

Monitoring the health effects of climate change

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Introduction

Detection and measurement of health effects of climate change are necessary to provide evidence on which to base national and international policies relating to control and mitigation measures.

Unequivocal evidence of health effects, and accurate measurements of their size, can come only from hard data. However, climate varies naturally as well as through human influences and in turn is only one of many determinants of health. There must be careful consideration of how best to collect and analyse information that will provide secure evidence of climate change impacts.

In this chapter, we consider how monitoring may help provide evidence of early health impacts, examining the principles on which monitoring should be based, potential sources of monitoring data, and discussing issues in the analysis and interpretation of such data. There is a complex relationship between climate-change and health. Detecting and quantifying impacts on health will be gained only through broad scientific effort rather than individual monitoring studies.

Methodological considerations

Monitoring has been defined as “the performance and analysis of routine measurements aimed at detecting changes in the environment or health of populations” (1). Thus, it encompasses the notion of continuous or repeated observation using consistent and comparable methods to detect changes in some parameter relating to health or the determinants of health.

In many investigations in public health, it is possible to measure changes in a defined health impact and attribute this trend to changes in a directly related risk factor. This is not so with the health effects of climate change. As climate varies naturally over time (and is one of many determinants of disease rates) modelling is required to identify the climate-attributable part of disease and the long-term trends. This lack of direct connection makes monitoring of climate change impacts on health more complex than many other forms of health monitoring. There are three main issues:

Evidence of climate change

When concerned with health effects resulting from climate change, it is necessary to clarify the extent to which the putative driving factor (the climate) itself

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has changed at the location where monitoring has been undertaken. This may seem an obvious point, but it is worth remembering that many markers of health show seasonal and inter-annual fluctuation: the demonstration of this provides no direct evidence of health impacts relating to climate *change*—merely that these diseases exhibit a form of seasonal or climatic dependence. An excess of heat-related deaths in a particularly hot summer, or even a succession of hot summers, is evidence of the *potential* for climate change to increase mortality. It does not constitute sufficient evidence that mortality has increased as a result of climate change. That would require additional evidence of a change in the baseline, i.e. that the hot summers were exceptional in historical terms and a consequence of climate change rather than random variation. Indeed, not only would it have to show that the climate had changed, but also quantify how much, so that its contribution to changes in health could be estimated. Chapter 2 summarizes the evidence for being in a period of global climate change. Interpretation of the reason for change in monitored health data at a given location also requires specific evidence of climatic change at that location. Thus, monitoring of climate change impacts on health is not simply a matter of recording certain health outcomes over time. It also requires an analytical process to quantify the component of change in those health outcomes that can be ascribed to measured change in the underlying climatic conditions.

Given this, should the goal of monitoring be to yield direct evidence of changes in health resulting from climate change, or to show that diseases are altered in the short-term by meteorological conditions? If the latter, separate evidence of a changing climate arguably would provide sufficient grounds for assuming an impact on human health. However, some researchers and policy-makers may not be content to make this assumption. Most would prefer to have data from one setting which could both establish that a change in climate had occurred and show that there had been linked changes in health. The difficulty is that very long time series of data, perhaps several decades or longer, may be needed to achieve these aims, yet the quality and consistency of data recording over the long term often are uncertain especially when past data are used.

Attribution

The second key methodological issue in monitoring climate change impacts is attribution. It is clear that climate is but one of many influences on health, and its influence needs to be separated from that of other factors. For example, heat-related deaths require some form of time series analysis, usually at daily or weekly time resolution. This permits researchers to quantify the relationship between mortality and temperature (or other meteorological variables) independently of season, secular trends, and time varying factors. In most cases, the principal focus of these analyses is entirely on within-year fluctuation, i.e. the extent to which daily or weekly variation in mortality can be explained by fluctuation in meteorological conditions. This is the climate-attributable part of the particular health measure. But it is important to realise that there are various choices in the method of model construction, and these analyses can yield varying estimates of attributable cases depending on such factors as the method of adjustment for season, assumptions about the lag between exposure and health effect, and the functional form used to characterize the temperature-health relationship. Those choices will influence the estimates of climate-related

health impact in individual years, and hence the assessment of trend in health impacts over the long term.

With some diseases (e.g. vector-borne diseases such as malaria), it is possible to investigate not only temporal changes but also changes in the geographical distribution of vectors and disease over years. Even so, similar questions of attribution arise: the influence of meteorological conditions has to be separated from that of change in other environmental conditions. This requires some form of analysis of the determinants of geographical or short-term temporal variation in disease. The interpretation of these analyses can be more difficult than that of analyses of fluctuation in many other climate-sensitive diseases.

Effect modification

Finally, the issue of effect modification must be acknowledged. Our interest is in changes in weather-related morbidity or mortality over decades, which is the time-scale when change in underlying climatic conditions becomes apparent. Specifically, the aim is to demonstrate a gradual increase or decrease from baseline in the annual climate-attributable part of a range of marker diseases. But over such long time-scales changes in relevant non-climate factors also may occur. The population vulnerability to meteorological influences may alter such that more or fewer climate-related cases of disease may occur even without any change in prevailing climatic conditions. For example, vulnerability to extreme weather events, including floods and storms, will depend on where and how residential housing is built, what flood protection measures are introduced, how land use is changed. Similarly, susceptibility to heat deaths will be affected by the age of the population (vulnerability rises with age), the underlying prevalence of cardio-respiratory morbidity and quality of housing (2), among other factors.

A central question for public health is the extent to which populations are able to adapt to changing climatic conditions, as this determines their vulnerability to future climate change impacts. That adaptation may include physiological acclimatization (the fact that, in a biological sense, people gradually 'get used to' a warmer, wetter, cooler or windier environment) as well as structural adaptation, such as the extension of flood protection measures, introduction of air-conditioning systems in buildings and transport systems, and the implementation of eradication programmes for vector-borne diseases.

Thus, proper interpretation of a long-term trend in a climate sensitive disease needs to pay close attention to these various potential modifiers so that there is sufficient confidence that any observed change in health is the result of a climate effect rather than alteration in population susceptibility. Further, it could be said that the priority for monitoring should be not just to detect change but also to quantify the effect on disease burdens of adaptation and changes in population susceptibility.

This provides a strong case for a broad and sophisticated monitoring programme to enable vital questions about emerging trends in climate-related disease, and the extent of future vulnerability, to be addressed. It also suggests that effective monitoring cannot be simply a matter of sequential recording of markers of climate-sensitive diseases. It also must entail parallel measurements of population and environmental data to allow study of potential modifying influences, accompanied by methodological development to improve methods of modelling the disease impacts attributable to climate change. The data for such

modelling must come from observations over periods of decades in multiple settings.

General principles

The objective of detecting health effects of climate change will require similar levels of data collection and analysis to those needed to address broader questions about climate and health relationships. Given that only limited resources will be available to implement new (or revise existing) monitoring systems, priorities must be identified. We suggest that the principal criteria for selecting diseases and settings for monitoring should include the following:

Evidence of climate sensitivity

This will be demonstrated through either observed health effects of temporal or geographical climate variation, or evidence of climate effects on components of the disease transmission process in the field or laboratory. For infectious diseases, detailed knowledge of transmission cycles is essential in identifying the major threats. Climate change effects are likely to be most profound for diseases caused by organisms which replicate outside of human hosts (where they will be subject to ambient conditions), and will be less important and/or more difficult to detect for those where human to human transmission is common.

Public health burden

Monitoring also should be preferentially targeted towards significant threats to public health. These may be diseases with a high current prevalence and/or severity (3) resulting in a large loss of Disability Adjusted Life Years (DALYs), or considered likely to become prevalent under conditions of climate change. For example, diarrhoeal illness is a major contributor to the global burden of disease, and is in part related to meteorological conditions. Spread of malaria, dengue and other important vector-borne diseases to new areas and populations also would cause a substantial burden for those populations.

Practicality

Logistical considerations are important given that monitoring requires dependable and consistent long-term recording of data of health-related indices and other environmental parameters. Monitoring sites must be chosen where change is most likely to occur, but appropriate structures and capacity for reliable measurement will be essential. In some cases, retrospective data series that could be a suitable basis for forward data collection may be available.

Such considerations have been used to identify the most important health issues for both research and monitoring on a global scale. These priorities include:

- direct effects of exposure to low and high temperatures
- health impacts of extreme weather events (floods, high winds etc)
- increased frequency of food and water-borne disease
- geographical change and altered transmission frequency of vector-borne disease, principally malaria, dengue, filariasis, sleeping sickness (African trypanosomiasis), leishmaniasis, shistosomiasis, and Chagas' disease (American trypanosomiasis).

Lower priority threats include:

- other vector-borne diseases, including tick-borne encephalitis, Lyme disease, Toscana virus
- aero-allergens, particularly pollen
- rodent-borne diseases, including hantavirus and leptospirosis.
- harmful algal blooms & biotoxins.

Priorities will vary between regions with differences in current climate, level of socioeconomic development and spectrum of disease (4). Altered food productivity, changes in air pollution, and social, economic and demographic dislocations due to effects on economic infrastructure and resource supply are additional climate-related concerns that may be of high priority in some settings (5).

Monitoring systems should take account of these local needs and be alert to the appearance of potential new health concerns. Systems such as the WHO Global Outbreak and Response Network Programme for Monitoring Emerging Diseases (PROMED) (6) provide a valuable resource in identifying new health concerns. Such emergent concerns may include new geographical distributions of diseases or changes in the frequency of established diseases in particular populations; but also include the possibility of the emergence of new threats. By definition, such occurrence is unpredictable and identifying such climate-related health impacts will require vigilance by the scientific and public health communities. A possible climate-related issue that has emerged within recent years is that of harmful algal blooms.

Data requirements and data sources

A broad range of data is needed to monitor climate effects on health. Where possible, monitoring systems should assemble data on all components required for statistical analysis (including assessment of effect modification) or process-based/biological models. Many relevant variables already are recorded by existing systems and may require only access and cross-referencing with other data sources. For others, new monitoring systems or radical changes to existing systems may be necessary. Relevant measurements fall into the following broad classes:

Meteorology

Various meteorological factors influence health processes either directly or indirectly. Temperature, relative humidity, rainfall and wind-speed are perhaps the most important and all are predicted (with a greater or lesser degree of certainty) to be affected by future climate change (4, 7, 8, 9). There are few difficulties in obtaining reliable series of daily measurements of these variables for representative sites, given that there are extensive networks of meteorological monitoring stations throughout nearly all regions of the world. These measurements also can be interpolated to give estimates for the entire globe, at spatial resolutions as high as 30km by 30km (10). In addition, satellite based sensors record proxy measurements of temperature, rainfall and humidity with true global coverage. Data from either source can be geographically and temporally cross-referenced to health and environmental monitoring data in a geographical information system (GIS), providing powerful tools for broad scale analysis of associations between climate and disease.

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 variation in climate (e.g. temperature in city centres vs. nearby rural areas), or microclimatic conditions in specific important environments (e.g. resting sites of adult mosquitoes). Climate measurements at a local level and in important microclimates (where these can be identified) should be recorded in intensively studied sites to test whether they provide closer correlation 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 allow scaling-up across large areas.

Health markers

Analysis of climate effects on health ultimately depends on reliable recording of health status, at suitable temporal and spatial resolution. Such monitoring should be sensitive and specific enough to quantify changes in the intensity and temporal and geographical distribution of climate-sensitive health impacts.

One way to address the complex causality of most health outcomes is carefully to select indicators that are highly sensitive to climate changes but relatively insensitive to other influences. This approach already has given clear evidence of climate-change driven effects in other ecological systems. For example, changes in the seasonality of bird egg-laying (11) and the gradual pole-wards shift of insect and bird populations (12, 13) is most plausibly explained by the gradual warming observed in the study regions. By analogy, long-term monitoring of health-relevant properties such as the seasonal pattern of insect vector abundance in areas without control programmes may demonstrate changes that can be confidently attributed to climate-change.

Human health differs from other systems, however: there is not only an interest in demonstrating that climate change is having some effect, but also in quantifying the effect and making an adaptive response. The data requirements for attributing and measuring impacts may be quite different and the utility of routinely collected data varies markedly, depending on the health issue and region. For studies of direct effects of heat and cold the essential requirement is daily series of counts of death or morbidity subdivided by age and cause. Date of death usually is routinely recorded on death certificates and daily statistics often are collated at regional and national levels. Studies of all-cause mortality therefore are feasible in many settings, though even mortality counts can be difficult to acquire for many low-income countries, especially if cause-specific breakdown also is required.

The difficulties of data assembly become more challenging where the intention is to look at disease morbidity or health effects resulting from complex ecological processes, such as infectious diseases transmitted through food, water or vectors. In these circumstances, case definition, completeness of case ascertainment and reporting efficiency are key issues, as are temporal and geographical variation in diagnosis. Future monitoring must aim to address these limitations. In some cases this may be achieved through revision of existing health data sets and linkage to climate records. For many climate-sensitive diseases, however, the coverage or quality of available data precludes this approach, and improved monitoring systems are necessary to monitor trends (both climate-dependent and independent).

Other explanatory factors

It has been stated that monitoring will need to measure more than just climate and health. Data on time varying risk factors and changes in potential population susceptibility are equally important in order to begin to assess the climatic contribution to any observed change in health status. This is particularly true of infectious diseases transmitted by water, food or vectors. Often these are highly sensitive to climate, but human infections are only the end product of a complex chain of environmental processes (14).

For such diseases climate and disease monitoring ideally should be linked with parallel monitoring of intermediate stages in the transmission cycle (e.g. parasites, vectors and reservoir hosts) and the wider ecosystem (e.g. distribution of habitats suitable for vectors or reservoirs). Collection of accurate data on these variables would help to improve the explanatory value of models in purely statistical terms, and by identifying the key biological processes underlying changes in human disease. For example, such integrated monitoring would help to give a secure answer to the question of whether variation in the incidence of tick-borne encephalitis (TBE) in Europe is mainly due to climate effects on tick population dynamics, changes in the abundance of reservoir hosts, changes in the distribution of habitats where ticks and reservoirs come into contact, or changes in disease control and reporting systems.

In some situations, it may be informative to define the relationship between climate and environmental intermediates, even in the absence of the disease itself. For example, although competent vectors for both dengue and malaria are present in many areas of western Europe, there is no active parasite transmission. However, mosquito population density, biting rate and adult longevity (all known to be affected by temperature) are important determinants of these vector populations' capacity to transmit the relevant pathogens (15). Therefore it is relevant to public health to assess the link between climate and vector populations so as to assess changes in the probability of establishment of autochthonous transmission when parasites are imported to currently non-endemic areas. The specific parameters that should be recorded vary depending on the transmission cycle of specific diseases.

Recording of population and environmental changes is necessary for interpretation of changes in all climate-sensitive diseases. The choice of variables to be measured will depend on the specific disease, but the principal categories of confounding or modifying factors include:

- age structure of the population at risk;
- underlying rates of disease, especially cardiovascular and respiratory disease and diarrhoeal illness;
- level of socioeconomic development;
- environmental conditions e.g. land-use, air pollutant concentrations, housing quality;
- quality of health care;
- specific control measures: e.g. vector control programmes.

Data on the first two of these usually is available at aggregate level from routine sources of demographic and health statistics. Socioeconomic indicators often are available in fairly crude form, but it is less easy to obtain markers that have direct bearing on the health impact of interest. Poverty and living conditions will influence exposure to almost all health threats (from direct thermal effects and natural

disasters to infectious diseases) and are likely to increase the harmful effects of such exposures. Other socioeconomic factors may affect a smaller range of health outcomes, such as exposure to some pathogens in occupational environments. Changes in such socioeconomic factors potentially are of great importance for disease changes over periods of decades.

An increasingly useful source of data on land-use and other environmental parameters is remote sensing data from satellites. Such data are not always easy to calibrate and interpret, and may not be available at the required level of spatial resolution or with the desired detail of ground conditions. However, their great advantage is that they are becoming available for most areas of the world, providing the opportunity to capitalize on spatial as well as temporal contrasts. Statistical methods can be used to compare distribution of disease frequency in relation to measured land-use patterns as well as climatic variation, providing valuable insights into the determinants of distribution of malaria and other vector-borne diseases, for example (16).

Disease control programmes (e.g. insecticide spraying against insect vectors or chlorination of water supplies) and health care factors are problematic, not because of the difficulty of obtaining data (though this may well be the case) but because it is difficult to quantify their influence on the occurrence of climate-sensitive diseases.

In general, monitoring should aim to record data on all these confounding and modifying factors so that they can be included in analytical models. The difficulty of data acquisition, and proportionate increase in the amount of data with the number of factors being assessed, makes this infeasible in many settings. Indeed, it is impossible even to identify all confounding effects. An alternative approach may be to restrict monitoring to areas where non-climatic factors are unlikely to exert a strong effect. For example, monitoring of climate effects on mosquito populations might be carried out in areas where there are no vector control activities. In this case, climate-health models can be generalized to other areas only under the assumption that the derived relationships hold true elsewhere (e.g. temperature will affect mosquito population dynamics in the same way in habitats which are different from the original study site).

Examples

Table 10.1 summarizes the principal health impacts of climate change, sources of data, methods of data acquisition and the types of climate and other data needed to support their analysis. Where possible, monitoring should be based on existing data acquisition systems for reasons of cost-effectiveness and sustainability, and to ensure fullest use of existing retrospective data series. Particular issues of monitoring arise in different settings for the various health effects. Examples of studies that have entailed direct measurement of health in relation to meteorological parameters are given in Boxes 10.1 and 10.2 below. Other examples recently have been outlined by Patz (17).

Data sources and methods of monitoring will depend on the precise purpose of the monitoring, the type of existing data acquisition systems and available resources. There are differences between the sorts of data and analysis needed to quantify long-term trends in the burden of heat-related mortality and those needed for an early warning system that provides the basis for public health action (heatwave warning systems). The former requires systems to link health data to temperature measurements and other factors over a matter of decades;

TABLE 10.1 Principal health impacts of climate change and the sources of monitoring data.

	Principal health outcomes	Which populations/locations to monitor	Sources and methods for acquiring health data	Meteorological data	Other variables
Thermal extremes	Daily mortality; hospital admissions; clinic/emergency room attendance;	Urban populations	National and sub-national death registries (e.g. city specific data)	Daily temperatures (min/max or mean) & humidity	Confounders: influenza & other respiratory infections; air pollution Modifiers: housing conditions (e.g. household/workplace air conditioning), availability of water supplies
Extreme weather events (floods, high winds, droughts)	Attributed deaths; hospital admissions; infectious disease surveillance data; mental state; nutritional status	All regions	Use of sub-national death registries; local public health records	Meteorological event data: extent, timing & severity	Disruption/contamination of food & water supplies; disruption of transportation Population displacement The above parameters will have an indirect impact on health
Asthma and allergy	Changes in seasonal patterns of disease	Sentinel populations in various locations	Primary care data; emergency room attendance; hospital admissions; survey data	Daily/weekly temperature and rainfall; pollen counts	Air quality; influenza & other respiratory infections;
Food- & water-borne disease	Relevant infectious disease deaths & morbidity;	All regions	Death registries; national & sub-national surveillance notifications	Weekly/daily temperature; rainfall for water-borne disease, including cryptosporidium	Long term trends dominated by host-agent interactions (e.g. S enteritidis in poultry) whose effects are difficult to quantify. Indicators may be based on examination of seasonal patterns.
Vector-borne disease	Vector populations; disease notifications; temporal and geographical distributions	Margins of geographical distribution (for changes in altitude, latitude) and within endemic areas (for changes in temporal patterns)	Local field surveys; routine surveillance data (variable availability)	Weekly/daily temperature, humidity and rainfall	Land use Surface configurations of freshwater

the latter would be based on a short-term weather forecast (coupled with evidence from analysis of comparatively short periods of daily data defining the temperature-health relationship).

On the other hand (see Box 10.1) longitudinal data on the inter-annual variation in malaria, which may serve as an analogue of climate change impacts, also have the potential to predict high and low-risk years of malaria to inform preventative action. In this instance, monitoring to detect changes in the frequency of disease over time also may serve a more immediate and practical public health function. On the whole it may be said that early warning systems usually require shorter-term meteorological data together with systems for forecasting, forecast dissemination and initiation of public health action. Monitoring to detect evidence of early impacts of climate change requires much longer series of meteorology, health and other data, together with an analytical framework that allows impacts attributable to climate change to be quantified separately from those of other time varying factors.

Box 10.1 Vector-borne disease

One of the earliest health impacts of climate change may be altered distribution and incidence of vector-borne diseases, already a major cause of illness and death, particularly in tropical and sub-tropical countries (3). There is substantial evidence for the effects of climate variables on both vector and pathogen population biology in the laboratory and geographical and seasonal patterns of transmission intensity in the field (see chapter 6) (18).

This group of infectious diseases also is affected by factors such as human population density and movement; control programmes; forest clearance and land-use patterns; surface configurations of fresh water; and the population density of insectivorous predators. A recent review of vector-borne diseases concluded that the literature to date does not include unequivocal evidence of an impact of climate change, though the authors suggested that this should be seen as 'absence of evidence' rather than evidence of no effect. They refer to a lack of good quality long-term data on disease and vector distributions in areas where climate change has been observed and where a response is most likely to have occurred (19).

Monitoring for research and early detection would benefit from the creation of enhanced datasets in such areas with prospective data collection of climate, disease and vector populations. As a pre-requisite current vector monitoring systems must be developed to improve their reliability. Data should be collected on demographic, socioeconomic and environmental change, including land use. For the present, however, data collected for other purposes are used to investigate effects of climate change on vectors and vector-borne diseases.

An example of the sort of data that could be provided is shown in a study by Bouma et al. (20) in the Northwest Frontier Province (NWFP) of Pakistan. These researchers showed that interannual variations in the proportion of all slides tested which were positive for *Plasmodium falciparum*, and the proportion of all positive slides which were identified as *P. falciparum* (rather than the more cold-tolerant and less pathogenic *P. vivax*), correlated with variation in temperature, rainfall and humidity during the transmission season. They also showed, separately, that all of these parameters have shown an increasing trend in this region since the late 1870s. In the absence of any evidence that other determinants of malaria incidence (e.g. control activities) changed significantly over the study period, it is therefore suggested that the recent increase in the severity of autumnal outbreaks of *P. falciparum* could most probably be explained by the trend towards more favourable climatic conditions.

This study illustrates the advantages of (i) selecting an appropriate indicator (i.e. proportion of *P. falciparum* cases, rather than total number, which would be more sensitive to variation in surveillance

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FIGURE 10.1a Annual proportion of *Plasmodium falciparum* infections in the districts of NWFP, against the estimated average October–December temperature difference from a reference point (Peshawar).

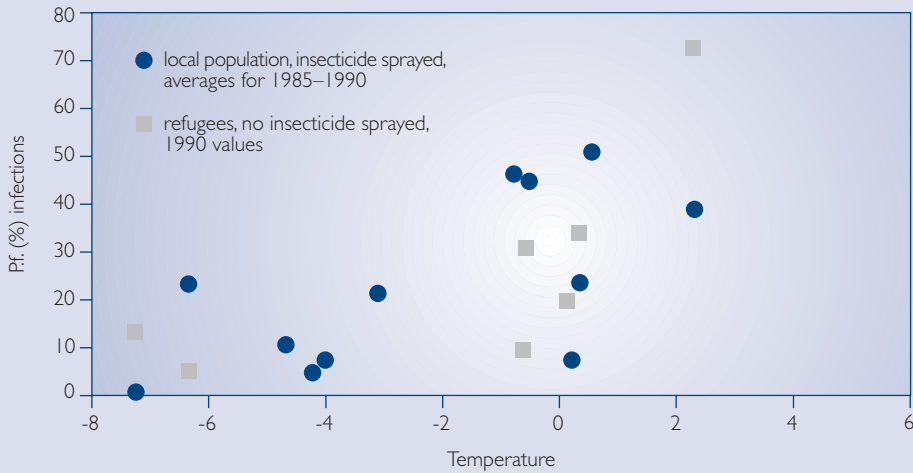
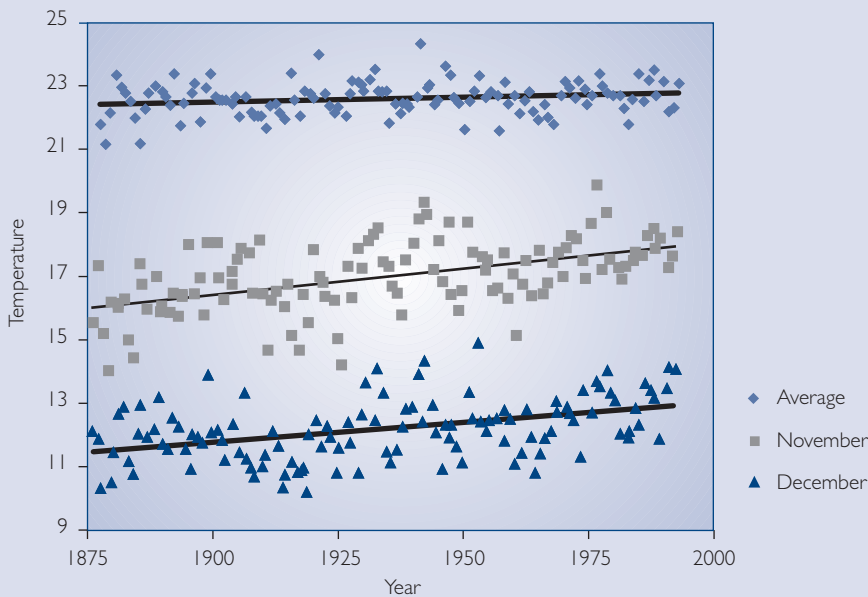


FIGURE 10.1b Mean temperatures in °C with a linear regression line since 1876, for Peshawar station. Source: reproduced from reference 20



effort), and (ii) defining climate/disease associations on the basis of short-term (i.e. inter-annual) variations, and using this relationship to interpret a long-term trend in climate and disease. It should be noted that even with this longitudinal series, it was not considered informative to correlate the gradual trend in the outcome against the trend in the climatic predictors, as it is very difficult to exclude completely the possibility that unmeasured factors also may contribute to the observed increase in *P. falciparum* frequency.

Aside from the difficulties of interpreting past changes, there is additional uncertainty in predicting how malaria and other vector-borne diseases will respond to the much larger climatic changes that

are expected over the coming century. The principal difficulty lies in limited understanding of the modifying influences of socioeconomic development, control programmes, and the ability of human immunity to absorb increases in transmission intensity, all of which may alter the apparently simple relationship between climate and disease (16, 22, 23, 24, 25). Understanding of these influences will be fundamental to proper assessment of both measured and projected changes in disease.

The IPCC (26) has concluded that climate change is likely to expand the geographical distribution of several vector-borne diseases to higher altitudes and extend the transmission seasons in some locations. There is less confidence that these diseases will expand into higher latitudes, or that decreases in transmission may occur through reductions in rainfall or increases in temperature above a threshold for vector survival. Thus, if monitoring is to find evidence of change, it will be important to ensure appropriate siting of monitoring stations that collect data relatively frequently. This might include frequent and long-term sampling along transects to monitor the full longitudinal and altitudinal range of specific vector species and their seasonal patterns.

Such studies may be the most cost-effective and robust methods of detecting directly the first health-relevant effects of this climate change impact. Unfortunately, current vector monitoring systems often are unable to provide reliable measurement of changes even in the limited number of parameters suggested. The design of surveillance programmes therefore may need to be adapted specifically to monitor sensitive aspects of climate change on vector-borne disease over the coming decades. These should be targeted at areas where the population at risk is large and adaptive capacity is low.

Box 10.2 Diarrhoeal illness

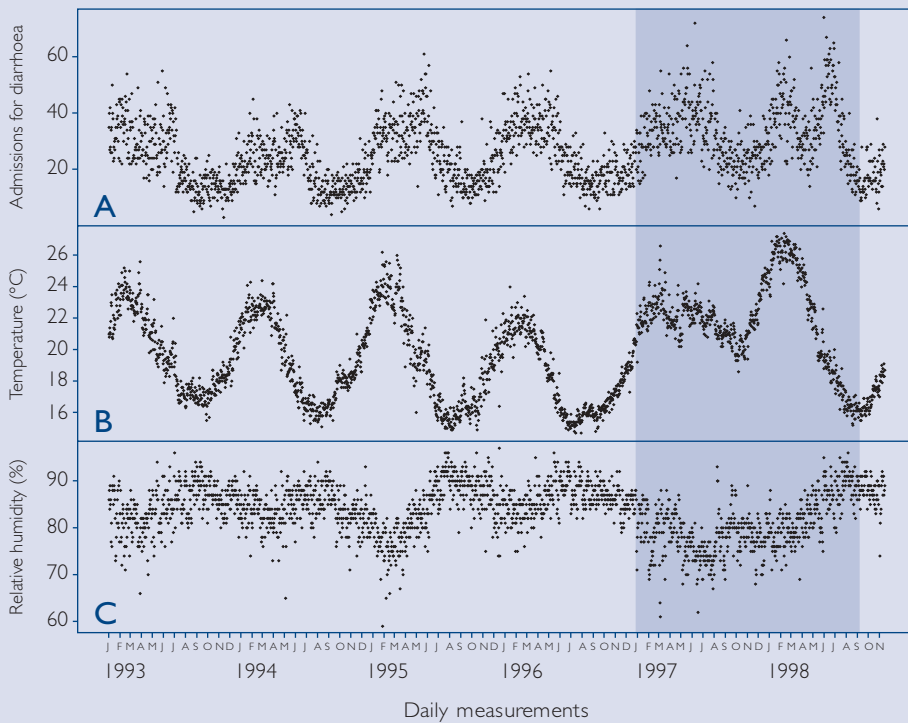
The relative importance of different pathogens and modes of transmission (e.g. via water, food, insects or human-human contact) varies between areas, and is influenced by levels of sanitation (27). As pathogens are known to vary in their response to climate (28, 29) this is likely to cause geographical variation in temperature relationships, depending on level of development. The quantitative relationship between climate and overall diarrhoea incidence (i.e. due to all pathogens) only rarely has been explicitly quantified.

A study by Checkley and colleagues provides evidence of the meteorological dependence of diarrhoeal illness and a possible analogue for longer-term climate change impacts (30). These workers reported a time series study of the relationship between temperature and relative humidity and daily hospital admissions at a single paediatric diarrhoeal disease clinic in Lima, Peru (Figure 10.2). Analyses based on 57331 admissions over a period of just under 6 years revealed a 4% increase in admissions for each 1 °C increase in temperature during the hotter months, and 12% increase per 1 °C increase in the cooler months. During the 1997–98 El Niño event, there was an additional increase in admissions expected on the basis of pre-El Niño temperature relationships. The time series methods used in this study independently controlled for seasonal variations, other climatic factors and long-term trend, so that the variation in diarrhoea rates can be attributed confidently to variations in temperature. The positive correlation is biologically plausible also, as a high proportion of diarrhoea cases in Peru, as in many tropical developing countries, are caused by bacteria, entamoeba and protozoa (27) which are favoured by high temperatures. Very long term data gathering is necessary to provide clear evidence of changes in disease burdens in relation to longer-term changes in climate. In the present example, ideally this would cover not just one but multiple ENSO cycles.

Daily temporal resolution may not be essential for such monitoring. Singh et al. (31) used similar time series methods to correlate monthly reported incidence of diarrhoea throughout Fiji, 1978–1998, against variations in temperature and rainfall. The reported incidence increased by approximately 3%

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FIGURE 10.2 Daily time series, 1 January 1993–15 November 1998, of admissions for diarrhoea, mean ambient temperature, and relative humidity in Lima, Peru. *Source: reproduced from reference 30*



(95% CI 1.2 to 5.0%) for each 1 °C increase in temperature, and also increased significantly with unusually high or low rainfall. These findings are supported by a positive geographical correlation between temperature and diarrhoea incidence in 18 Pacific Island countries. However, adjustment for non-meteorological seasonal factors can be a difficulty especially when the temporal resolution of the data is fairly crude.

Diarrhoeal illness is already of major importance for tropical developing countries because of its large contribution to the burden of ill-health (32). Although that burden is much more a consequence of poor sanitation and nutrition than of climatic conditions, the demonstration of climate sensitivity suggests that climate change is likely to contribute to an increase in morbidity unless counteracted by increasing standards of living and improved public health.

Conclusions

Monitoring the health impacts of climate change is an important task by which the public health community provides much needed scientific and policy evidence related to global warming. There are many methodological challenges in carrying out such monitoring but a body of analytical expertise has been acquired through the research efforts of recent years.

It must be recognized that the process of climate change is gradual and detectable only over decades. The impact of such climate change on health will

therefore similarly be slow to evolve. Over long periods changes occur also in non-climatic risk factors and in disease detection and recording. These factors often render it difficult to assess the contribution of climate change to trends in attributable burdens, and thus to detect early health effects of climate change. Monitoring studies therefore should be either designed to allow analysis of potential confounding and modifying influences or established in settings where such influences can be minimized.

For the health effects of thermal extremes, reliable temperature, mortality and morbidity data are available in many countries, and the methodological framework is sufficiently developed to allow assembly, analysis and interpretation of data from long time series in multiple locations. The principal focus of such research should be to characterize modification of the temperature-mortality/morbidity relationship by individual, social and environmental factors (poverty, housing quality, pre-existing morbidity etc).

Various databases already exist (e.g. EM-DAT) for extreme weather events and these could be a key resource for monitoring trends. To maximize their utility, attention is needed to ensure completeness and consistency of reporting of extreme weather events across a wide geographical area, and use of standard definitions of events and the application of comparable methods of attribution. Interpretation of temporal patterns will be aided by work to examine the extent to which human activity and environmental modification protects or increases vulnerability to extreme weather. Similarly, concerns over the consistency of notifications of food and water-borne diseases over the long term impose constraints on the interpretation of long-term monitoring data. Methodological work is needed to characterize variation in the temperature-disease relationships (including duration and amplitude of the seasonal rise) between populations in different geographical areas.

For most vector-borne illnesses (malaria, Leishmaniasis, tick-borne encephalitis, Lyme disease) current monitoring data can provide only very broad quantification of the relationship between climate and human disease. Assessment of the climate contribution to long-term trends requires data on factors such as land use, host abundance and intervention measures. Understanding of these relationships could be improved by obtaining high quality serial data on vector abundance at a modest number of sites within or at the margins of endemic areas. Data from sites along specified transects could provide useful indication of changing vector distributions. The latter could include sites to measure altitudinal shifts (e.g. malaria). Use of geographical comparisons based on remote sensing data may offer additional insights into disease trends.

With all forms of monitoring, interpretation of the evidence will be strengthened by procedures for standardization, training and quality assurance/quality control. Linkage of multiple data sets covering meteorology, health, intermediate stages (e.g. vectors, pathogens) and effect modifiers (land use, control programmes) also will be important. Most will be learned from long time series of health changes in populations with steep climate-disease functions—for example, on the edge of endemic areas for vector-borne diseases. Such monitoring will be made more effective through international collaboration and integration with existing surveillance networks.

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