

# ATLAS OF HEALTH AND CLIMATE



World Health  
Organization



World  
Meteorological  
Organization

Weather · Climate · Water



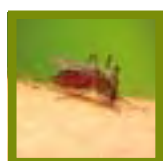
ATLAS OF  
HEALTH AND CLIMATE

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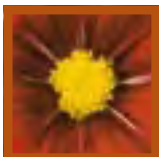
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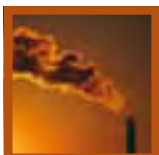
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# PREFACE

## ATLAS OF HEALTH AND CLIMATE: REALIZING THE POTENTIAL TO IMPROVE HEALTH OUTCOMES THROUGH THE USE OF CLIMATE SERVICES

Human health is profoundly affected by weather and climate. Extreme weather events kill tens of thousands of people every year and undermine the physical and psychological health of millions. Droughts directly affect nutrition and the incidence of diseases associated with malnutrition. Floods and cyclones can trigger outbreaks of infectious diseases and damage hospitals and other health infrastructure, overwhelming health services just when they are needed most.

Climate variability also has important consequences for health. It influences diseases such as diarrhoea and malaria, which kill millions annually and cause illness and suffering for hundreds of millions more. Long-term climate change threatens to exacerbate today's problems while undermining tomorrow's health systems, infrastructure, social protection systems, and supplies of food, water, and other ecosystem products and services that are vital for human health.

While the impact of climate change on health is felt globally, different countries experience these impacts to different degrees. Evidence shows that the most severe adverse effects tend to strike the poorest and most vulnerable populations. In addition, the adverse health impacts of climate are worsened by rapid and unplanned urbanization, the contamination of air and water, and other consequences of environmentally unsustainable development.

Concern about how a changing climate will affect health is reflected in the UN Framework Convention on Climate Change and the Global Framework for Climate Services. Countries have also recognized the need to protect health from climate-related risks through collaborative action on managing disaster risk, ensuring access to safe and adequate water and food, and strengthening preparedness, surveillance and response capacities needed for managing climate-sensitive diseases.

In order to achieve these goals, decision-makers at all levels need access to the most relevant and reliable information available on the diverse connections between climate and health. The World Health Organization and the World Meteorological Organization are working together to meet this need through a practical and innovative approach that uses climate services to strengthen the climate resilience of health systems and support proactive decision-making. These climate services will contribute to protecting public health and achieving better health outcomes.

The Atlas of Health and Climate is a product of this unique collaboration between the meteorological and public health communities. It provides sound scientific information on the connections between weather and climate and major health challenges. These range from diseases of poverty to emergencies arising from extreme weather events and disease outbreaks. They also include

environmental degradation, the increasing prevalence of noncommunicable diseases and the universal trend of demographic ageing.

The Atlas conveys three key messages. First, climate affects the geographical and temporal distribution of large burdens of disease and poses important threats to health security, on time scales from hours to centuries. Second, the relationship between health and climate is influenced by many other types of vulnerability, including the physiology and behaviour of individuals, the environmental and socio-economic conditions of populations, and the coverage and effectiveness of health programmes. Third,

climate information is now being used to protect health through risk reduction, preparedness and response over various spatial and temporal scales and in both affluent and developing countries.

It is our hope that the Atlas of Health and Climate will serve as a visual “call to action” by illustrating not only the scale of challenges already confronting us – and certain to grow more acute – but also by demonstrating how we can work together to apply science and evidence to lessen the adverse impacts of weather and climate and to build more climate-resilient health systems and communities.



**Margaret CHAN**  
Director General  
World Health Organization  
Geneva,  
October 2012



**Michel JARRAUD**  
Secretary-General  
World Meteorological Organization  
Geneva,  
October 2012



**A patient suffering from dengue fever lies on a bed covered by a mosquito net at San Felipe hospital in Tegucigalpa, Honduras**



# SECTION 1

# INFECTIONS

**Infectious diseases take a heavy toll on populations around the world. Some of the most virulent infections are also highly sensitive to climate conditions. For example, temperature, precipitation and humidity have a strong influence on the reproduction, survival and biting rates of the mosquitoes that transmit malaria and dengue fever, and temperature affects the life-cycles of the infectious agents themselves. The same meteorological factors also influence the transmission of water and food-borne diseases such as cholera, and other forms of diarrhoeal disease. Hot, dry conditions favour meningococcal meningitis – a major cause of disease across much of Africa. All of these diseases are major health problems. Diarrhoea kills over two million people annually, and malaria almost one million. Meningitis kills thousands, blights lives and hampers economic development in the poorest countries. Some 50 million people around the world suffer from dengue fever each year. The public health community has made important progress against all of these diseases in recent decades, but they will continue to cause death and suffering for the foreseeable future.**

One of the important challenges for control of all of these diseases is to understand and, where possible, predict their distribution in time and space, to allow control programmes to target interventions and to anticipate and prevent epidemics. All of these diseases are strongly influenced by climate and weather – but these effects are mediated by other determinants. For diarrhoea, meningitis and malaria, these are closely associated with poverty and weaknesses in health programmes, which leaves populations without the protection of reliable water and sanitation services, protective vaccines and life-saving drugs. In the case of dengue, unplanned urbanization, the proliferation of mosquito breeding sites in household

waste, and population movement, are contributing to a re-emergence of the disease. The climate sensitivity of these diseases means that there is an important role for meteorological information. The interaction with other determinants means that climate services will only reach their full potential through a true collaboration between the meteorological and health communities.

By working with disease control programmes, meteorological services can help to identify where their information can be applied most effectively. Early experience shows that providing the relatively simple meteorological monitoring data that are collected by National Meteorological Services can often bring the greatest value to health programmes. These include short-term observations of local precipitation to provide an alert for epidemics of cholera or malaria, or gridded maps of routinely collected temperature and humidity data, to generate maps of suitability for meningitis or malaria transmission, in order to improve targeting and efficiency of disease surveillance and control. Disease control programmes, meteorological services and researchers, are also beginning to work together to explore the potential of more sophisticated climate products, such as seasonal forecasts, to provide more advance warning of risks of infectious disease.

While the evidence base in favour of collaboration between health and climate services continues to expand, these techniques are not currently used to their full potential. This requires building the capacity of the meteorological services to collect information and to process it into useful products, and the capacity of health services to interpret and apply these products to health challenges – and thereby increase their own demand for climate services.

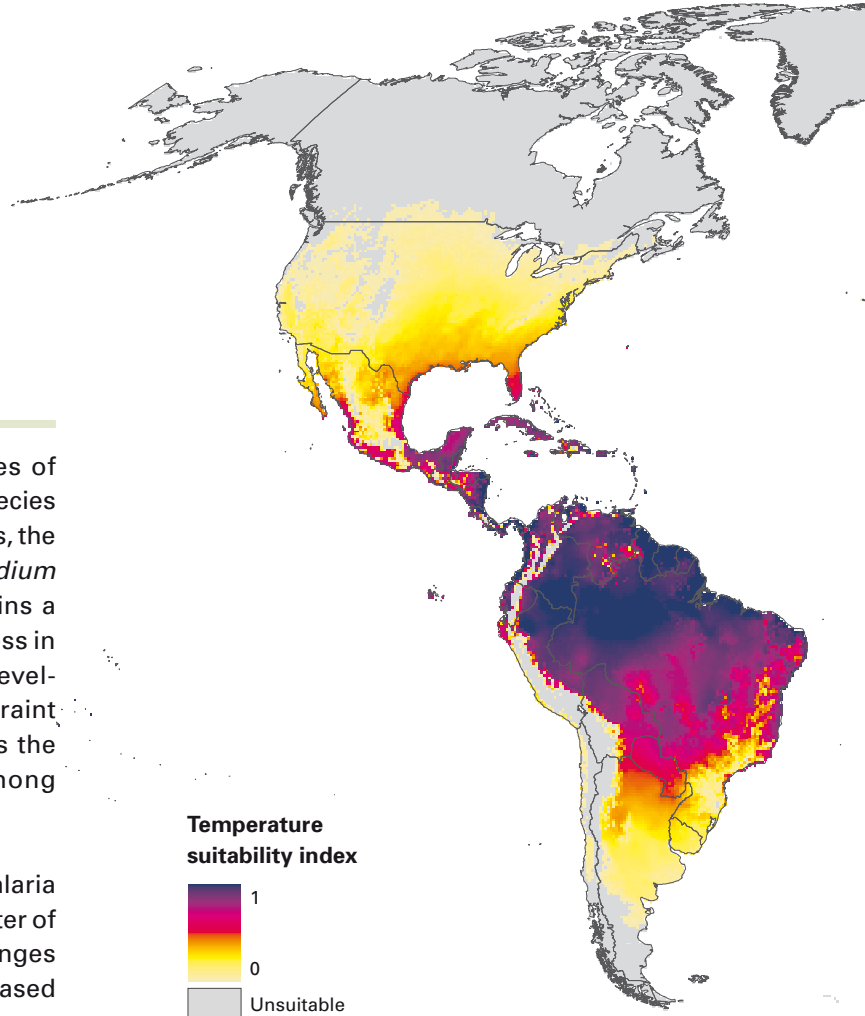


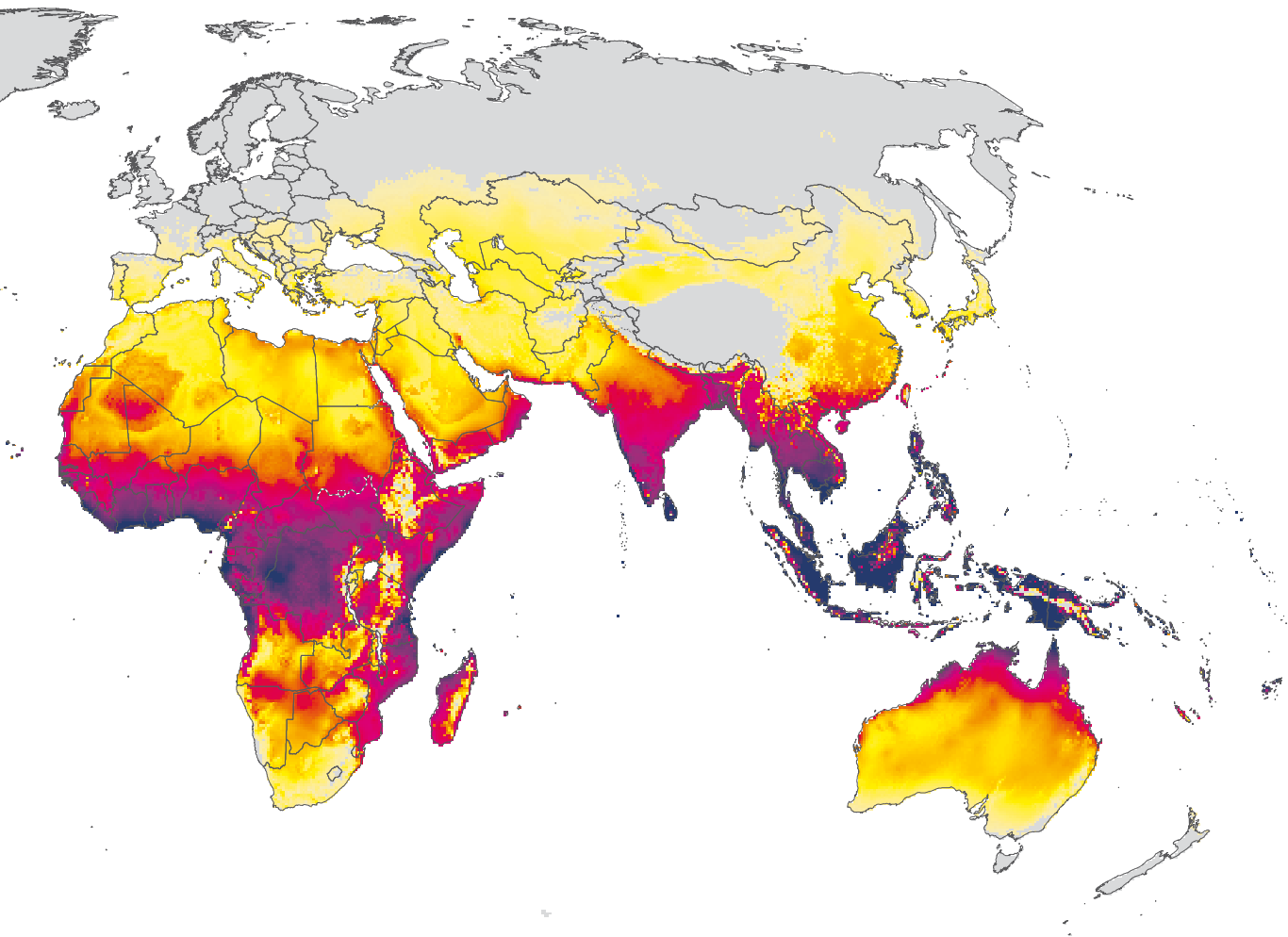
# MALARIA

## THE BURDEN OF MALARIA

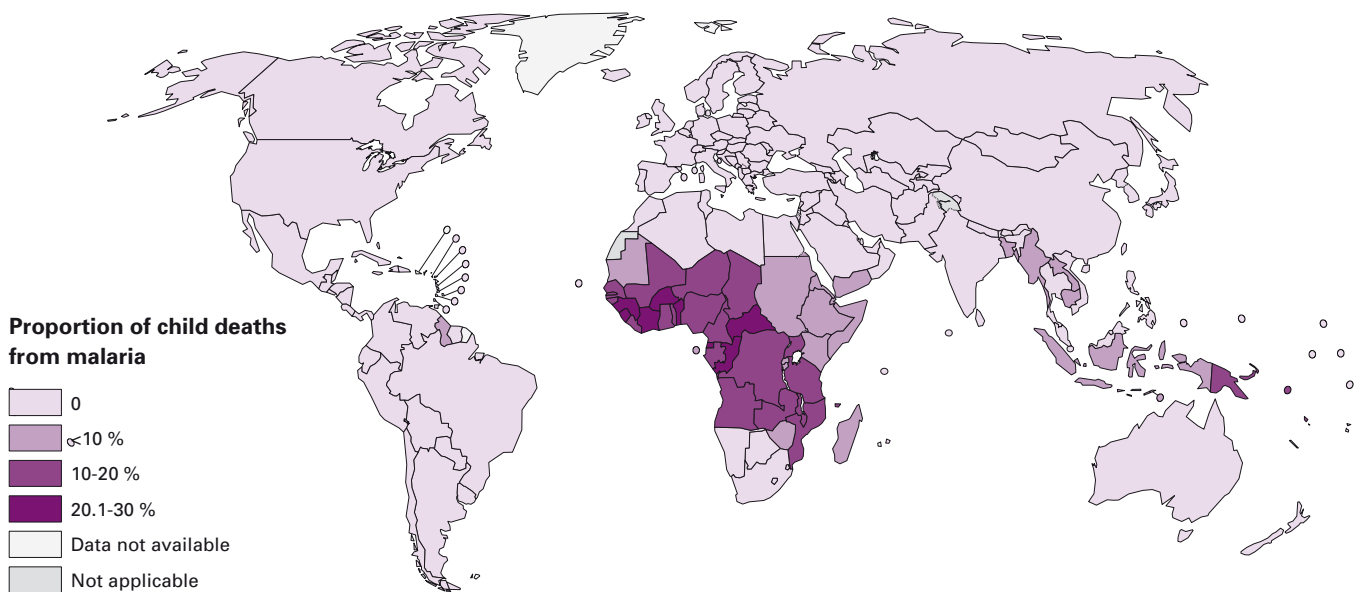
Malaria is a parasitic disease spread by the bites of infected *Anopheles* mosquitoes. There are many species of malaria parasites but, of the five affecting humans, the greatest threat to health comes from the *Plasmodium vivax* and *Plasmodium falciparum*. Malaria remains a disease of global importance despite much progress in recent years. It is a persistent threat to health in developing nations where it represents a major constraint to economic development measures and reduces the likelihood of living a healthy life, especially among women, children and the rural poor.

Over the last century, the surface area on which malaria remains a risk has been reduced from half to a quarter of the Earth's landmass, but due to demographic changes the number of people exposed to malaria has increased substantially over the same period. Estimates of cases and deaths differ greatly: the number of cases stands between 200 million and 500 million while the death estimate is around 1 million per year. According to the World Malaria Report in 2011, malaria remains prevalent in 106 countries of the tropical and semi-tropical world. Thirty-five countries in central Africa bear the highest burden of cases, more than 80 per cent, and deaths, more than 90 per cent. This is due to a number of factors: most deadly parasite species, most efficient mosquito vectors and poor rural infrastructure.<sup>1</sup>





*Temperature suitability for transmission of Plasmodium falciparum<sup>2</sup>*



*Estimates of the percentage of mortality in children aged under 5 years that was related to malaria cases in 2010<sup>3</sup>*

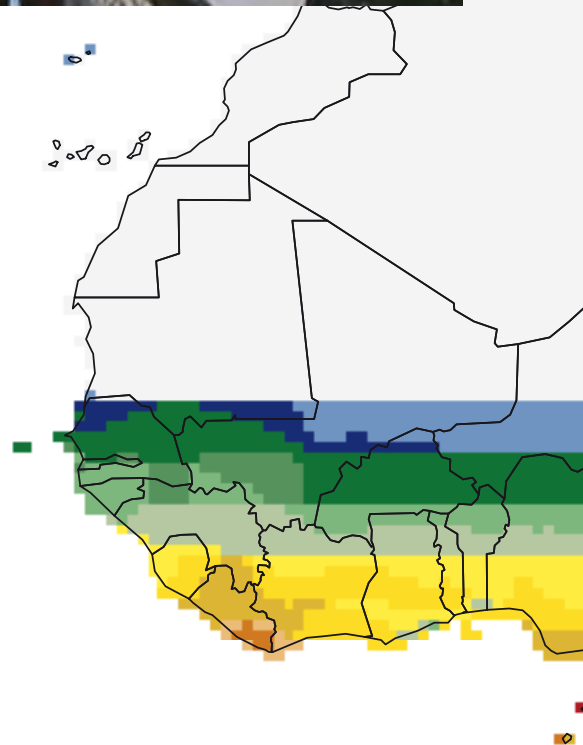
## REDUCING THE INCIDENCE OF MALARIA

Where malarial control is inadequate, the climate can provide valuable information about the potential distribution of the disease in both time and space. Climate variables – rainfall, humidity and temperature – are fundamental to the propagation of the mosquito vector and to parasite dynamics. Rainfall produces mosquito-breeding sites, humidity increases mosquito survival and temperature affects parasite development rates. Mapping, forecasting and monitoring these variables, and unusual conditions that may trigger epidemics such as cyclones or the breaking of a drought in a region, enable health services to better understand the onset, intensity and length of the transmission season.

WHO, WMO and the Famine Early Warning Systems<sup>4</sup> have routinely produced such information products for continental Africa for a number of years. More recent collaboration with National Meteorological Services have built capacity in seasonal forecasting<sup>5</sup> and enabled a much denser network of ground station data to be combined with the extensive coverage of satellite data.<sup>6</sup> The resulting mapping, forecasting and monitoring products are made available to health services through National Meteorological and Hydrological Services websites and joint training workshops encourage mutual learning and negotiation around information needs. Regional Outlook Fora<sup>7</sup> and National Climate and Health Working Groups<sup>8</sup> have been established in a number of countries to elicit priorities for research, policy, practice and training.



WHO / STEPHENIE HOLLYMAN



## CASE STUDY: MALARIA EARLY WARNING IN SOUTHERN AFRICA

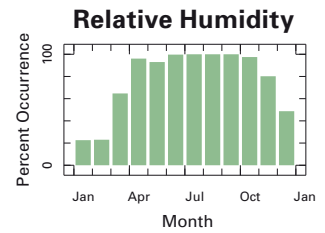
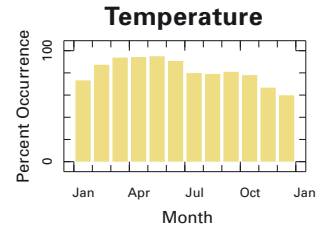
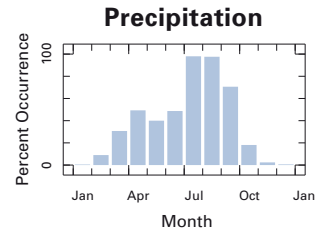
The WHO's Global Malaria Programme in the southern African countries of Angola, Botswana, Namibia, Madagascar, Mozambique, South Africa, Swaziland, Zambia and Zimbabwe offers a good example of the practical use of weather and climate information in combating disease. The programme uses the seasonal climate forecasts issued by the Southern African Regional Climate Outlook Forum to predict malaria epidemics several months ahead of time, allowing effective control, and other preventive measures, to be put in place. The climate forecasts have been central to the development of the Malaria Early

Warning System. Through programmes co-sponsored by WMO, several projects based on the "Learning through Doing" concept have been launched to help National Meteorological and Hydrological Services (NMHSs) collaborate and build partnerships with their health communities. Thus, in Botswana and Madagascar, the health ministries now have longer lead times on the likely occurrence of malaria, plague and Rift Valley Fever epidemics, based on climate predictions provided by the NMHSs. Similar projects have been launched in Ethiopia, Burkina Faso, Chile, Panama and Peru.

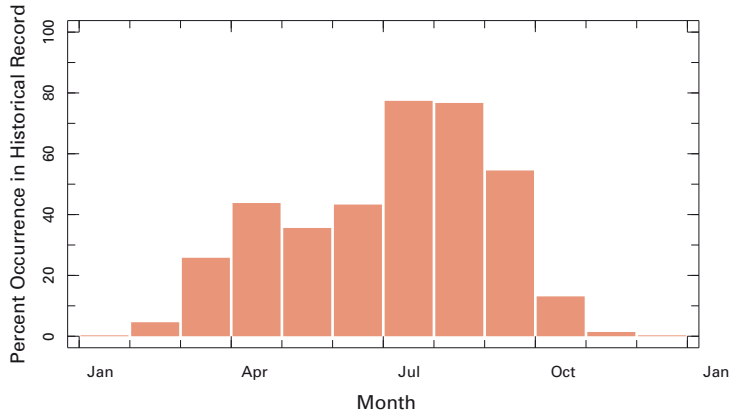


Climatology for  
 ~11 km x 11 km grid box  
 centred on 36.15E, 6.35N  
 (located within Ethiopia).

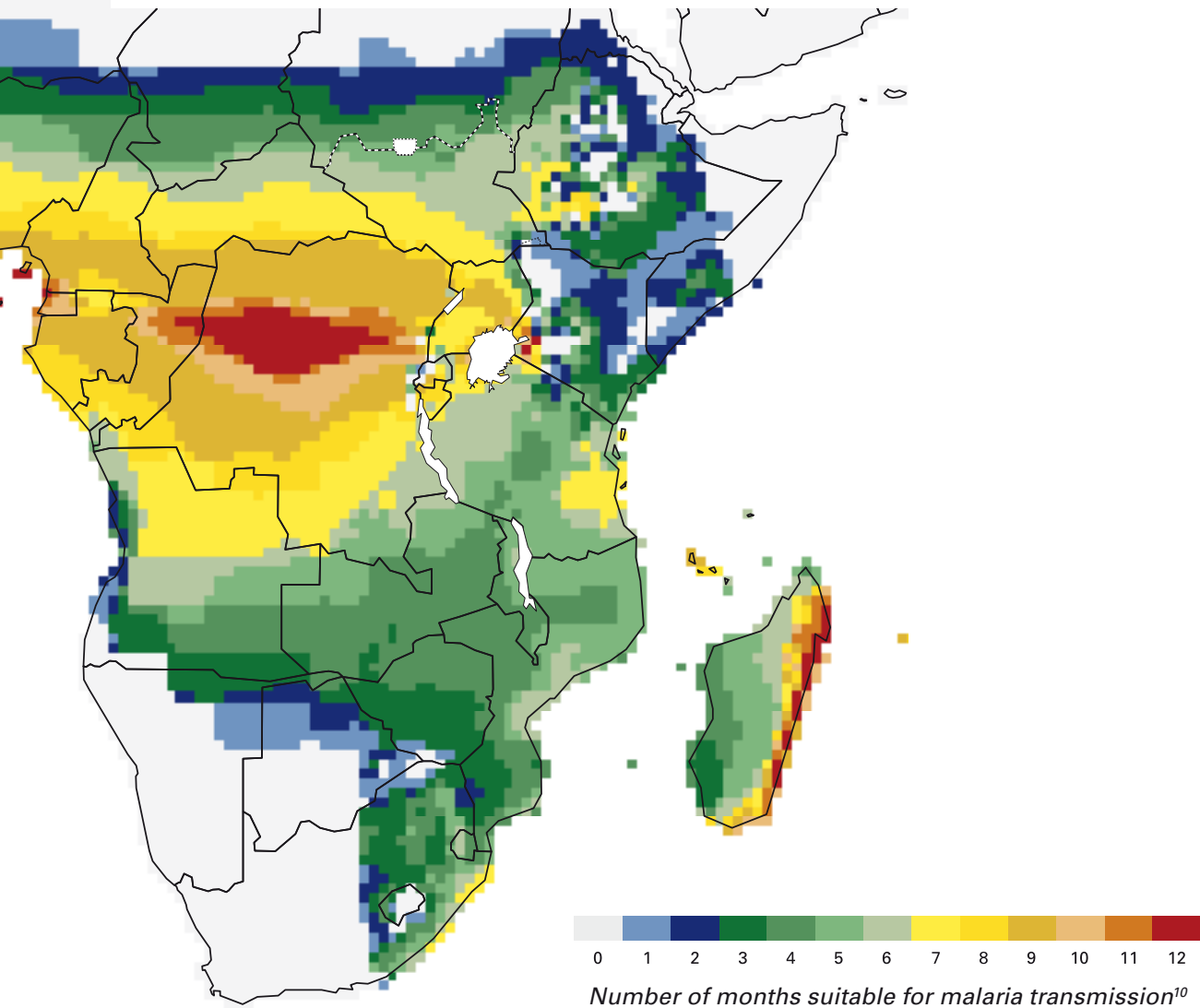
for parasite:



### Percent Occurrence of Climate Conditions Suitable for Malaria Transmission



*National Meteorological Services can supply more accurate local assessments<sup>9</sup>*



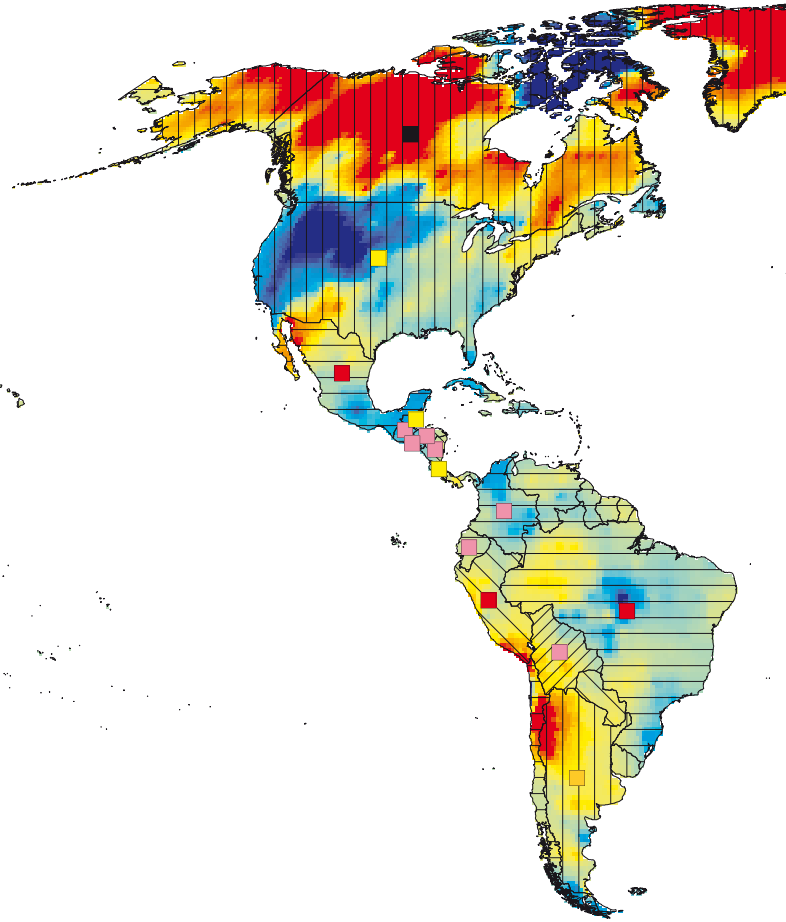


# DIARRHOEA

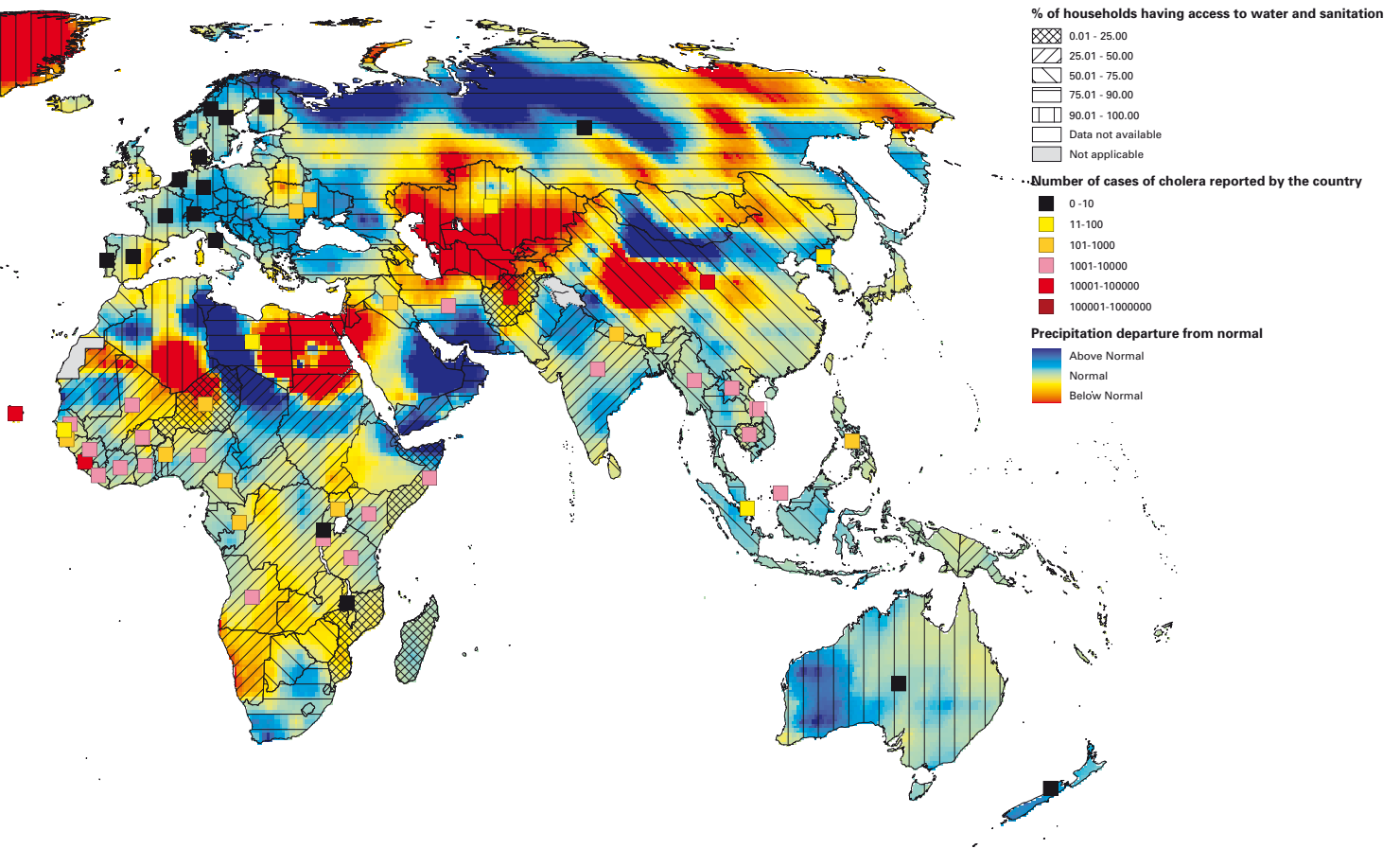
Around two million people die every year due to diarrhoeal disease – 80 per cent are children under 5. Cholera is one of the most severe forms of waterborne diarrhoeal disease. There are sporadic incidences of the disease in the developed world, but it is a major public health concern for developing countries, where outbreaks occur seasonally and are associated with poverty and use of poor sanitation and unsafe water. Extreme weather events, such as hurricanes, typhoons, or earthquakes, cause a disruption in water systems resulting in the mixing of drinking and waste waters, which increase the risk of contracting cholera.

In 1995 a combined average of 65 per cent of the world's population had access to improved drinking water sources and sanitation facilities.<sup>1</sup> That left two billion people relying on drinking water that could potentially contain pathogens, including *Vibrio cholerae*, the causative organism of cholera. There is a definite correlation between disease outbreaks and inadequate access to safe water and lack of proper sanitation. Therefore people in the least developed regions of the world who only have access to unsafe water and poor sanitation also have the greatest burden of related diseases, like cholera or other diarrhoeal diseases.

Extreme weather-related events such as increased precipitation and flooding further contaminate water sources, contributing to an oral-faecal contamination pathway that is difficult to manage and which increases the cases of disease and fatalities. When such events take place, *Vibrio cholerae* persists in aquatic ecosystems, causing the rapid spread of seasonal epidemics in many countries.

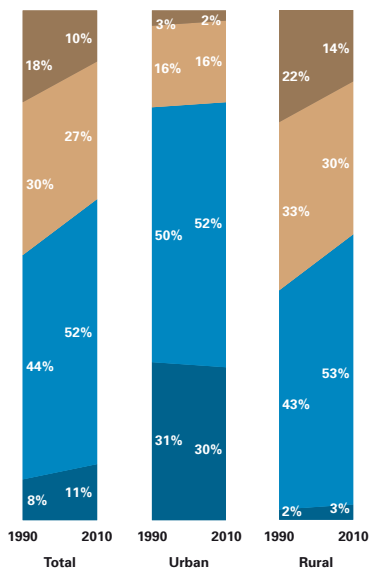


WHO / DERMOTTATLOW

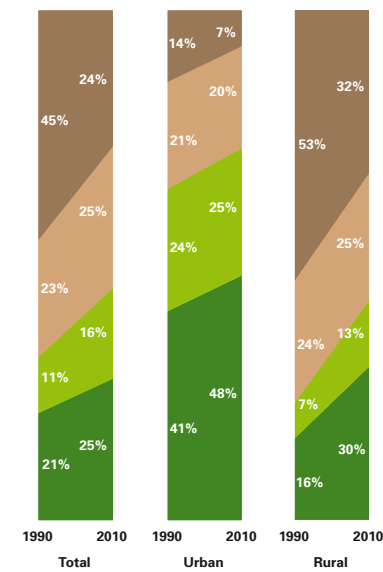


*This map demonstrates that in 1995 there was a widespread correlation between cholera prevalence and poor access to water and sanitation as well as precipitation anomalies<sup>2</sup>*

**Ten percent of the population in least developed countries rely on surface water**



**Open defecation is practised by nearly a quarter of the population in least developed countries**



*Left: Trends in the use of piped water on premises, improved drinking water sources, unimproved sources and surface water in least developed countries by urban and rural areas<sup>1</sup>*

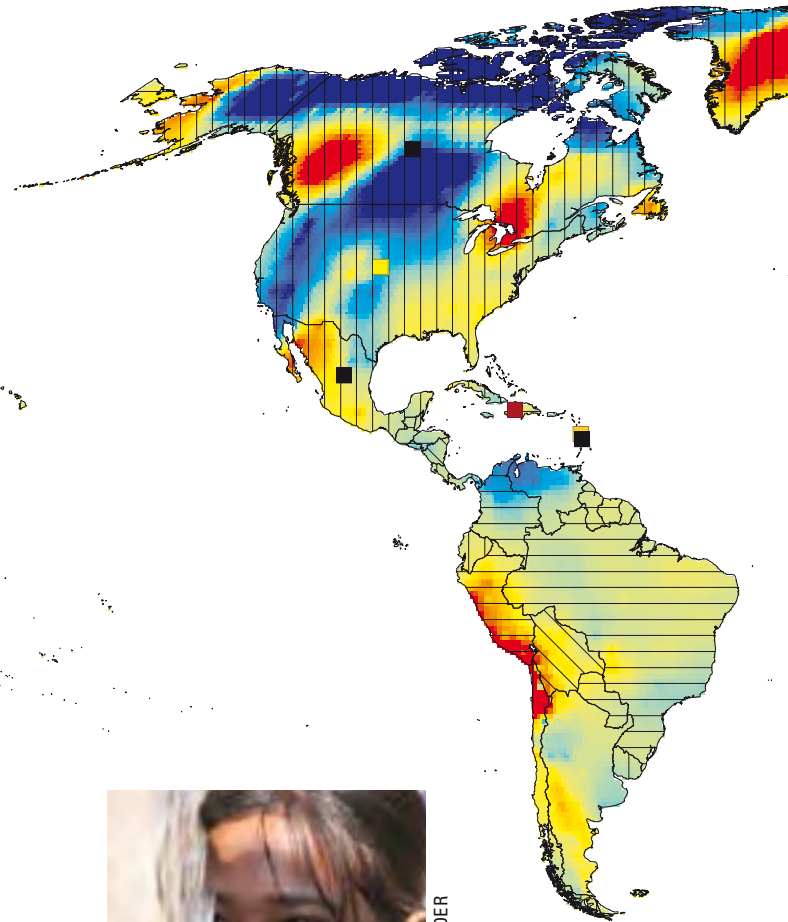
*Right: Trends in the use of improved, unimproved and shared sanitation facilities and open defecation in least developed countries by urban and rural areas<sup>1</sup>*

## THE CLIMATE DATA LAYER

In 2010, the world met the Millennium Development Goals' target on water, as measured by its proxy indicator: "(by 2015) halving the proportion of (1990) population without sustainable access to an improved source of drinking water" (see the figure below). Despite such progress nearly eight hundred million people still lacked access to water from such sources, and public health research<sup>3</sup> has shown that billions are still using unsafe water. At the same time we are still badly off track to meet the Millennium Development Goal on sanitation. Access to water and sanitation improved from 1995 to 2010, but not substantially in the parts of the world where cholera is recurring. Cases of cholera continue to rise in parts of poverty-stricken Africa and Asia where access to water and sanitation are already poor and progress towards improving such services is slow or stagnant.

Extreme weather-related events have made disease transmission pathways worse. Thus, climate services have an important role to play if effective prevention is to be put in place. By adding a climate layer such as precipitation anomalies, including flooding, to maps containing other datasets such as disease burden, one can pinpoint hotspots where further analyses would be needed and data gathering should be improved and enhanced. Such maps can help decision-makers to visualize the water, sanitation and the environmental problems in their region and to put measures in place to avoid outbreaks and thus diminish the spread of such diseases.

This complex topic is part of an ongoing research. Nevertheless, these high level maps can contribute to informing policymakers on measures to reduce the disease burden of cholera.



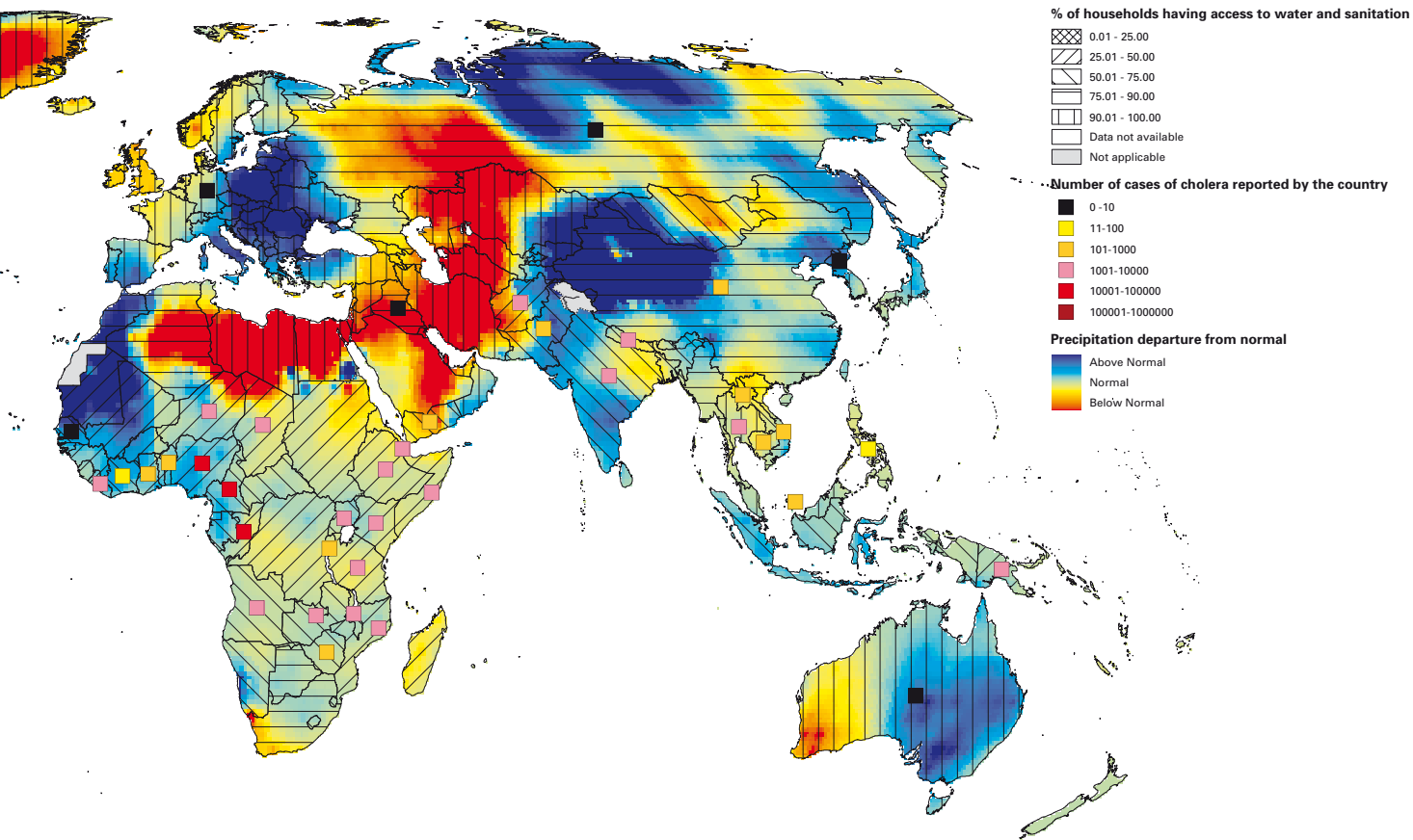
WATERAID / JUTHIKA HOWLADER

## CASE STUDY: GLOBAL INFORMATION MANAGEMENT SYSTEM ON HEALTH AND ENVIRONMENT

The goal of the WHO project Global Information Management System on Health and Environment (GIMS)<sup>4</sup> is to save lives by preventing communicable water borne diseases through providing an evidence base for ensuring good environmental health modalities like access to safe water and basic sanitation in a sustainable manner under changing global environmental conditions. Prevention of environment-related disease requires a comprehensive information system for

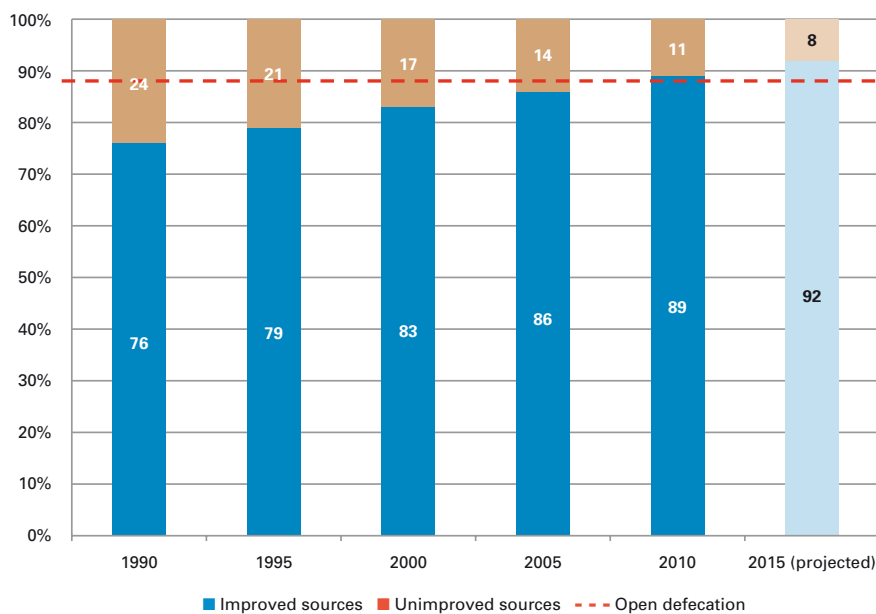
adequate planning and targeted resource use for assisting the most vulnerable populations in hotspot analyses. GIMS plans to produce these maps on a real time basis and with its in-built predictive tool also aims to contribute to an early warning system for diarrhoeal diseases. In its initial phase, which will last until 2015, the project will focus on cholera and be tested in selected pilot countries where cholera is present.





*Information on precipitation anomalies, overlaid with 2010 reported cholera cases from the countries where access to water and sanitation remains poor, indicate priority areas for further research and health intervention<sup>2</sup>*

**Trends in global drinking water coverage, 1990–2010, projected to 2015**



*The MDG proxy indicator for the drinking water target, which is showing steady improvement, has been met<sup>1</sup>*



# MENINGITIS

## MENINGITIS – THE HEALTH CHALLENGE

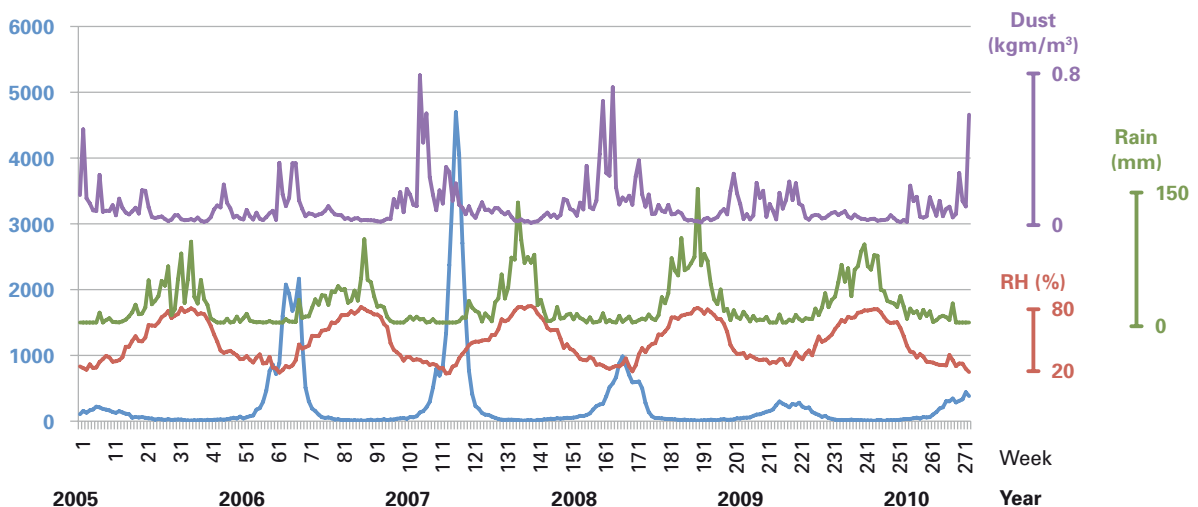
Meningococcal meningitis is a severe infectious disease of the meninges, a thin layer around the brain and spinal cord. Several micro-organisms can cause meningitis. The bacterium with the greatest epidemic potential is *Neisseria meningitidis*.

Although meningitis is a ubiquitous problem, most of the burden of disease lies in sub-Saharan Africa in an area called the “Meningitis Belt”. The Meningitis Belt is regularly hit by epidemics that occur only during the dry season, from December to May. Over the past 10 years, more than 250 000 cases and an estimated 25 000 deaths have been reported. The disease is an obstacle to socio-economic development: outbreak management is extremely costly and paralyses the health system – about 10 per cent of the survivors suffer life-long sequels such as deafness and blindness. A study in Burkina Faso<sup>1</sup> – one of the world’s poorest countries with an annual income of US\$ 300 – indicated that the financial burden for the

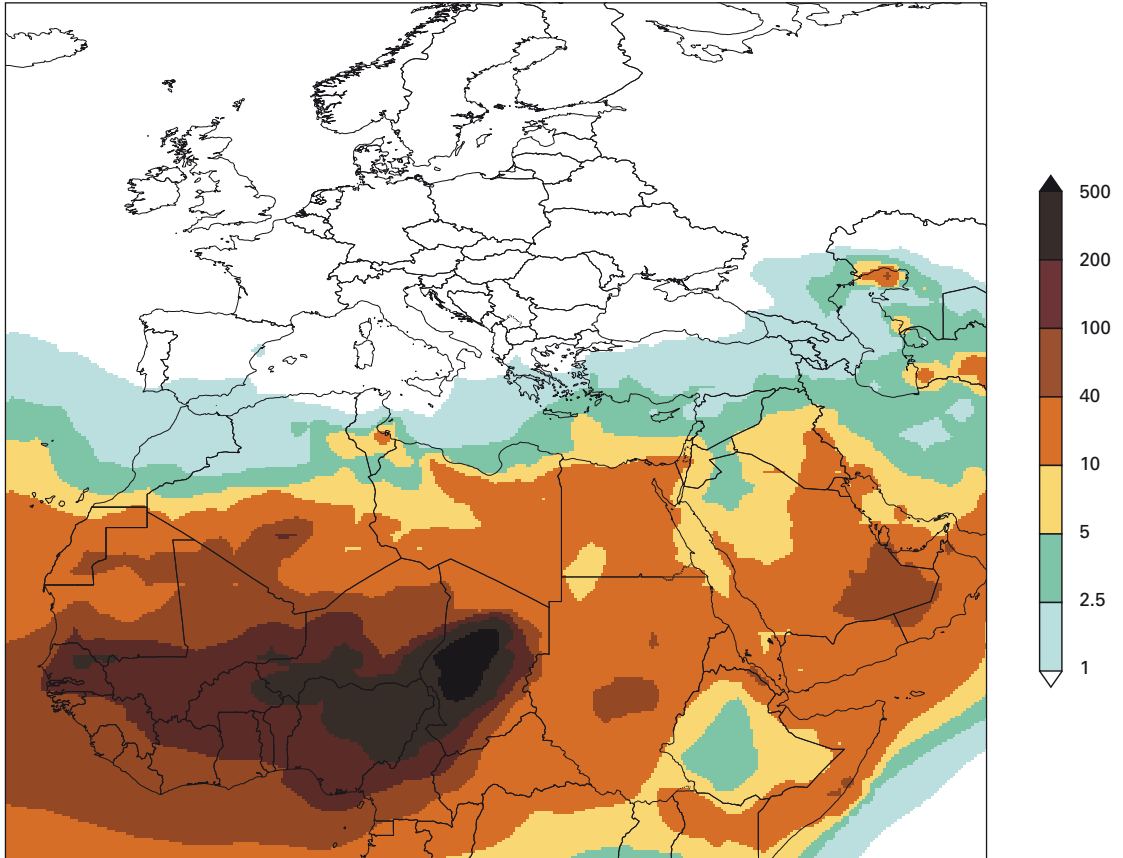
family of a patient suffering from meningitis is on average US\$ 90 and up to US\$ 154 more when meningitis sequels occur.

There is a clear seasonal pattern of meningitis cases that corresponds to the period of the year when there are increases in dust concentrations as well as reductions in humidity levels linked to the movement of the Inter Tropical Convergence Zone. While the temporal association between climate and meningitis is evident, what triggers or ends an epidemic is as yet unknown. One hypothesis is that dry, hot and dusty air irritates the respiratory mucosa thus facilitating invasion of the bacteria.

Meningitis cases per week

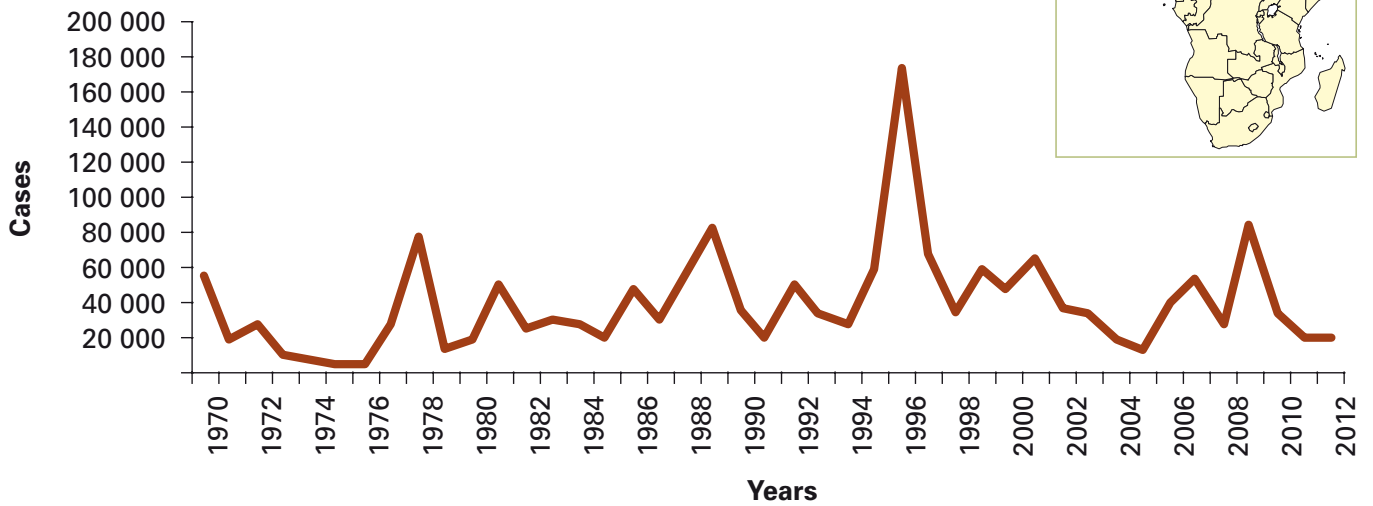
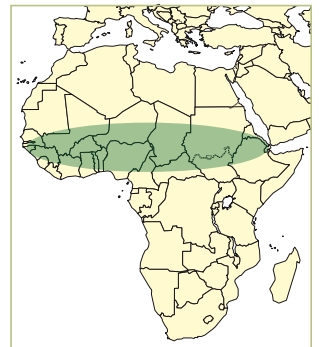


Meningitis cases increase in the dry, hot and dusty season. Data from Burkina Faso (2005-2011)<sup>2</sup>



Dust surface concentration ( $\mu\text{g}/\text{m}^3$ ) across the Meningitis Belt in December to February, averaged over 1979-2010<sup>3</sup>

African Meningitis Belt:  
Loosely defined as areas that experience frequent epidemics during the dry season<sup>4</sup>



Number of suspect cases of meningitis per year in the Meningitis Belt between 1970 and 2012<sup>5</sup>

## ADDRESSING THE MENINGITIS CHALLENGE

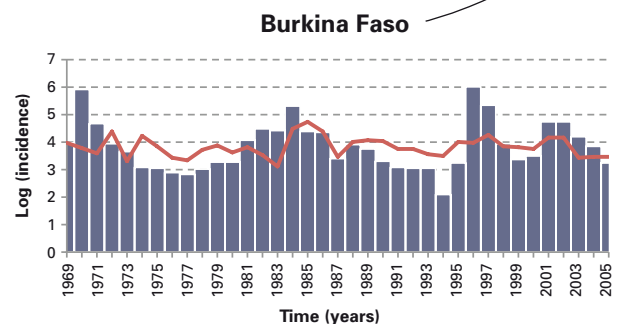
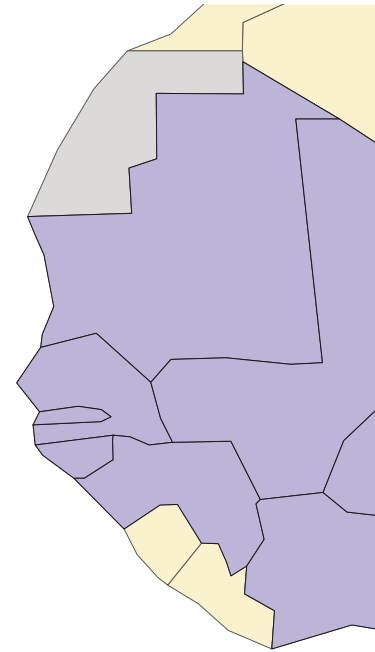
The public health strategy to control meningitis epidemics relies on the implementation of large-scale vaccination campaigns in a timely manner to prevent further cases.

Knowing if, where and when an outbreak is likely to occur would help public health decision makers prepare for vaccination campaigns and procure sufficient vaccine quantities to immunize the population at risk and ultimately reduce the impact of the disease. By increasing the understanding of meningitis risk factors and how they influence the occurrence of an epidemic, public health officials will have greater capacity to predict and prepare for potential outbreaks through reactive vaccination campaigns.

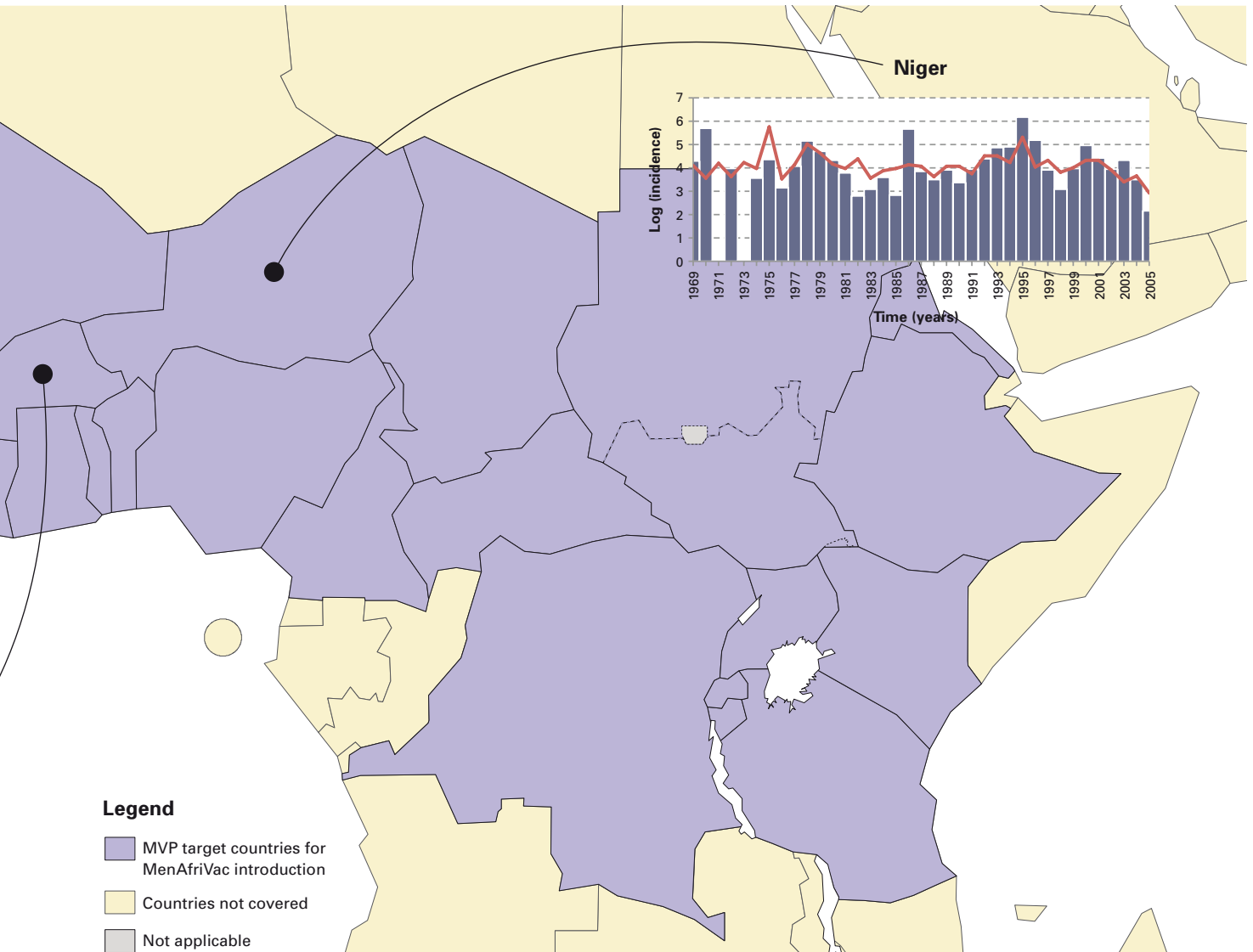
A preventive vaccination strategy, involving a conjugate vaccine against *Neisseria meningitidis* serogroup-A, is being implemented in the highest risk countries in sub-Saharan Africa. This offers great potential to eliminate large meningitis outbreaks as a public health problem. While the introduction of the meningitis A conjugate vaccine promises to significantly reduce the problem of meningitis epidemics in Africa, the reactive vaccination approach remains an important part of the control strategy.<sup>6</sup>

Improving the prevention and control of meningitis epidemics is the focus of numerous research projects in Africa and internationally. Under a collaborative partnership initiative known as Meningitis Environmental Risk Information Technologies 'MERIT' constituted by WHO, WMO, the International Research Institute for Climate and Society and other leaders within the environmental and public health communities, research projects have been designed and developed to respond directly to public health questions and priorities.

The combined output of operational research activities is being assessed to determine the effectiveness of predictive models in strengthening the public health strategy. For example, the expected probability of an epidemic occurring based on climatic and environmental factors combined with epidemiological spatio-temporal models at the district level, may in the future help public health officials respond to potential outbreaks. The climate service in support of the public health officials in meningitis-affected countries, should supply forecasts of the likely duration and end of the dry season and update these with any pertinent meteorological forecasts.



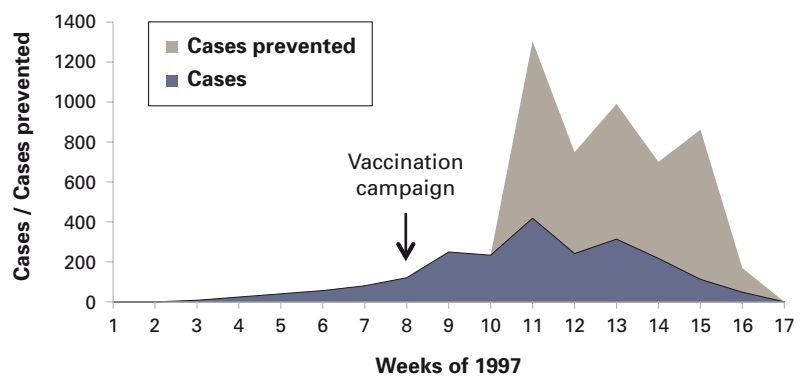
*Observed annual meningitis incidence (purple bars) and predictions based on meridional winds (red lines); offering potential to inform outbreak response<sup>7</sup>*



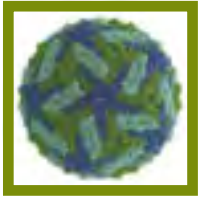
Target countries for the meningitis A conjugate vaccine, containing approximately 450 million people at risk of meningitis<sup>9</sup>



WHO / CHRISTOPHER BLACK



Early vaccination prevents many cases. Data and modelling for Reo district, Burkina Faso, 1997<sup>9</sup>



# DENGUE FEVER

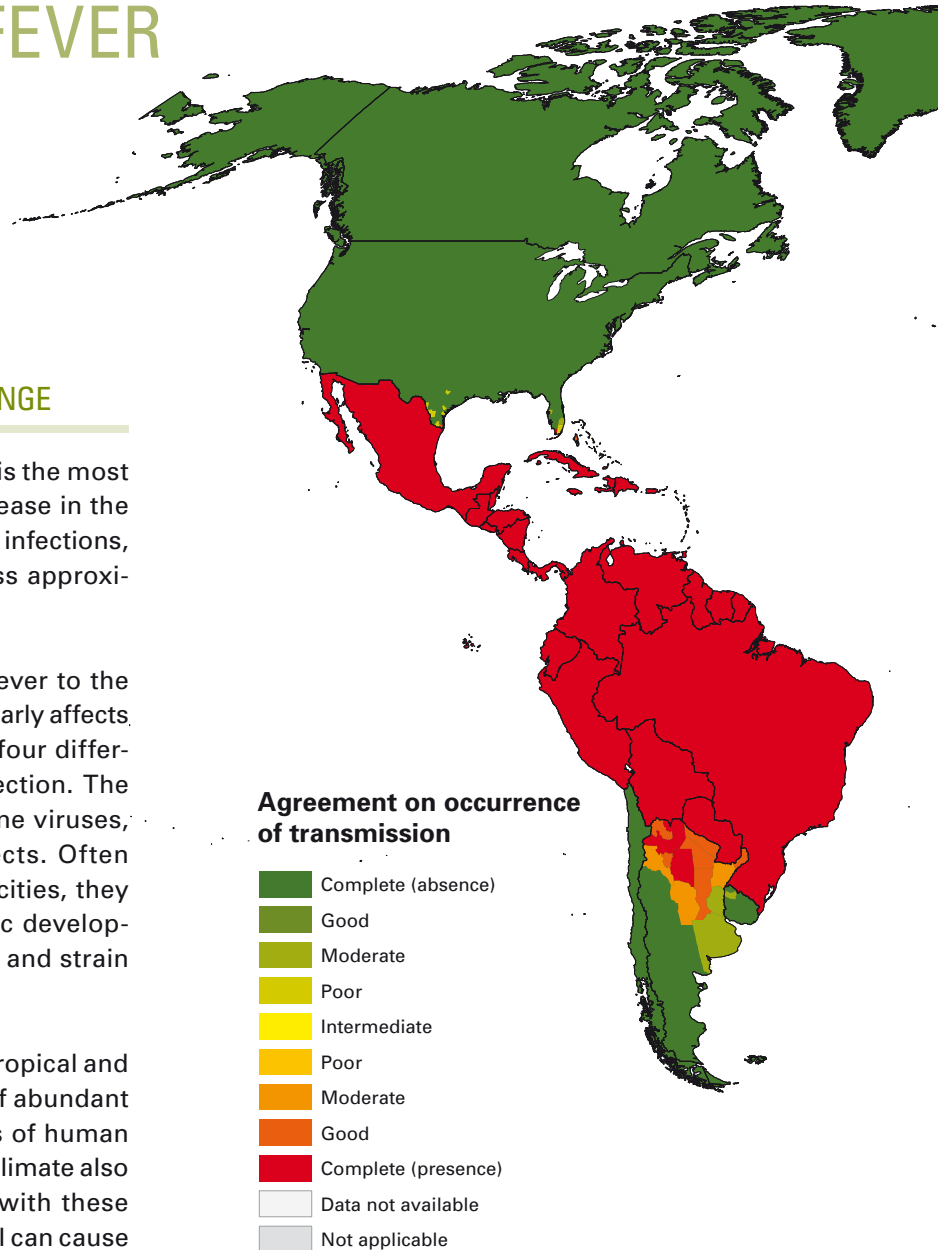
## DENGUE FEVER – THE GROWING CHALLENGE

Transmitted by *Aedes* mosquitoes, dengue is the most rapidly spreading mosquito-borne viral disease in the world. It is estimated to cause over 50 million infections, and around 15,000 deaths every year across approximately 100 countries.<sup>1,2</sup>

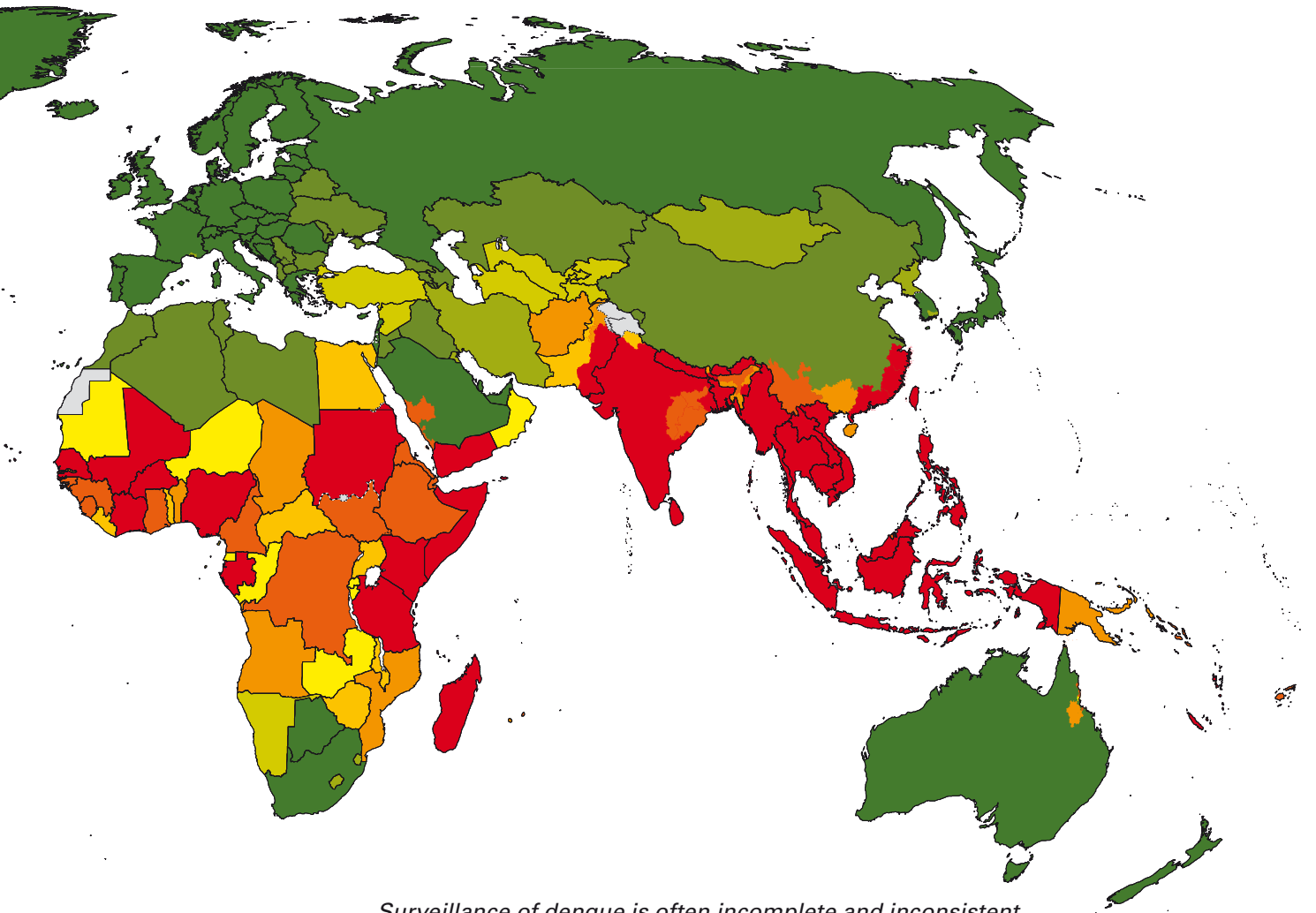
Infection could range from a mild flu-like fever to the potentially fatal severe dengue, which particularly affects individuals who are exposed to one of the four different strains of the virus as a secondary infection. The impact of dengue, and other mosquito-borne viruses, goes beyond the immediate medical effects. Often occurring as epidemics, including in large cities, they can have an important impact on economic development – for example, it may affect tourism – and strain health systems, crowding hospitals.

Dengue is particularly prevalent in cities in tropical and subtropical areas, where the combination of abundant mosquito breeding sites and high densities of human populations support high rates of infection. Climate also exerts a strong influence, in combination with these socio-economic determinants. Heavy rainfall can cause standing water, while drought can encourage people to store more water around the home, both providing breeding sites for *Aedes* mosquitoes. Warm temperatures increase the development rates of both the mosquito vector and the virus, fuelling more intense transmission.

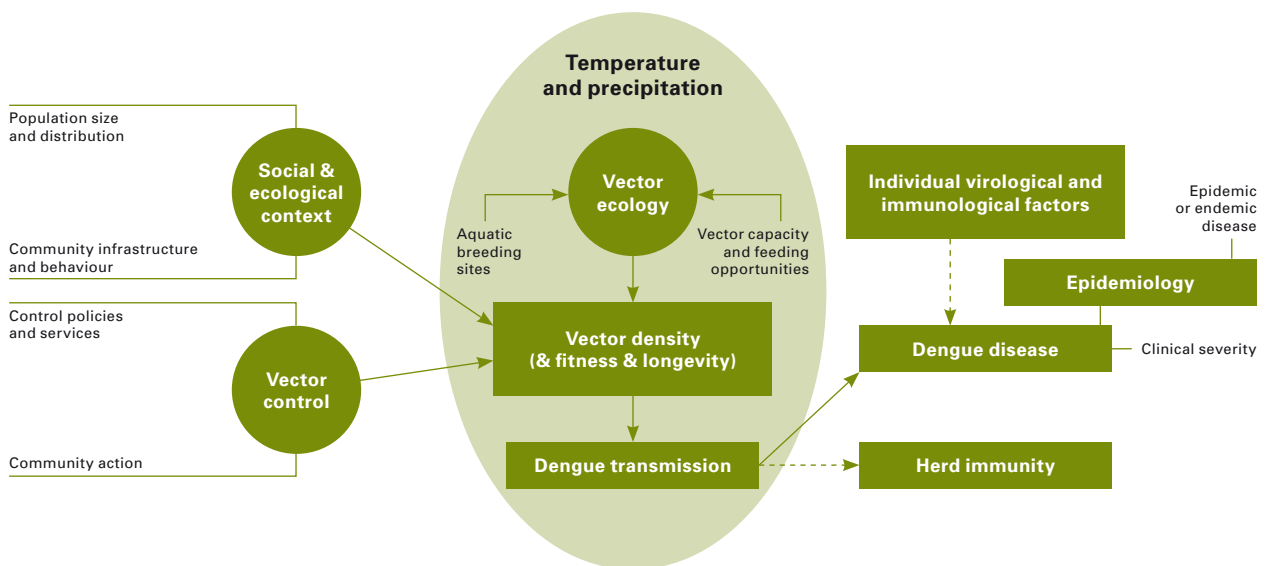
Dengue is now increasing in many parts of the world, driven by development and globalization – the combination of rapid and unplanned urbanization, movement of goods and infected people, dispersal of mosquitoes to newer territories, spread and mixing of strains of the virus, and more favourable climatic conditions.<sup>3</sup>



ASIANET-PAKISTAN / SHUTTERSTOCK.COM



*Surveillance of dengue is often incomplete and inconsistent. The map combines information from different sources to show the degree of consensus as to whether dengue transmission occurs in each country<sup>4</sup>*



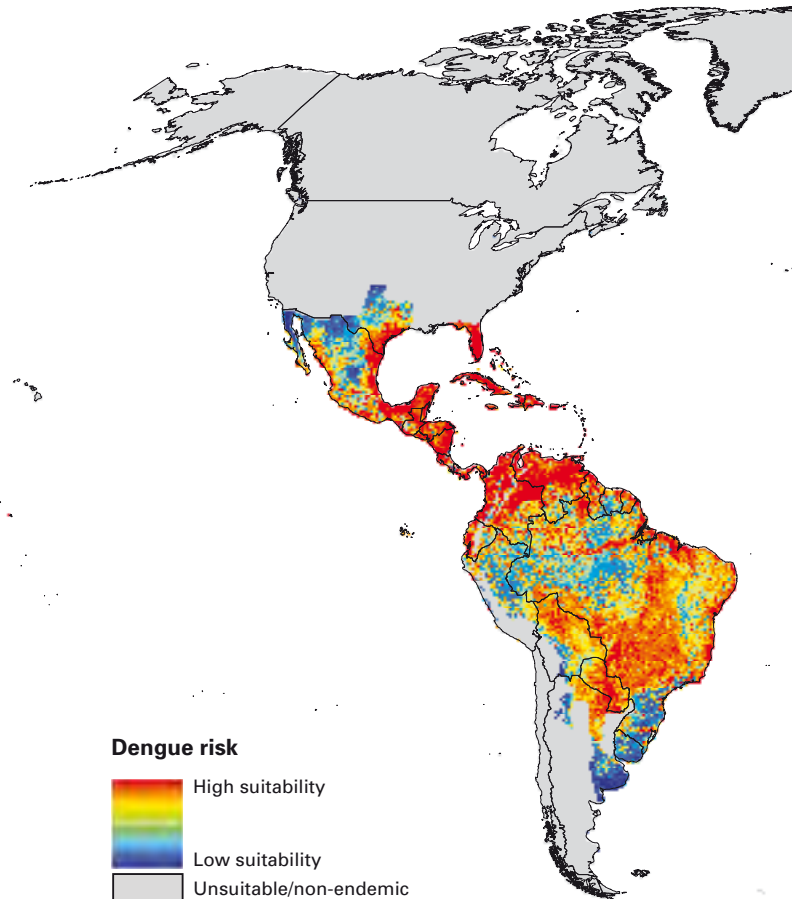
*Climate exerts a strong influence on dengue transmission - in interaction with many other non-climate factors<sup>5</sup>*

## USING CLIMATE SERVICES TO SUPPORT DENGUE CONTROL

There is currently no effective vaccine or drugs for dengue. Control programmes rely on environmental or chemical control of the vectors, rapid case detection and case management in hospitals for severe dengue. But these interventions are challenging, and there has been only very limited success in disease outbreak control within the most suitable transmission zones. Future initiatives are likely to depend not just on development of better interventions, but also on more effective targeting of control in time and space. In such scenarios, meteorological information can make an important contribution to understanding where and when dengue cases are likely to occur.

For example, statistical models, based on correlations between climate and other environmental variables and incidence of dengue in areas with good epidemiological and entomological surveillance, can be used to make predictions of the likelihood of transmission in locations where disease surveillance is weak or absent. Such information can also be used to alert authorities to the potential spread of dengue by mapping where the climate and other conditions either are, or may become, more suitable for transmission. Such information can be shared with neighbouring countries for sound planning and effective control of transmission.

Meteorological information – knowledge of seasonal patterns and weather forecasts – can also play a role in targeting resources in time. Combining information on precipitation and temperature, with an understanding of

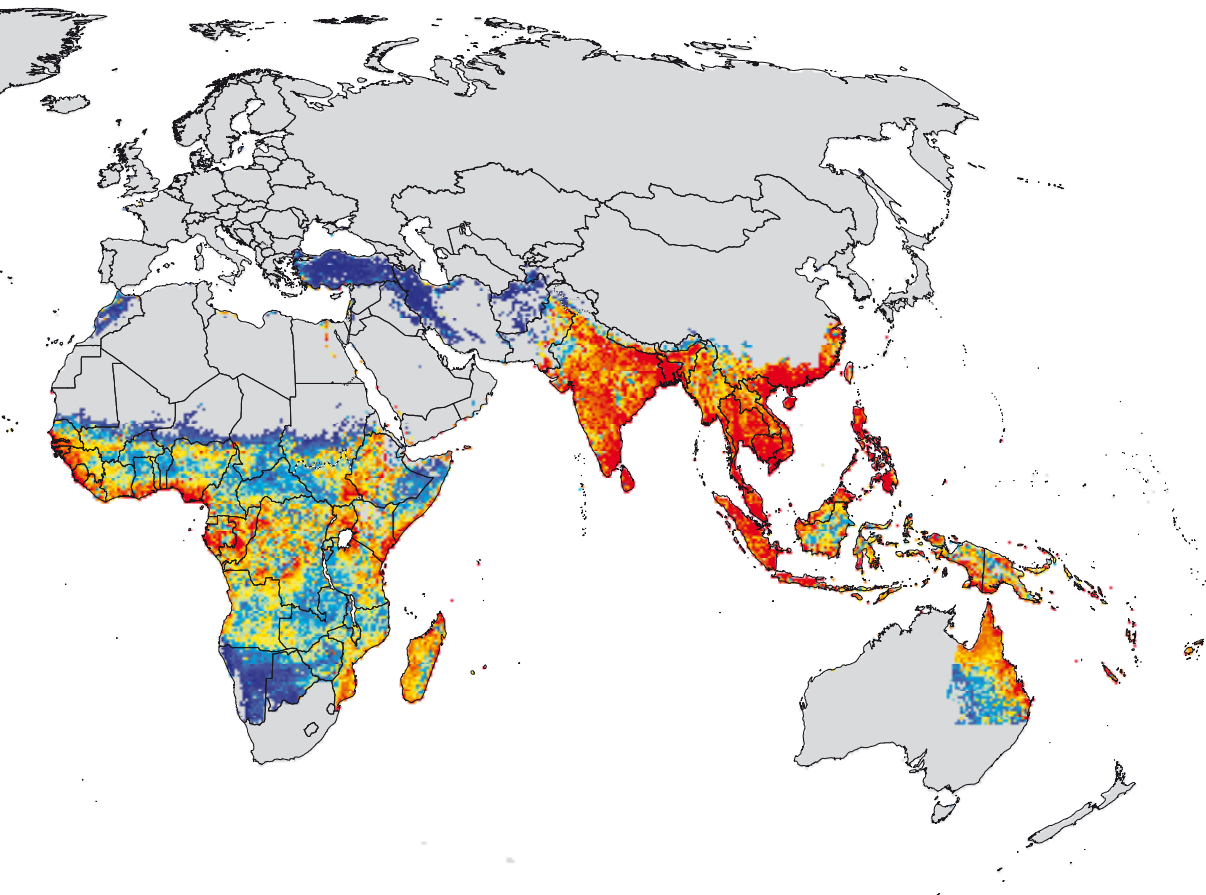


non-climate factors such as availability of breeding sites and the previous exposure of populations to infection, can help to predict when and where epidemics may occur, or be particularly severe.

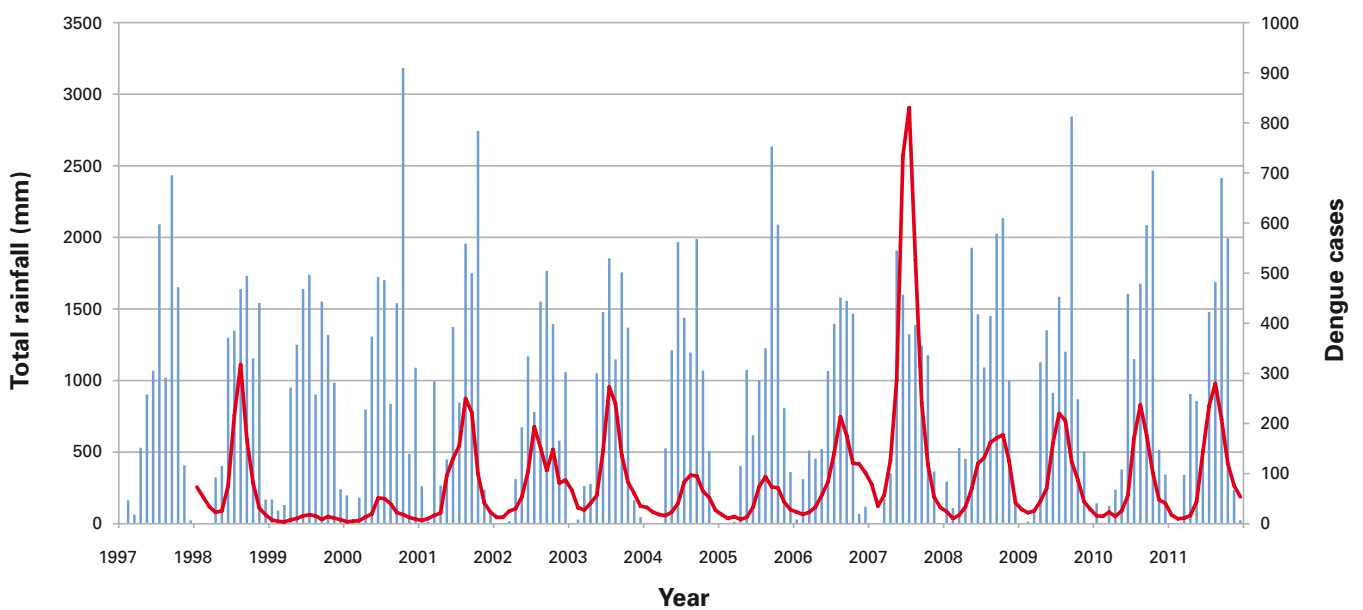


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*Climate information can be used to improve dengue surveillance. The map shows the estimated suitability for dengue in specific locations, based on a combination of disease surveillance data, and predictions based on climate and other environmental factors<sup>6</sup>*



*In many locations, dengue shows a strong seasonal pattern, and understanding of meteorological effects may help preparedness and targeting of control efforts. The figure shows pooled monthly dengue cases (red line) and monthly rainfall (blue bars) in Siem Reap and Phnom Penh, Cambodia<sup>7</sup>*



**A girl is helped off a truck after being evacuated from the flooded area of Thailand's Ayutthaya province**