The Socio-Economic Benefits of Climatological Services to the Health Sector

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CONTENTS

1. Overview
2. Description of climate sensitive diseases
3. Climate, disease and economy
4. Health sector needs for climate information and products
5. International Coordination
6. Current climate support
7. Case studies
   Developed country
   Developing country
8. Future possibilities
9. Recommendations for action
References
Records afford evidence of an undoubted relation between the meteorology of a place and its liability to cholera activity

H.W. Bellew (1884)

1. Overview

At the close of the twentieth century, the health situation in the world has continued to improve in general. This is reflected in the national averages of life expectancy at birth and mortality rates. These improvements are associated with social, economic, environmental, and technological advances, as well as the increased availability of health care services and effectiveness of public health programs. These health gains, however, have not been achieved to the same degree in all the countries of the world, nor have all groups within a population benefited equally from them. The least favourable health situations are those in which the persistence of communicable diseases is associated with deficient living conditions, including poverty and progressive environmental degradation. In some countries, health problems related to lifestyles, urbanization, and population aging have actually increased (PAHO, 2002).

In addition to the well-known relationship that exists between a people’s health status and that population’s economic level, health inequalities are further influenced by the degree of equity in the distribution of income. Gains in life expectancy, infant and child mortality and survival, and per capita health expenditures, for example, have been systematically greater in those countries with more equitable income distribution and associated access to treatment. Thus, healthier societies are not necessarily those that are wealthier, but those which are the most equitable in the distribution of their income, regardless of its amount (PAHO, 2002).

Since the 1980s, the dynamics of the environment and health have been changed by worldwide integration of the world’s economy, politics and culture. But human health has begun to feel the effects of even larger scale changes globally, including environmental and socio-economic changes that have occurred simultaneously and often interactively. International assessments have shown that changes in the climate system, the ozone layer, biodiversity, land use and degradation have all impaired human health (McMichael, 2003).

Knowledge of the interactions between climate and health date back to the time of Aristotle, but our understanding of this subject has recently progressed rapidly as technology has become more advanced. At the same time, the ability to forecast weather (in terms of both accuracy and lead-times) has greatly improved...
in recent years, especially with the use of remote sensing. The increased accuracy of climate predictions and improved understanding of interactions between weather and infectious disease have motivated attempts to develop models that predict changes in the incidence of epidemic-prone infectious diseases. Such models are designated to provide early warning of impending epidemics that, if accurate, would be invaluable for epidemic preparedness and prevention (WHO, 2004).

Climate risk is a complex variable related to hazard types and patterns of vulnerability, the losses and damage produced by hazard events, and the capacity of households, communities, businesses, utilities and others to absorb and recover from loss and damage. Vulnerability is much more than the possibility of suffering loss or damage. It refers to the capacity of a household, community, business or organization to absorb losses or damage and then to recover from them. Together, they link the proximate and underlying processes that influence risk behavior (for example, activities favouring mosquito breeding), transmission behavior (for example, activities around high risk areas), and the capacity for protective behavior (for example, use of vector barriers, access to vaccines).

Various meteorological factors affect population health directly through extremes of temperature or precipitation, and indirectly by affecting agents that can cause disease. Temperature, relative humidity, rainfall and wind-speed are perhaps the most important and are all predicted (with a greater or lesser degree of uncertainty) to be affected by climate change (Houghton et al., 2001). For example, it is generally accepted that the transmission of many infectious diseases is affected by climatic conditions. Diseases caused by pathogens that spend part of their life cycles outside of human or other warm-blooded hosts are particularly climate-sensitive. Some of these diseases are among the most important global causes of mortality and morbidity, particularly in poorer populations in developing countries. In many environments, these diseases occur as epidemics, possibly triggered by changes in climatic conditions favouring transmission rates (WHO, 2004).

Risk reduction involve cross-scale actions (from individual and households to nations) taken to reduce both vulnerable conditions and, when possible, the source of the hazard, addressing for instance land-degradation and water quality (Pulwarty and Riebsame, 1997). In combination with natural resource degradation, climatic hazards are leading to an increased frequency of small- or medium-impact disasters produced by recurrent floods, for example, as well as slow on-set disasters such as drought. Thus, another aspect of cross-scale climatic impacts is that accumulated losses from these smaller disasters may often be responsible for even more aggregate suffering than individual major disasters. The succession of small- or medium-scale events can accentuate the vulnerability that culminates in a major disaster. Despite considerable efforts and the resources expended on disaster response, these small- and medium-scale
disasters are increasing in frequency in many parts of the world.

Climatological information, sometimes in conjunction with other data, can be a major tool in the reduction of disease, injury and death and in the improvement of health and health care (Nicholls, 1996).

Some benefits might be achieved through climate information, such as better personal protective measures in adverse environments; reduction of some intestinal, respiratory and infectious diseases now that their climate associations are known; better control of living conditions for disease susceptible people; and enabling of further studies of causal relationships (Nicholls, 1996). Better understanding of climate health and health effects in human population will also require new analytical tools, including geographical information systems to map localized diseases, climate and demographic data, and remote sensing satellite technology to provide valuable data on land use patterns, habit characteristics and marine ecosystems.

Such databases will clearly benefit investigations of causes for a wide range of medical problems, and not only for the emergence, spread and control of disease, but also for improved prediction of seasonal climatic events that will provide early warning of conditions related to morbidity and mortality and permit timely preventive measures, distribution of medication and assessment of hospital demand. Longer term predictions will increase preparedness through the honing of national and international health policy, warning and response systems (Nicholls, 1996).

Large regional variations in economic value are to be expected, because, for example, different mitigative and adaptive policies are required in different parts of the world and only some regions are capable of flexibilities in their responses. Value, therefore, can be said to depend on the accuracy of predicted climate, the actual use made of the information by decision makers, and the relative importance of other information on which decisions are based (Nicholls, 1996).

2. Description of climate sensitive diseases

Both climate and weather have a powerful impact on human life and health. People have adapted to living in a wide variety of climates around the world -- from the tropics to the arctic, and long-term changes in world climate may affect requisites of good health, such as sufficient food, safe and adequate drinking water, and secure dwellings.

The IPCC concludes, “There is now good evidence that regional changes in climate, particularly increases in temperature, have already affected a diverse set
of physical and biological systems in many parts of the world” (McCarthy et al., 2001). Many diseases are influenced by weather conditions or display strong seasonality suggestive of a possible climatic contribution. Indeed, the World Health Organization (WHO) estimated in its “World Health Report 2002” that climate change was estimated in 2000 to be responsible for approximately 2.4 per cent of worldwide diarrhoea and 6 per cent of malaria in some middle-income countries (Corvalán et al., 2003).

Health outcomes of climate change can be grouped into those of (a) direct physical consequences (for example, heat mortality or drowning); (b) physical/chemical sequelae (for example, atmospheric transport and formation of air pollutants); (c) physical/biological consequences, response of vector- and waterborne diseases, and food production; and (d) socio-demographic impacts (for example, climate or environmentally induced migration or population dislocation) (Patz et al., 2000; Patz and Khaliq, 2002).

The first detectable changes in human health may well be alterations in the geographic range (latitude and altitude) and seasonality of certain infectious diseases, including vector-borne infectious diseases such as malaria and dengue fever, and food-borne infections (for example, salmonellosis) which peak in the warmer months. Warmer average temperatures combined with increased climatic variability would alter the pattern of exposure to thermal extremes and resultant health impacts in both summer and winter. By contrast, the public health consequences of the disturbance of natural and managed food-producing ecosystems, rising sea-levels, and population displacements from physical hazard, land loss, economic disruption and civil strife may not become evident for up to several decades (Corvalán et al., 2003).

The IPCC has also concluded, with high confidence, that climate change will cause increased heat-related mortality and morbidity, decreased cold-related mortality in temperate countries, greater frequency of infectious disease epidemics following floods and storms, and substantial health effects following population displacement from sea level rise and increased storm activity (McCarthy et al., 2001).

One clear example of the economic and social burden of a climate sensitive disease is the case of malaria. Malaria-endemic countries are not only poorer than non-malarial countries, but they also have lower rates of economic growth. Malaria affects almost every aspect of social and economic endeavors, including fertility, savings and investment rates, crop choices, schooling, and migration decisions. Where transmission is intense, the diseases create a complex set of biological responses with long-term effects on economic growth and development that goes well beyond the additive costs of individual cases (Sachs and Malaney, 2002). For example, between 1965 and 1990, countries in which a large proportion of the population lived in regions with *Plasmodium falciparum* malaria experienced an average growth in per-capita Gross Domestic Product (GDP) of 0.4 per cent per year, whereas average growth in other countries was...
2.3 per cent per year (Gallup and Sachs, 2001). In Sudan, for example, the mean expenditure on diagnosis and treatment of an episode of malaria has been US $5.12 per home-treated case and US $17.2 per hospitalized case, representing a significant economic burden to family income. This cost varied according to the type of treatment, the type of health care provider, and the location of treatment (Abdel-Hameed et al., 2001). Table 1 shows a summary of the known effects of weather and climate.

<table>
<thead>
<tr>
<th>Health outcome</th>
<th>Known effects of weather and climate</th>
</tr>
</thead>
</table>
| Cardiovascular and respiratory mortality and heat stroke mortality | - Short-term increases in mortality during heatwaves  
- V- and J-shaped relationship between temperature and mortality in populations in temperate climates  
- Deaths from heat stroke increase during heat waves |
| Allergic rhinitis | - Weather affects the distribution, seasonality and production of allergens |
| Respiratory and cardiovascular diseases and mortality | - Weather affects concentrations of harmful air pollutants |
| Deaths and injuries | - Floods, landslides and windstorms cause death and injuries |
| Infectious diseases and mental disorders | - Flooding disrupts water supply and sanitation systems and may damage transport systems and health care infrastructure  
- Floods may provide breeding sites for mosquito vectors and lead to outbreaks of disease  
- Floods may increase post-traumatic stress disorders |
| Starvation, malnutrition and diarrhoeal and respiratory diseases | - Drought reduces water availability for hygiene  
- Drought increases the risk of forest fires  
- Drought reduces food availability in populations that are highly dependent on household agriculture productivity and/or economically weak |
| Mosquito, tick-borne diseases and rodent-borne diseases (such as malaria, dengue, tick-borne encephalitis and Lyme disease) | - Higher temperature shorten the development time of pathogens in vectors and increase the potential transmission to humans  
- Each vector species has specific climate conditions (temperature and humidity) necessary to be sufficiently abundant to maintain transmission |
Micronutrient deficiencies and malnutrition

- Climate change may decrease food supplies (crop yields and fish stocks) or access to food supplies

Waterborne and food-borne diseases

- Survival of disease-causing organisms is related to temperature
- Climate conditions affect water availability and quality
- Extreme rainfall can affect the transport of disease-causing organisms into the water supply


3. Climate, disease and economy

Every culture teaches that “health is wealth” (Report of the Commission on Macroeconomics and Health (CMH), 2001). Economic output is known to be a function of policies and institutions (economic policies, governance, and supply of public goods), on the one hand, and factor inputs (human capital, technology, and enterprise capital), on the other. A detailed report produced for the WHO (CMH, 2001) showed that “health” is the basis for job productivity, the capacity to learn in school, and the capability to grow intellectually, physically, and emotionally. In economic terms, therefore, health and education are the two cornerstones of human capital, which is the basis of individual and community economic productivity (Dreze and Sen, 1989; Sen, 1999). As with the economic well-being of individual households, good population health is a critical input into poverty reduction and economic growth. In other words, health status seems to play an important part in the difference in economic growth rates, even after controlling for standard macroeconomic variables. Bloom and Sachs (1998) found that more than half of Africa’s growth shortfall relative to the high-growth countries of East Asia could be explained statistically by disease burdens, demography, and geography, rather than by more traditional variables of macroeconomic policy and political governance. Longer-lived and healthier households, in contrast, will tend to invest a higher fraction of their incomes in education and financial saving because their longer time horizon allows them more years to reap the benefits of such investments.

The channels of influence from disease to economic development are related to the direct loss of well-being to the individual (CMH, 2001). The quantitative accounts of the loss of well-being are usually calculated from three parts: (1) the reduction in market income caused by disease; (2) the reduction in longevity caused by disease; and (3) the reduction in psychological well-being caused by disease, often labeled “pain and suffering”, even when there is no reduction in market income or longevity. The reduction in market income, in turn, has at least four sub-components: (i) the costs of medical treatment; (ii) the loss of labor-
market income from an episode of illness; (iii) the loss of adult earning power from episodes of disease in childhood; and (iv) the loss of future earnings from premature mortality. One goal of economic analysis is to convert these disease-induced losses into monetary terms in order to assess the economic benefits of reducing the disease burden. The economics literature on the value of life has a very strong and consistent conclusion: the value of an extra year of healthy life — as a result of successfully treating a disease, for example — is worth considerably more than the extra market income that will be earned in the year. According to some estimates, each life year is valued at around three times the annual earnings. This multiple of earnings reflects the value of leisure time in addition to market consumption, the pure longevity effect, and the pain and suffering associated with disease.

Using these concepts, the CMH illustrates the enormous costs of malaria on African well-being. The authors multiply the annual number of lost life years due to the disease by some multiple of per capita income to obtain a rough estimate of the aggregate economic loss. In sub-Saharan Africa, for example, malaria accounted for an estimated loss of 36 million disability adjusted life years (DALYs) in 1999 out of a population of 616 million. If each DALY is valued very conservatively as equal to per capita income, the total cost of malaria would be valued at 5.8 per cent (= 36 / 616) of the gross national product of the region. If each DALY is valued instead at three times the per capita income, the total cost would be 17.4 per cent of GNP (5.8 per cent x 3). Note that these cost estimates do not include the effects of disease on the level of annual per capita income itself. Econometric estimates suggest that in the short term, an economy in which the population is at zero risk of malaria tends to grow more than one percentage point per year more rapidly than an economy with high malaria risk, controlling for other determinants of growth (such as income level, schooling, quality of institutions, and fiscal policy). As is mentioned in the report itself, even if the precise estimates are open to uncertainty, the magnitude of the economic losses is clear.

**Climate, gender and health**

In traditional settings, economic losses due to health are invisible for female home workers and the health of those in their care (that is those dependent on household economics and informal economies). Studies after Hurricane Andrew illustrate many of these issues (Enarson and Morrow, 1997). Women’s care giving roles in the aftermath of disasters dramatically expanded all stage of disaster response and, though often invisible to disaster responders, women’s formal and informal networks were central to both household and community recovery. But women’s economic losses are often invisible as home workers, and providers of nutritional care and sanitation. Increasingly, however, studies show that women are often present in disaster response as mitigators, rescuers, caregivers, sanitation providers, and are typically key to a local economy’s recovery and the mitigation of
future impacts. **In other words,** the active participation of women increases the effectiveness of prevention, disaster relief, reconstruction and transformation. For instance, after Hurricane Mitch (1998) in Honduras, women’s involvement in running shelters and processing food was crucial to the healthy recovery of families and communities (Buvinic et al., 1999). There is thus a clear need to **incorporate a gender perspective in country development plans for** basic disaster prevention and preparedness, ensuring, as far as possible, equal access for women and men to information related to disaster risk reduction issues.

### 4. Health sector needs for climate information and products

Public health has taken only limited advantage of the possibilities offered by the increasing skill of weather and climate forecasters. Incorporating advances in climate forecasting with a better understanding of vulnerable sub-populations, **for instance,** can be the basis of effective public health interventions to reduce the burden of climate-sensitive diseases. Climate information can **also** play an integral role in early warning systems (EWSs) for heat waves, floods, droughts, vector-borne diseases, air pollution-related diseases, and other diseases. **Users of such climate information for health benefits** include individuals, communities, nations, regions, and international organizations.

Early warning systems for extreme weather and climatic events are designed to alert the population and relevant authorities in advance about developing adverse meteorological conditions, and then to implement effective measures designed to reduce adverse health outcomes during and after the event. An effective and efficient EWS should both reduce vulnerability and increase resilience to future extreme events. Early warning systems thus constitute several integrated subsystems, including: (1) a monitoring sub-system; (2) a risk information sub-system; (3) a preparedness sub-system, and (4) a communication sub-system. Early warning systems are more than scientific and technical instruments for forecasting hazards and issuing alerts. They should be understood as credible and accessible information systems designed to facilitate decision making in the context of disaster management agencies (formal and informal) in a way that empowers vulnerable sectors and social groups to mitigate potential losses and damages from impending hazard events (Maskrey, 1997).

The three principal components of a health-based EWS (HEWS) include: forecasting of the event, which is the domain of meteorology and climatology; prediction of possible health outcomes that could occur; and effective and timely response plans (Woodruff, 2005). A HEWS must have the capacity, not only to disseminate warnings of impending hazards, but **also to** enable health officials to generate risk scenarios of potential losses and damages to be expected from impacts, including considerations of the vulnerable groups most likely to be affected. The incremental development of EWSs also enables new technology to be introduced gradually as system specifications evolve. An effective warning structure requires the development of institutional capacity for risk analysis,
warning, disaster preparedness and communication at the local level, as well as the horizontal and vertical flow of information. In a similar vein, simpler, economical, and readily available technologies are recommended whenever possible. At the same time, EWSs need to be developed as an integral component of a broad program of long-term vulnerability reduction and surveillance activities.

The definition of an extreme event requires collaboration between relevant agencies and stakeholders, that takes into consideration the factors that determine what constitute risk in a particular population. Public health responses need to consider how the interventions developed for high probability events with low consequences (that is, a heavy rain event not associated with flooding) will differ from the responses for low probability events with high consequences (that is the 2003 European heat wave) (Ebi and Schmier, submitted). A variety of population-specific factors, including cultural, economic, status of the public health infrastructure, also determine whether an extreme event is actually a risk. What is considered a hot day, for example, varies considerably by latitude across the summer season and is conditioned by the experience of people affected, requiring localized determinations of risk.

Public health authorities must collaborate with local, national, and international meteorological organizations to understand advances in forecasting and monitoring, including understanding the accuracy and timeliness of warnings, in order to develop both scenarios of plausible future weather anomalies and mechanisms for coordination during an extreme event. Climate change projections, for example, suggest that past weather is no longer a prologue for the future; therefore, EWSs and other public health interventions need to incorporate plans for an unpredictable future. Another example is that of the weather anomaly that resulted in the 2003 heat wave, which was outside of the range of anomalies currently considered in the development of heat health warning systems implemented in Rome and Lisbon (Kalkstein, personal communication, 2004). This event may be a harbinger of future European summers and provides a warning to other regions (Beniston, 2004).

A model to predict possible health burdens associated with extreme events must be accurate, population- and location-specific, and timely (Woodruff, 2005). Disease prediction models need to consider not just weather but also confounding or modifying factors that could affect the potential for an outbreak. But the usefulness of models also depends on the ability to obtain reliable and up-to-date information on both the health outcomes and the factors critical to disease incidence in time for effective responses to be implemented. Table 2 shows the principal health impacts of the climate and the sources of meteorological data.
<table>
<thead>
<tr>
<th>Principal Health Outcomes</th>
<th>Which populations/locations to monitor</th>
<th>Meteorological Data</th>
</tr>
</thead>
<tbody>
<tr>
<td>Thermal extremes</td>
<td>Daily mortality; hospital admissions; clinic/emergency room attendance</td>
<td>Urban populations</td>
</tr>
<tr>
<td>Extreme weather events (floods, high winds, droughts)</td>
<td>Attributed deaths; hospital admissions; infectious disease surveillance data; mental state; nutritional status</td>
<td>All regions</td>
</tr>
<tr>
<td>Asthma and allergy</td>
<td>Changes in seasonal patterns of disease</td>
<td>Sentinel populations in various locations</td>
</tr>
<tr>
<td>Food- &amp; water-borne disease</td>
<td>Relevant infectious diseases death &amp; morbidity</td>
<td>All regions</td>
</tr>
<tr>
<td>Vector-borne disease</td>
<td>Vector populations; disease notifications; temporal and geographical distributions</td>
<td>Margins of geographical distribution (for changes in altitude, latitude) and within endemic areas (for changes in temporal patterns)</td>
</tr>
</tbody>
</table>


5. International Coordination

One of the core functions of the World Health Organization is the establishment and maintenance of communicable disease surveillance programs to identify, verify, and respond to public health emergencies of international concern. Modifications of current surveillance programs are needed to account for and anticipate the effects of climate variability and change (Wilson and Anker, 2005). In particular, surveillance systems will be needed in new locations when climate-sensitive diseases and vectors change their range in response to changing climatic, environmental, and other conditions (NRC, 2001). Improvements in international surveillance systems facilitate national and regional preparedness and reduce future vulnerability to epidemic-prone diseases.
6. Current climate support

Weather and climate forecasts and early warnings may be used to provide information, which enables and persuades people and organizations to protect themselves and their property, thereby reducing the death, injury and damage caused by the hazard (Kovats et al., 2000).

Through the contribution of modern meteorological and hydrological sciences and technology such as meteorological satellites, weather radar, and numerical weather prediction models, providing communities threatened by potential major disasters with information to allow them to take preventive action in time is possible. Effective early warning can help to avert enormous losses of life and social turmoil. Recent experiments using ensemble forecasts show promising results for forecasting weather up to 10-14 days in advance.

The main difficulties associated with the use of climate data in monitoring health impacts lie in linking climate and health data at a suitably high resolution. Measurements are either discontinuous point data or averages over an area, and may not describe either local variations in climate (for example, temperature in city centers vs nearby rural areas), or microclimatic conditions in specific important environments (for example, resting sites of adult mosquitoes). Climate measurements at a local level and in important microclimates, where identifiable, should be recorded in intensively studied sites to test whether they provide closer correlations with health outcomes. As it is not feasible to take such measurements at all sites, their relationship with data from monitoring systems with global coverage should be modelled in order to enable scaling-up across large areas (Wilkinson et al., 2003).

Few difficulties should impede acquisition of reliable series of daily measurements of these variables for representing sites, given that there are extensive networks of meteorological monitoring stations throughout nearly all regions of the world. These measurements can also be interpolated to give estimates for the entire globe, at spatial resolutions as high as 30 x 30 km (New et al., 1999). In addition, satellite based sensors record proxy measurements of temperature, rainfall and humidity with true global coverage. Furthermore, data from either source can be geo-referenced to provide powerful tools for broad scale analysis of the relationships between climate and disease (Wilkinson et al., 2003).

One important consideration for researchers is the ongoing change in the climate baseline. Many archives of meteorological data contain baseline parameters, or climatological normals, based on the average data for three decades, which are re-calculated every 10 years. Analysis methods need to take into account this...
changing baseline to avoid erroneous, potentially overly-conservative, conclusions. The WMO addresses this by maintaining the Climatological Standard Normals (CLINO) (WMO, 1996). Re-computed each 30 years, the CLINO provides a stable baseline throughout that period. As all CLINO datasets reflect the same input period, the differences in values between observing locations reflects the differences in climate rather than differences caused by non-common time periods (Corvalán et al., 2003). With the relatively rapidly warming climate, climatological normals updated every 10 years are definitely needed in the Northern Hemisphere high latitude regions, like Finland. In fact, the Finnish Meteorological Institute is already adapting this practice and is currently using climatological normals for 1971-2000.

The advances in seasonal forecasting are generating new opportunities to mitigate the impacts of climate variability on health. In assessing the sensitivity and vulnerability of communities to weather and climate hazards, long-term climate records and related sectoral information are of vital importance. Such records are also essential for preparedness planning and response strategies that build resilience for coping with extreme events. The most effective measures for preparedness require a well-functioning EWS (WMO, 2002; Glantz, 1994). As discussed earlier, decision-makers should also be included in the process of assessment to better understand the uncertainties of forecasts (Kovats et al., 2000) and the perception of risk in different contexts. Early warning systems can have direct health and economic benefits (Epstein, 2002).

An EWS encompasses not only predictions of disease in time and space but also active disease surveillance and a pre-determined set of responses. This distinction between prediction and early warning must be clearly defined: early warning is prediction but not all prediction is early warning. There are two principal aims of health-based EWS (WHO, 2004):

1. To identify whether an epidemic will occur within a specific population, according to a pre-defined threshold of cases, and,
2. To predict the number of cases within a period of time.

The relative importance of the two aims will depend on the control decisions to be taken and the degree of interannual variation of the disease. For example, for diseases which are absent from the human population for long periods followed by explosive epidemics, early detection and/or predictions of the probability of an epidemic may be more important than predictions of the epidemic size (WHO, 2004).

Both geographical and seasonal distributions of many infectious diseases are linked to climate, therefore, the possibility of using seasonal outlooks as predictive indicators in disease EWSs have long been a focus of interest. During
the 1990s, however, a number of factors led to increased activity in this field: significant advances in data availability, epidemiological modelling and information technology, and the implementation of successful EWSs outside the health sector. In addition, convincing evidence that anthropogenic influences are causing the world’s climate to change has provided an added incentive to improve understanding of climate-disease interactions (WHO, 2004).

Attempts to initiate EWS development within a specific country should be preceded by a collaborative decision-making process that identifies principal disease(s) of interest, critical areas or communities, and appropriate entry points into planning. This will depend on the burden of various infectious diseases in the region and on levels of national and international funding available for disease-specific activities (WHO, 2004).

A good example of collaboration between meteorological and health services is the development of hot weather/watch warning systems. Such systems are frequently based on the identification of air masses associated with increased mortality (Kalkstein et al., 1996). These EWSs can predict specific air masses up to two days in advance, and once an air mass is classified as oppressive with the likelihood of high mortality, a “health warning” is issued to public health authorities who prepare a public health response (Kovats et al., 2000). These systems prevent deaths in urban centers, which are particularly likely to experience the adverse effects of heat (Kalkstein, 2000).

Forecast of the risk of an epidemic is an essential component of epidemic control. Seasonal statistical correlations may provide a simple but powerful tool in forecasting outbreaks and for developing early warnings of meteorological conditions conducive to outbreaks (Poveda et al., 2001). Seasonal outlooks and malaria forecasts enable early intervention, which can mitigate effects of epidemics and improve the cost-effectiveness of control activities. To achieve these ends, forecasts must not only be accurate but they must also be trusted, accessible and usable (that is compatible with existing decision making models and strategies) in a timely way.

Improved skills in seasonal outlooks can forecast an El Niño with a lead-time of up to six months, which provide decision makers with the earliest possible warning on natural disasters linked to flood and drought. Seasonal outlooks are also used to predict major climate trends for the following few months to few seasons. They indicate areas where there is an increased probability of some deviation from the climate mean, such as wet or dry, or warm or cold conditions (Kovats et al., 2003).

The assessment of health-related weather and climate hazards requires data and knowledge about potentially damaging phenomena that occur at the country or regional level (Corvalán et al., 2003). The integration of weather- and climate-
related information into community-based emergency response plans to reduce the vulnerability of communities and the effects of hazards as diverse as tropical cyclones, floods, wildfires and drought is now a well-established practice in many countries. There is, however, a continuing need to upgrade these plans in line with advances in science and technology. Many countries still need to formalize plans (WMO, 2002).

7. Case studies

7.1 Developed country

Heat Health Warning Systems Save Lives

Partly in response to heat waves in 1993 and 1994, the Philadelphia Hot Weather-Health Watch/Warning System (PWWS) was developed in 1995 to alert the city’s population when weather conditions pose risks to health (Kalkstein et al., 1996; Sheridan and Kalkstein, 1998). At that time, the local National Weather Service (NWS) issued heat advisories that relied heavily on the heat index, which identifies oppressive conditions based on a combination of temperature and relative humidity. The PWWS uses six readily available weather elements to identify major air mass types in Philadelphia for the current day and the coming two days during the summer season (Kalkstein et al., 1996). This system is the basis for many other heat-health watch warning systems being instituted in cities worldwide (Kalkstein, 2003; Sheridan and Kalkstein, 1998). Once a heat-related warning is issued, the Philadelphia Department of Health implements emergency precautions and mitigation procedures to reduce the mortality risk (Kalkstein et al., 1996).

The number of lives saved and the economic benefits of this system were estimated using data from 1995-1998 (Ebi et al., 2004). Excess mortality in people 65 years of age and older during heat waves (defined as maritime tropical and dry tropical air masses), including the three days following the end of each heat wave, was explained using multiple linear regressions. Excess mortality was calculated as the difference between reported mortality and the underlying mortality trend estimated from years prior to 1995. Variations around such a mortality trend line are a better indicator of the effects of daily weather and of efforts to counter those effects than are medical examiners' determinations that deaths were caused by extreme temperatures. Two explanatory variables were convincingly associated with mortality: the Time of Season when a particular heat wave started, and a Warning variable indicating whether or not a heat wave warning had been issued. The estimated coefficient of the warning variable was about -2.6, suggesting that when a warning was issued, 2.6 lives were saved, on average, for each warning day and three days after the warning ended. Given the number of warnings issued over the three-year period, the system saved an estimated 117 lives. Estimated dollar costs for running the system were small compared with estimates of the value of a life, suggesting that the benefits of...
implementing heat health warning systems in terms of lives saved far outweighs the operational costs of such systems, at least for cities located in temperate regions.

7.2 Developing country:

Where malaria has flourished most, human populations have flourished least (Sachs and Malaney, 2002). Malaria is the most deadly vector-borne disease in the world, particularly in Africa, where 80 per cent of all cases occur and 90 per cent of all mortality results (Bremen, 2001; D’Alessandro and Buttiens, 2001). Besides the toll on health, malaria has also been shown to have enormous economic consequences, directly resulting from its health impacts. For example, the direct and indirect losses due to malaria in Africa rose from US $800 million in 1987 to more than US $2,000 million in 1997. As the disease spreads to the highlands as a result of global warming and climate variability, losses are bound to increase. As discussed earlier, the disease has also been shown to increase poverty.

In Africa, the population at risk of epidemic malaria is estimated at 124,748,180; furthermore, an estimated 155,000-310,000 deaths result out of the 12.4 million cases of malaria due to epidemics (Worral et al., 2004).

The distribution of malaria is closely linked to climate and socioeconomic conditions. Since 1988, malaria epidemics have been increasingly reported, particularly in the highlands of Eastern Africa. Historically, such epidemics have caused great suffering and human loss. The extensive epidemic that occurred in Ethiopia in 1958 serves as an illustrative lesson. This epidemic, which occurred during a period of abnormally warm, wet weather and after an early shift of the rain season (Fontaine et al., 1961), affected 3 million and caused the death of 150,000 people in 6 months (Ministry of Health (MOH), Ethiopia 2000). Earlier in the century, an epidemic of "fever" which was undoubtedly malaria, caused up to 307,316 deaths in Punjab; these deaths were associated with excessive rains and food scarcity (Connor et al., 1999).

In 1998, an epidemic in Rwanda led to a four-fold increase in malaria admissions among pregnant women and a five-fold increase in maternal deaths due to malaria (Hammerich et al., 2002), and in Sri Lanka in 1934–1935, a case fatality rate of 13 per cent was recorded among pregnant women. The rate of fetal loss or neonatal death at this time was almost 70 per cent (Wickramasuriya, 1937).

In the epidemic prone highlands of East Africa, anomalies from the mean monthly maximum of 2.2-4.5°C observed between January and March 1997 and 1.8-3.0°C between February and April 1998 were associated with 150–300 per cent increases in admissions for malaria treatment (AIACC, AF91), overwhelming the medical facilities and affected communities. A major outbreak also occurred in January and February 1998 during the 1997/98 El Niño, a period when malaria transmission is typically lowest, catching people unawares and resulting in...
devastating effects.

As a result of this event, attempts were made to develop means of forecasting malaria epidemics using climate data. Such a model was developed, and it was shown that epidemics could be predicted with a lead-time of two to three months, thus providing ample time and opportunity to prepare for outbreaks (Githeko and Ndegwa, 2001). Further work on climate and malaria transmission has indicated that 12-63 per cent (mean = 36.1 per cent) of variance in the number of monthly malaria outpatients (Zhou et al., 2004) in East Africa and 85 per cent in Ethiopia (Abeku et al., 2004) could be explained by variations in temperature and rainfall. This new knowledge indicates that malaria transmission can be partially modelled using climate data and, furthermore, epidemics can be predicted.

The greatest challenge in containing malaria epidemics has been the inability to predict when and where they will occur. As a result, interventions have often only been undertaken when epidemics are well underway and damage has already been done. If pre-epidemic conditions can be detected, however, then drugs and other medical supplies can be delivered in advance to where an outbreak is expected. Communities in such areas can also be informed of the pending outbreak, so they can acquire bed-nets or spray their houses and seek early and effective treatment as necessary. Such actions can be expected to substantially reduce the number of malaria cases, which can translate to significant savings from expensive hospitalization.

The principal features of the East African model are now applied to evaluate seasonal outlooks in the Greater Horn of Africa countries to predict whether seasonal weather conditions are conducive to malaria outbreaks. Interpretations of the weather data is then widely circulated by the press and the electronic media.

Researchers found that in two Tanzanian districts, malaria alone accounted for 30 per cent of all deaths in 1996-97. In response, government planners increased the budget for malaria prevention and treatment programs from 10 per cent to 26 per cent by 2000-2001. Overall, these programs have resulted in a better match between disease burden and health budget allocation, and the child mortality rate has been reduced by more than 40 per cent since the late 1990s.

A five-fold difference has been shown in the GDP between malarial and non-malarial countries (Sachs and Malaney, 2002). The highlands of Eastern Africa, for instance, are rich in terms of agricultural productivity due to good rains and moderate temperatures. Increases in the incidence and prevalence of malaria as a result of global warming and climate variability in these highlands could negatively impact their economic productivity, especially if the frequency of outbreaks increases. Fortunately, the opportunity now exists to reduce the impacts of epidemics through improved use of climate information.

While some limited data is available on the cost of controlling a malaria epidemic,
virtually no data is available on how much can be saved by forecasting an epidemic. For this reason, the authors made a rough estimate of the costs to treat a child with severe and complicated malaria in a hospital compared to simple home treatment of an uncomplicated infection in Kenya. The majority of people use government hospitals, as they are the cheapest, so the average cost of treating a child with complicated malaria at such a hospital (five to seven days of in-patient care) can be estimated at about US $30.00. This is about nine percent of the income of an average Kenyan, whose per capita income is about US $330.00. If, on the other hand, an epidemic was forecasted and children were treated early after onset of the illness, the cost is estimated at only about US $2.50 per child. The savings here is US $27.50, which translates, for a million children a year, to a savings of about US $27,500,000.

8. Future possibilities

Tremendous opportunities exist to expand the use of climate-based disease EWSs as a means of improving preparedness for, and response to, disease epidemics (WHO, 2004). In addition to integrating climate and health data, these systems can also take advantage of advances in the availability of other environmental data and the use of geographical information systems and remote sensing to enhance prediction capabilities. Additionally, early warning systems can benefit from advances in forecasting to develop seasonal outlooks that can be coupled with weather data to improve risk management at the local and regional level. An example of such a multistage approach is the model developed by Woodruff et al. (2002) for Ross River virus disease in the Murray River region in Australia. Bioclimatic regions were identified in the study regions and data were obtained for a range of weather variables relevant to the biology of the mosquito vector, reservoir hosts, and virus replication. A monthly spatial summary value was then calculated for each weather variable in each bioclimatic region. Early and late warning models were developed using multiple logistic regression, and the early warning model was used to decide whether to implement control measures to reduce mosquito breeding. The late warning model could also be used to predict the probability of an epidemic and to issue public alerts if the results were conclusive. This multistage approach enabled response plans to be adjusted as forecast certainty increased, allowing health authorities to make the best use of limited resources.

9. Recommendations for action

Institutions responsible for responding to health-related climate impacts must take a more pro-active stance to assist sectors through their own private and public institutions in preparing not only for disaster events but also in analyzing vulnerability and proposing practical pre-event mitigation actions. Mitigating the potential economic impacts of climate related health risks requires assessment of impediments to flows of knowledge and identification of appropriate information.
entry points into policies and practices that would otherwise give rise to crisis situations (Pulwarty et al., 2003).

Management and communication about demographic, behavioral and climatic drivers of health-related disasters as well as more effective communication about the importance and economic benefits of disaster mitigation for educators, the media, advocacy groups and local communities is also needed. While no clear numbers for the health sector alone exist, the World Bank estimates that economic losses worldwide from natural hazards in the 1990s could have been reduced by US $280 billion if US $40 billion had been invested in preparedness, mitigation and prevention strategies.

According to a recent review by WHO, 18 diseases met defined criteria for the potential development of climate-based EWSs. Of these, only a few are not associated with some research project to develop an EWS, but many systems are undertaken as research and do not provide sufficient information for planning public health interventions. Furthermore, the resources for most research projects are limited so EWSs that are developed are rarely tested outside the original study area. Clearly, however, opportunities exist to reduce the burden of climate sensitive diseases through investment in the development of EWSs, which can be facilitated through collaborations between WMO, WHO, and other relevant agencies.

Meteorological and hydrological agencies must become or be allowed to become involved with other governmental organizations, local and national officials, emergency managers, local decision makers, the media, voluntary organizations, and weather-sensitive business, all of which are known collectively as the hazards community, to create effective preparedness plans, warning systems, mitigation strategies and public education programs (Kovats et al., 2000).

The resource costs of collecting and analyzing new data are not well understood. Thus, the actual estimates of costs saved as a result of using climate data and forecasts are not easy to discover. Clearly, however, such information can and does have value beyond the costs of its production. In the general absence of good baseline data (especially for decadal-scale changes), climate scientists and service providers will need to collaborate with epidemiologists to ensure that assessment and surveillance activities are simple, flexible and credible. There is, thus, a need to develop closer working relationships between practitioners to determine information and training requirements.


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