the "protection of health by personal and community wide efforts" (Last 2001).

It aims to prevent the onset of disease in an otherwise unaffected population by preventing individual exposures to sufficient doses of an agent to initiate disease. Regulation of potentially hazardous environmental exposures, such as by setting limits on criteria air pollutants to prevent the onset of disease, is an example of primary prevention.

When primary prevention is not feasible, which is often the case with many naturally occurring environmental exposures, secondary prevention includes "measures available to individuals and populations for the early detection and prompt and effective intervention to correct departures from good health" (Last 2001). It focuses on preventive actions taken in response to early evidence of health impacts (e.g., strengthening disease surveillance and responding adequately to disease outbreaks such as the West Nile virus outbreak in the United States). Surveillance is necessary to gather early evidence of adverse health impacts.

Finally, tertiary prevention "consists of the measures available to reduce or eliminate long-term impairments and disabilities, minimize suffering caused by existing departures from good health, and to promote the patient's adjustment to irremediable conditions" (Last 2001). These measures include healthcare actions taken to lessen the morbidity or mortality caused by the disease (e.g., improved diagnosis and treatment of cases of malaria).

Primary prevention is generally more effective and less expensive than secondary and tertiary prevention. Although disasters due to adverse weather and climate events cannot be entirely prevented, primary prevention, particularly development of early warning systems, can reduce the number of adverse health outcomes that occur during and following an event. Current primary prevention activities, where they exist, are generally limited to educational programs to inform the public of what to do (and not do) during and immediately following an event. These educational programs often were implemented in a city or region after an event caused injuries and deaths; few programs have been established proactively. Instead, public health activities have focused on surveillance and response systems (secondary prevention) to identify disease outbreaks following an event, such as an outbreak of waterborne disease following a flood.

Surveillance and response systems are a cornerstone of infectious disease prevention and health promotion activities. However, they are ineffective for identifying and preventing many of the adverse health outcomes associated with extreme weather and climate events. Even with improvements, surveillance systems will not provide a basis for effective public health response to an extreme weather event. In order to reduce the number of adverse health events due to extreme weather and climate events, effective prediction and prevention programs that incorporate recent advances in weather and climate forecasting need to be designed and implemented. The increasing ability to predict extreme events, particularly heatwaves, provides public health authorities and agencies with the opportunity to develop early warning systems to reduce the burden of disease associated with these events. Because climate change is projected to increase climate variability, early warning systems can both reduce current vulnerability to extreme events and increase the capacity to cope with a future that may be characterized by more frequent and more intense events (McGregor, this volume).

Forecasting Extreme Weather and Climate Events

The skill with which extreme weather events can be forecast has increased significantly over the past thirty years as more has been learned about the climate system. During this period, weather forecasting gradually increased from same-day forecasting to the three day advance forecast, and our understanding of the mechanics and teleconnections of El Nino Southern Oscillation (ENSO) now provides the capacity for seasonal and annual forecasting – assumed as recently as the 1970s to be the stuff of fancy not science (Nicholls 2002). In fact, Chen et al. (2004) recently suggested that El Nino events can be predicted two years in advance.

Public health has taken only limited advantage of the possibilities thus offered (Kovats et al. 1999; WHO 2004). For example, the timing and intensity of a number of diseases change during and after El Nino events. Coupling understanding of these disease relationships with forecasting of the timing of an El Nino event can be used to develop early warning systems that improve current public health responses. For example, Bouma and van der Kaay (1996) analysed historical malaria epidemics using an El Nino Southern Oscillation index, then predicted high-risk years for malaria on the Indian subcontinent. There was an increased relative risk of 3.6 for an epidemic in El Nino years in Sri Lanka and a relative risk of 4.5 for post El Nino years in the former Punjab province of India. Subsequently, associations were reported between El Nino events and malaria in other parts of the world, including South America (Bouma and Dye 1997; Bouma et al. 1997). This ability to predict malaria epidemics allows public health authorities to implement interventions, such as the distribution of bednets and anti-malarials, before surveillance would have detected an outbreak, thereby reducing disease and death. This more efficient allocation of resources allows for more effective use of scarce public health funds.

The value of early warning systems to prevent adverse health outcomes will increase in the future if projections of increased climate variability due to climate change are realized (McGregor, this volume). One likely consequence of increased climate variability will be surprises with regard to the timing, intensity, location, and duration of extreme events (Glantz 2004). Climate variability may already be increasing, resulting in extreme weather and climate events for which decision makers and the public are ill prepared. Increasing climate variability could affect the extreme event frequency-magnitude distribution in a number of ways (McGregor, this volume). One possibility is that the more rare or extreme events will be affected disproportionately such that only these events become more frequent. In this situation, the probable maximum flood or heatwave would increase, perhaps substantially. Another possibility is that the whole frequency-magnitude distribution might shift such that all events become more frequent. A third possibility is that only smaller events become more frequent. Thus, there is high uncertainty about the rate and intensity of any changes in climate variability in a particular location over a specified time period, but high certainty that without adequate preparation, extreme events will lead to increased morbidity and mortality. Extreme events cannot be prevented, but the vulnerability to these events can be reduced through a variety of measures, if appropriate warning mechanisms are in place.

Development of early warning systems in anticipation of increased climate variability due to climate change can be viewed as an application of the precautionary principle. The precautionary principle is an approach to public policy action that can be used in situations of potentially serious or irreversible threats to health or the environment, where there is a need to act to reduce potential hazards before there is strong proof of harm. The precautionary principle and its application to environmental hazards and their uncertainties began to emerge as a foundation for decision-making in the 1970s; it has been increasingly included in national legislation and international treaties. To this end, on 2 February 2000, the European Commission approved a communication on the precautionary principle that provided guidelines for its application (CEC 2000). Elements of a precautionary approach include research and monitoring for the early detection of hazards, cost-benefit analysis of action and of no action, and the taking of action before full proof of harm is available if impacts could be serious or irreversible (Boehmer-Christiansen 1994; EEA 2001). Application of the precautionary approach should trigger research to provide more certainty about the exposure-response relationship.

Because the character and intensity of extreme weather and climate events are changing, it would be useful to develop scenarios identifying potential impacts that may not be anticipated by decision makers and the public. For example, if a major heatwave were to result in the shutdown of power plants that supply electricity to another country, and if the recipient country did not have backup sources of power, then a range of impacts can be imagined for which responses would need to be developed. These scenarios can then be used to inform development of early warning systems, including specific interventions to be implemented.

Limitations of Surveillance and Response for Extreme Weather Events

Surveillance aims to continually scrutinize all aspects of the occurrence and spread of disease that are pertinent to effective control (Last 2001). Surveillance activities include the systematic collection of health, disease, and exposure information; the analysis of disease and exposure patterns; interpretation of trends; and distribution of results to responsible agencies, whether local, regional, national or global, to identify and implement appropriate responses to disease events (Wilson and Anker 2005). Surveillance is the means by which public health agencies keep themselves informed about the health status of the populations that they serve. Surveillance data are used to monitor levels and trends in disease occurrence, characterize geographical spread of disease over time, detect and investigate outbreaks as they occur, recognize new strains of pathogens, etc. Surveillance data are used to detect and respond to outbreaks of infectious diseases, such as West Nile virus. Typically, many cases need to occur before the surveillance systems can detect that an outbreak is in progress. Unfortunately, it is not uncommon for actions to be initiated after the peak of the epidemic has passed.

In the case of extreme weather and climate events, surveillance is needed in the time period immediately surrounding an event to determine if the event is associated with an increase in disease, such as diarrheal disease following a flood, in order to institute appropriate measures (such as a boil water alert). In addition, surveillance of age and cause-specific deaths over time are needed to calculate baseline or normal mortality rates in order to recognize unusual increases in mortality over what would have been expected for that time and place (Wilson and Anker 2005). Knowledge of the usual pattern of deaths allows calculation of the number and type of excess deaths resulting from a flood, heatwave, or cold spell. However, because there is a considerable lag between when deaths occur and when the data are available for analysis by public health authorities, surveillance is not effective for determining during an extreme weather event if it is causing excess deaths. For example, mortality begins to rise within one day of a heatwave, but these data are often not available for days to months.

The limitations of surveillance were demonstrated during the 2003 European heatwave. This heatwave took French public authorities by surprise (Abenheim, this volume). There are a number of reasons why this heatwave caused nearly 15,000 excess deaths in about a two-week period, from characteristics of the event itself to surveillance systems not designed to detect and respond to a heatwave. Health surveillance systems did not provide authorities with information quickly enough to detect the increased number of deaths in a timely manner. For example, a retrospective assessment determined there had been about 3900 deaths at the time when 10 deaths had been reported via normal surveillance. In fact, it would have been difficult for the current surveillance system to determine the size of the problem: the number of emergency ward visits in August (1900 visits) was not higher than usual (2100 visits in 2000); and the number of deaths attributed to the heat was less than one per nursing home. Surveillance systems are designed to detect outbreaks of a variety of usual or new infectious diseases, such as measles, but are not designed to determine if more deaths from cardiovascular disease are occurring today or this week. In addition, health surveillance systems are not designed to cope with the large numbers of people who were at risk for mortality from chronic diseases, such as cardiovascular and respiratory diseases; it is estimated in France that there were 6 million people at risk, of which 1 million were at very high risk. There were 500,000 at very high risk and isolated. Finally, emergency public health interventions have not been designed to address sudden increases in endemic and common diseases, such as cardiovascular disease. There were no widely available and efficient measures for reducing heat-related mortality. Air conditioning may have saved some lives, but is generally not available, particularly for the populations at highest risk, such as the elderly in nursing homes.

The French public health surveillance system is being re-evaluated to identify limitations and areas for improvement (Abenheim, this volume). But improvements to surveillance systems can only partly address the adverse health impacts of extreme weather and climate events. There needs to be increased focus on prediction and prevention if further disasters are to be avoided. Surveillance and early warning systems, coupled with effective response capabilities, can reduce current and future vulnerability.

Early Warning Systems Can Reduce Current and Future Vulnerability to Extreme Weather Events

Whereas surveillance systems are intended to detect, measure, and summarize disease outbreaks as they occur, early warning systems for extreme weather and climate events are designed to alert the population and relevant authorities that meteorological conditions are such that adverse health events could result. Early warning systems can be very effective in preventing deaths, diseases, and injuries as long as effective prediction is coupled with adequate communication strategies and timely response capabilities . For extreme weather events, forecasting is needed of both the event itself, which is the domain of meteorology, and prediction of the health impacts that could occur. In theory, an effective early warning system should both reduce vulnerability and increase preparedness (Committee on Climate Ecosystems, Infectious Disease, and Human Health 2001).

The development of an early warning system assumes that the responsible agencies have agreed upon what constitutes a risk. Risk can be viewed as a combination of the probability that an adverse event will occur and the consequences of that event (USPCC RARM 1997). Both factors need to be considered when evaluating risk because the public health responses developed for high probability events with low consequences will differ from the responses for low probability events with high consequences. An example of a high probability event with low consequences is a heavy rain event not associated with flooding. Responses, including early warning systems, for the low probability events with high consequences can be considered within the context of the precautionary principle.

An event that has the potential to cause harm is considered a hazard. The consequences of a hazardous event in the public health sector are measured in terms of the burden of associated morbidity and mortality. As discussed elsewhere in this volume, extreme weather and climate events have caused severe consequences over the past few years. However, as discussed in Hajat et al. (2003) the health risks associated with flooding are surprisingly poorly characterized. The dearth of good quantitative data results in uncertainty of the full range of potential health impacts associated with flooding events. There is better understanding of the health risks of heatwaves, but more information is needed on effective interventions to reduce morbidity and mortality. In order to more effectively target intervention programs for extreme weather and climate events, better understanding is needed of vulnerability risk factors. Projections of more, and more intense, extreme weather and climate events as a consequence of climate change increase the importance of improving our understanding of population vulnerability and interventions that can effectively reduce that vulnerability.

The principal components of public health early warning systems are disease prediction and response (Woodruff 2005).

Disease Prediction

A disease prediction model needs to be accurate, specific, and timely. To do so, there must be knowledge of disease dynamics and the ability to obtain reliable and up-to-date information on both the health outcome and the factors critical to disease incidence. This knowledge of disease dynamics applies primarily to communicable diseases, such as those that can follow an extreme weather event. For example, the disease outbreaks reported after flooding events have well-described etiologies. Such disease outbreaks are rare in Europe due to the public health infrastructure, including water treatment and sanitation. However, fever and waterborne disease have been reported following flood events (Hajat et al. 2003). One example of an outbreak occurred when cases of leptospirosis were reported in the Czech Republic following flooding in 1997; however, the quality of data appears to be poor (Kriz et al. 1998). Analysis of waterborne disease outbreaks in Finland over the period 1998 – 1999 found that thirteen of fourteen outbreaks were associated with groundwater that was not disinfected, mostly related to flooding (Miettinen et al. 2001).

The association between elevated ambient temperatures and morbidity is well documented. Historically, cardiovascular diseases have accounted for 13 % to 90 % of the increase in overall mortality during and following a heatwave, cerebrovascular disease 6 % to 52 %, and respiratory diseases 0 % to 14 % (Kilbourne 1997). Heatwaves also increase the rate of nonfatal illnesses. Disease prediction models have been constructed within the context of heatwave early warning systems (Kalkstein 2003; Sheridan and Kalkstein 1998).

However important, disease prediction models are not sufficient for developing an early warning system (Woodruff 2005). Consideration needs to be taken of confounding or modifying factors that affect the potential for an outbreak. An effective response plan also is required to reduce the predicted burden of disease. The second component of disease prediction is the availability of reliable and timely information on critical factors in the exposure-disease relationship. As discussed above, surveillance systems are relatively effective for communicable diseases. Surveillance systems are relied upon after flooding to detect increases in diarrheal and other diseases. However, also discussed above, surveillance systems are not designed to detect increases in common chronic diseases. Different approaches need to be developed to determine if deaths increase during a heatwave, such as obtaining reports from a random sample of funeral directors to determine if more deaths than usual are occurring. This implies that the funeral directors have analyzed historical data to determine, for a particular time period, the expected or baseline number of deaths. This also means that thresholds need to be established, beyond which specific responses are taken. For example, one excess death per week is unlikely to be sufficient to suggest an increase in mortality. But should actions be taken at two, three, four, etc.? Thresholds need to balance between recommending actions when they are not needed, and not recommending actions when they would reduce morbidity and mortality.

It is important to consider the sensitivity and specificity of a predictive model in the design of public health responses. All models have multiple sources of uncertainty, from data uncertainties to incomplete understanding of disease etiology. Uncertainties need to be characterized because they have implications for the design of response activities. For example, no early warning system can ever be completely accurate. False positives (issuing a warning when none was required) and false negatives (not issuing a warning when one was needed) have consequences, not only in terms of increased morbidity and mortality, but also in terms of public willingness to rely on subsequent warnings. Incorporating understanding of these uncertainties, and their associated costs, into the design of an early warning system can improve its effectiveness.

Even when models are available that are reasonably predictive and surveillance data provides timely information, models are still of limited value until they are actually used to direct disease prevention efforts (Woodruff 2005).

Response

Response is the second principal component of a public health early warning system. The design and implementation of response activities needs to be within the context of the cultural, social, economic, and political constraints of a particular region. The components of response include:

- a response plan, detailing thresholds for action;
- available and effective interventions;
- economic assessment of the cost-effectiveness and affordability of the system;

- communication strategy; and
- involvement of all relevant stakeholders in the process (Woodruff 2005).

A variety of response plans exist or are being developed for heatwaves and floods. Emergency management agencies in most countries have flood plans in place, but these focus on post-disaster response and often do not include adequate pre-disaster planning. Early warnings of flooding risk have been shown to be effective in reducing flood-related deaths when the warning is coupled with appropriate responses by citizens and emergency responders (Malilay 2001). An example of the effectiveness of response plans is the differences between the 1993 – 94 flooding along the Rhine and Meuse in Germany and the 1995 flooding along the same rivers (Estrela et al. 2001). The two floods had similar characteristics, although the 1993 – 94 flood had a second peak discharge. Persistent high precipitation caused both events: in December 1993, the accumulated precipitation was more than double the long-term average for that month. Ten people lost their lives in the 1993 – 94 flood and the total damage was estimated at USD 900 million for Belgium, Germany, France, and the Netherlands (Bayrische Ruckversicherung 1996a,b; Estrela et al. 2001). The economic cost of the flood damage in Germany in 1995 was half this amount because people were aware of the risks and were better prepared.

There are several areas in which flood plans can be improved. As discussed in Hajat et al. in this volume, current plans focus on the larger events even though more frequent smaller events also have important health impacts, and have not incorporated consideration of the mental health impacts that can follow a flooding event. The mental health impacts of a flood may be considerable, and may last for months to possibly even years after the flood event. Currently it is unclear whether reduction of mental health impacts will respond best to psychological and/or pharmacological interventions delivered through health services, or whether the interventions would best be targeted at providing financial or other assistance with recovery activities.

Although periodic heatwaves have led to excess morbidity and mortality, few Ministries of Health have made heatwave prediction and response a high priority. Prior to the 2003 heatwave, high ambient temperatures were considered a rare problem about which public health authorities could do little. Few heat/health warning systems were in place in Europe and most of those that were had only recently been implemented. Initial funding for several of these systems came from the World Meteorological Organization. Systems recently established in Lisbon and Rome were able to notify public health authorities and/or the population of the hazardous conditions during the 2003 heatwave, which presumably saved lives – as has been found in other cities. For example, the combination of a heat watch warning system and a response plan to reduce the exposure of vulnerable population groups to extreme heat likely led to the substantial reduction in deaths from extreme heat in the midwestern United States in 1999 as compared with a similar heatwave in 1995 (Palecki et al. 2001). It took an extreme event such as that in 2003 to demonstrate to Ministries of Health and others that heatwaves are dangerous, with the potential to cause large numbers of excess deaths, and that effective early warning systems need to be designed and implemented in advance of the next heatwave if additional lives are not to be lost.

The characteristics of an early warning response plan are informed by the political, social, and cultural setting in which the system operates (Glantz 2004). Therefore, an effective plan developed for one community, region, or country, may not have the same degree of effectiveness if implemented elsewhere. The appropriateness of the plan components, including thresholds of action and the interventions that these trigger, need to be evaluated and modified to maximize response effectiveness for the region for which it is designed. For example, some heatwave early warning systems in the United States have two levels of health alerts: a watch, which indicates that meteorological conditions are such that a heatwave could arise; and a warning, which indicates that a heatwave has started (Kalkstein et al. 1996). In essence, a watch means to be prepared, and a warning means that an extreme event is in progress so response plans should be activated. 'Watch' and 'warning' have been used by the United States National Weather Service in early warning systems for other climatic events, such as tornados, so the public understands their meaning. The same may not be true in other regions and countries.

Response plans require the explicit definition of thresholds for action. For example, a heat/health warning system needs to define what constitutes a heatwave. Such a definition is contextual within a population; what is considered a hot day in Stockholm differs from what is considered a hot day in Athens. Thresholds need to consider not only at what point interventions should be implemented to protect the health of the entire population, but also when interventions should be implemented to protect various vulnerable sub-groups, such as the elderly or tourists. As noted above, there may be more than one threshold for action. In addition, there needs to be sufficient lead-time for response plans to be activated once the threshold is reached.

Development of an early warning system is predicated on the availability of effective interventions to reduce the burden of disease. Further, interventions should be specific to a vulnerable group. The elderly, disabled, children, ethnic minorities, and those on low incomes may be at increased risk during and after an extreme event. Although there will be common interventions, such as lowering body temperature to prevent the onset of heat stress, there should be messages specific to particularly vulnerable groups. For example, the messages designed to alert parents to the risk of leaving infants unattended in automobiles during a heatwave should be different than messages designed to motivate seniors to spend time at a cooling center. Tourists are often not considered in the design of response plans, yet can be particularly vulnerable because they are unlikely to know what specific actions to take and may be difficult to inform because of language barriers. A variety of interventions are in use in flood and heatwave early warning systems. Unfortunately, their effectiveness has generally not been evaluated.

Response plans need to assess the cost-effectiveness of the system. This includes knowledge of the effectiveness of specific interventions; unfortunately little research has been conducted in this area. One study looked at the cost-effectiveness of the Philadelphia Hot Weather-Health Watch/Warning System (Ebi et al. 2004). This system was initiated in 1995 to alert the city's population to take a variety of precautionary actions during a heatwave. It was estimated that issuing a warning saved, on average, 2.6 lives for each warning day and for three days after the warning ended; the system saved an estimated 117 lives over a three-year period. Estimated dollar costs for running the system were small compared with estimates of the value of a life. Unfortunately, data were not available on the specific interventions included in the system, so their individual effectiveness could not be evaluated. This is an area in which further research is much needed.

The existence of the response plan, along with the interventions included in the plan, need to be communicated to all potentially affected groups. A communication strategy is a critical element of the response plan. This strategy needs to define who is responsible for the communication program; when the program should be initiated; who are the key audiences; what are the key messages to be delivered and how they should be delivered; and how the effectiveness of the communications will be monitored and evaluated (Kovats et al. 2003).

Finally, a response plan needs to be developed and operated in a transparent manner that includes all stakeholders in the process (Glantz 2004). Stakeholders include the agencies and/or organizations that will fund the development and operation of the system; the groups who will be expected to take actions (such as emergency responders and others); and those likely to be affected by the extreme event. Such involvement increases the likelihood of success of the system. In addition, including those who have been affected by extreme events in the past may reveal local knowledge about responses and their effectiveness.

Conclusion

The skill with which extreme weather and climate events, such as floods and heatwaves, can be forecast has increased significantly over the past thirty years as more has been learned about the climate system. However, public health agencies and authorities have taken only limited advantage of the possibilities thus offered. Instead, the focus of public health activities has been on surveillance and response systems to identify disease outbreaks following an event. Although surveillance and response systems are a cornerstone of disease prevention and health promotion activities, they are ineffective for identifying and preventing many of the adverse health outcomes associated with extreme events. In order to reduce the number of adverse health events due to extreme weather, effective prediction and prevention programs need to be designed and implemented that incorporate advances in weather and climate forecasting. Because climate change may increase climate variability, early warning systems can both reduce current vulnerability to extreme events and increase the capacity to cope with a future that may be characterized by more frequent and more intense events.

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Temperature Extremes and Health Impact