Using climate to predict infectious disease epidemics

Report authors:
Katrin Kuhn
Diarmid Campbell-Lendrum
Andy Haines
Jonathan Cox

Project coordination:
Diarmid Campbell-Lendrum
Carlos Corvalán
Martha Anker

Communicable Diseases Surveillance and Response
Protection of the Human Environment
Roll Back Malaria

World Health Organization

Geneva
2005

WHO Library Cataloguing-in-Publication Data

Using climate to predict infectious disease epidemics / Communicable Diseases Surveillance and Response, Protection of the Human Environment, Roll Back Malaria.

1. Climate. 2. Disease outbreaks. 3. Forecasting. 4. Temperature. I. World Health Organization.

ISBN 92 4 159386 5 (NLM classification: WB 700)

Printed by the WHO Document Production Services, Geneva, Switzerland

CONTENTS

PREFACE

This document was written to provide guidance for the Department of Communicable Diseases Surveillance and Response (CSR), the Department of Protection of the Human Environment (PHE) and the Roll Back Malaria Department (RBM) on the potential of early warning systems (EWS) based on climate variations to enhance global surveillance and response to epidemic-prone diseases.

CSR has a unique mandate to lead international efforts to achieve global health security. Its strategy has three components: to improve preparedness of Member States by strengthening national surveillance and response systems; to contain known risks; and to respond to unexpected health events. PHE aims to achieve safe, sustainable and health-enhancing human environments, protected from biological, chemical and physical hazards and secure from the adverse effects of global and local environmental threats. Founded in 1998, RBM aims to halve the world's malaria burden by 2010. Its four main technical strategies are: prompt access to treatment, especially for young children; prevention and control of malaria in pregnant women; vector control; and prevention and containment of epidemics.

Knowledge of the interactions between climate and health dates back to the time of Aristotle (384–322 BC), but our understanding of this subject has recently progressed rapidly as technology has become more advanced. At the same time, our ability to forecast weather and climate (in terms of both accuracy and lead-times) has improved significantly in recent years. The increased accuracy of climate predictions, and improving understanding of interactions between weather and infectious disease, has motivated attempts to develop models to predict changes in the incidence of epidemic-prone infectious diseases. Such models are designed to provide early warning of impending epidemics which, if accurate, would be invaluable for epidemic preparedness and prevention.

This document evaluates the potential of climate-based disease early warning as a means of improving preparedness for, and response to, epidemics. On the basis of the history of the development of EWS to date, the authors develop a conceptual framework for constructing and evaluating climate-based EWS. They identify the climate-sensitive diseases of major public health importance and review the current state of the art in climate-based modelling of these diseases, as well as future requirements and recommendations.

This document lays the foundation for future development of EWS that capitalize on new knowledge about interactions between climate and infectious diseases, as well as improved capabilities for assessing vulnerability, monitoring the environment and climate and producing seasonal climate forecasts. It reviews the current state of development of EWS for a number of key infectious diseases. The last few years have seen rapid progress in research; many new studies have demonstrated significant associations between climate variability and infectious disease transmission, and have specifically highlighted the potential for developing climate-based EWS. To date, however, only limited experience of full operational application has been gained. For some diseases, such as malaria and Rift Valley fever (RVF), early warnings based on climatic conditions are beginning to be used in selected locations to alert ministries of health to the potential for increased risk of outbreaks and to improve epidemic preparedness, but coverage is patchy.

The document highlights the most important challenges that need to be overcome before the full potential of EWS can be realized. These include:

►developing and strengthening disease surveillance systems to produce the high-quality, long-term data needed for the development and testing of models;

►identifying and testing a range of climatic, environmental and socioeconomic indicators as potential co-variables in predictive models of infectious disease;

►developing standard terminology and criteria for evaluating the accuracy of such models;

►ensuring that modelling efforts are carried out in collaboration with the disease control community in order to make them directly relevant to specific response decisions and to the particular needs and constraints of policy-makers; and

►developing suitable frameworks for the rigorous epidemiological, institutional and economic evaluation of EWS that are implemented.

This joint CSR, PHE and RBM publication was prepared with the understanding that climate-based EWS, when fully developed, do have the potential to provide increased lead-times in which to implement epidemic prevention and/or control activities. Therefore their development should be encouraged, and both the positive and negative experiences of using such systems should be recorded and disseminated. It is only with experience that such systems will become useful operational tools.

Mike Ryan

Director

Department of Communicable Disease Surveillance and Response (CSR)

World Health Organization

Maria Neira

Director

Department of Protection of the Human Environment (PHE)

World Health Organization

Fatoumata Nafo-Traoré

Director

Roll Back Malaria Department (RBM)

World Health Organization

LIST OF ABBREVIATIONS

ADDS	Africa Data Dissemination Service
ARIMA	Autoregressive-moving average
AVHRR	See NOAA AVHRR
CCD	Cold cloud duration
CDC	Centers for Disease Control and Prevention, Atlanta, GA, USA
CDNA	Communicable Disease Network Australia
CIMSiM	Container Inhabiting Mosquito Simulation Model
CL	Cutaneous leishmaniasis
CPC	Climate Prediction Center
CSR	Department of Communicable Diseases Surveillance and Response
DALY	Disability-adjusted life years
DENSiM	Dengue simulation model
DEWS	Dengue early warning system(s)
DHF	Dengue haemorrhagic fever
EIR	Entomological inoculation rate
ENSO	El Niño Southern Oscillation
EUMETSAT	European Organisation for the Exploitation of Meteorological Satellites
EWS	Early warning systems
FAO	Food and Agriculture Organization of the United Nations
FEWS	Famine early warning systems
GIS	Geographical information systems
HMIS	Health management information system
IDSR	Integrated disease surveillance and response
JE	Japanese encephalitis
LST	Land surface temperature
MARA	Mapping Malaria Risk in Africa Project
MODIS	Moderate Resolution Imaging Spectroradiometer
MVE	Murray Valley encephalitis
NOAA AVHRR	National Oceanic and Atmospheric Administration Advanced Very High Resolution Radiometer
NDVI	Normalized Difference Vegetation Index
PHE	Department of Protection of the Human Environment
RBM	Roll Back Malaria
RFE	Rainfall Estimate (derived from remote sensing data)
RRV	Ross River virus
RVF	Rift Valley fever
SADC	Southern African Development Community
SD	Standard deviation
SLE	St Louis encephalitis
SSH	Sea surface height
SST	Sea surface temperature
STD	Sexually transmitted disease
TB	Tuberculosis
VL	Visceral leishmaniasis
WNV	West Nile virus

EXECUTIVE SUMMARY

It is commonly accepted that climate plays a role in the transmission of many infectious diseases, some of which are among the most important causes of mortality and morbidity in developing countries. Often these diseases occur as epidemics which may be triggered by variations in climatic conditions that favour higher transmission rates. With increasing demand for operational disease early warning systems (EWS), recent advances in the availability of climate and environmental data and increased use of geographical information systems (GIS) and remote sensing make EWS incorporating information on climate increasingly feasible from a technical point of view.

This report presents a framework for developing disease EWS. It then reviews the degree to which individual infectious diseases are sensitive to climate variability in order to identify those diseases for which climate-informed predictions offer the greatest potential for disease control. The report highlights that many of the most important infectious diseases, and particularly those transmitted by insects, are highly sensitive to climate variations. Subsequent sections review the current state of development of EWS for specific diseases and underline some of the most important requirements for converting them into operational decision-support systems.

Considerable research is currently being conducted to elucidate linkages between climate and epidemics. Of the 14 diseases meeting the defined criteria for potential for climate-informed EWS, few (African trypanosomiasis, leishmaniasis and yellow fever) are not associated with some sort of EWS research or development activity. For West Nile virus, an operational and effective warning system has been developed which relies solely on detection of viral activity, and it remains unclear whether the addition of climatic predictors would improve the predictive accuracy or lead-time. For the remaining diseases (cholera, malaria, meningitis, dengue, Japanese encephalitis, St Louis encephalitis, Rift Valley Fever, Murray Valley encephalitis, Ross River virus and influenza), research projects have demonstrated a temporal link between climatic factors and variations in disease rates. In some of these cases the power of climatic predictors to predict epidemics has been tested. In many of the early studies these tests were preliminary, based either on a very limited dataset or else they provided little description of the methods used. Most of the studies published in the last few years, however, have been both considerably more comprehensive in their consideration of climate and non-climatic effects, and more rigorous in terms of testing predictive accuracy.

The published literature to date, however, includes no full descriptions of climate-based EWS being used to influence disease control decisions.

This report suggests a number of likely explanations for this:

► affordable and accessible data and analytical tools have only recently become widespread, so that this field is at a relatively early stage of development and new studies are now being published at a rapid rate;

► as yet, there is no common consensus on good practice in building predictive models, or on assessing their accuracy and lead-times: as a consequence it is often difficult to judge the utility of existing models;

► most research projects have had relatively limited resources and therefore have not been tested in locations outside the original study area;

► many studies in this area focus solely on climatic factors and do not explicitly test other hypotheses that might explain variations in disease rates over time; and

► many studies are undertaken as “pure research”, therefore, neither the extent to which they address specific control decisions nor their potential utility for planning public health interventions is clear.

This report concludes that a number of steps could be taken to begin to address these issues. These include:

►Maintaining and strengthening disease surveillance systems for monitoring the incidence of epidemic diseases. High-quality data on the incidence of infection or disease, covering long periods, are essential for generating and refining models relating climate to infectious disease; lack of disease data is a more common limiting factor than lack of climate data. In some cases existing approaches to surveillance may generate disease data appropriate for use within an early warning system – in others it may be necessary to either modify existing systems or to build new ones. The introduction of computer hardware and software at appropriate levels within the surveillance system can facilitate timely collation and analysis of incoming disease data. Widespread introduction of GIS tools, for example, the WHO Healthmapper software, would enable surveillance data to be stored and accessed in a disaggregated form, allowing the detailed analysis of spatial and temporal disease distributions. Consideration should be given to integrating this type of monitoring into single systems (e.g. by combining disease and famine EWS) to facilitate data access and maximize comparability.

►Clarifying definitions of terminology and methods for assessing predictive accuracy. For instance, while the threshold value used to define an "epidemic" (i.e. number of cases in a specific population over a specified time) may vary depending on the disease and the local context, it should be clearly defined before the modelling process begins. The accuracy of the system should also be measured using standard epidemiological tools that provide an objective overall measure of model "skill", and are also directly relevant to control decisions (e.g. sensitivity, specificity, positive and negative predictive value). The accuracy of models for predicting incidences or rates could be measured as the root mean square error, or as correlation coefficients between observed and predicted case numbers. Assessments of predictive accuracy should always be made against independent data (i.e. using data not included in the original model-building process).

►Testing for non-climatic influences (e.g. population immunity, migration rates and drug resistance) on disease fluctuations is dependent on the availability of appropriate data. Distinguishing underlying trends from interannual variability should help to avoid disease variations being attributed incorrectly to climate. More importantly, in practical terms, incorporating the data available for non-climatic variables should lead to greater accuracy in predictive models.

►Early consideration of operational mechanisms. Including health policy-makers in all stages of system design (e.g. involving local control personnel in defining epidemic thresholds and in determining the most appropriate warning lead-time) should increase the likelihood that the system will be implemented effectively, and thereby increase its chances of having a positive impact on disease control. Discussions should relate to specific control decisions and consider local constraints (particularly on resources) on the implementation of the EWS. Discussions should also identify opportunities for implementation over wider areas (i.e. regions comprising several countries) with similar climate and disease conditions. Experience with famine EWS in the 1990s suggested that the effectiveness of predictions depended less on their accuracy than on political and operational factors.

►Making final recommendations on implementation of EWS on the basis of rigorous assessments