

Report
Expert Meeting on

*Using climate and weather information for predicting and
preparing for cholera and vector-borne diseases*

Convened and supported by:



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Executive Summary

Background

Climate variability and change influence, in many cases negatively, health risks around the world. An important component of the overall goal of building health resilience, intersecting with strengthening health security and emergency preparedness, is the enhancement of surveillance, preparedness and response to climate-sensitive infectious diseases.

Organized as part of the implementation of the DFID-funded projects on “Delivering climate resilient water and sanitation in Africa and Asia” led by WHO and “Predicting and preparing for Cholera in Yemen” led by the UK Met Office, an expert meeting on *“Using climate and weather information for predicting and preparing for cholera and vector-borne diseases”* was held in Geneva on 25-26 June 2019. The meeting aimed to advance a common understanding, evidence base and best practice in this field and brought together representatives from the operational community of practice as well as selected experts on the use of climate information in modelling of these diseases.

The aims of the meeting were to:

- Articulate a common approach, functions and steps for integration of climate information into Integrated Disease Surveillance and Response, led by user-needs.
- Gather examples of relevant applied modelling initiatives, discuss feasibility of implementation within the current projects.
- Outline objective criteria for evaluating and promoting policy-relevant, evidence-based and replicable initiatives in the field.
- Synthesize common needs for training and capacity development materials, guide to existing resources, opportunities to fill gaps.

Outcomes of the meeting

The common themes discussed over the different sessions of the meeting are included below:

- Validation of the fact that the different models and tools being currently used to predict and prepare for infectious disease, ranging from humanitarian response to cholera in Yemen, to Lyme disease in Canada have commonalities in scope, functions and analytical approaches;
- The need to start and base whole process on the public health response – decisions on products, model validation etc. iterate from there;
- Particular attention to be paid to data governance/ownership, quality and access, for both health and climate/meteorological data;

- Importance and need for clearer guidance on principles and best practice (rather than prescriptive rules) for the essential step of model validation;
- Need for sustained dialogue and co-development to bridge the gap between traditional epidemiology and predictive approaches;

Agreed next steps to advance the field overall in the mid-term:

- Review and inputs to draft WHO/WMO guidance on developing climate-informed early warning systems for health;
- Review and inputs to capacity development /training package planned between PAHO, WHO-SEARO and WHO-HQ;
- Identify the most effective convening forum to carry on developing the community of practice, with engagement of health and meteorological actors at national and international level.
- Development of quality criteria for model validation.

Scope and Purpose

Background

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This expert meeting aimed to advance a common understanding, evidence base and best practice in this field. It was organized as part of the implementation of the DFID-funded projects on “Delivering climate resilient water and sanitation in Africa and Asia” led by WHO and “Predicting and preparing for Cholera in Yemen” led by the UK Met Office.

The meeting brought together representatives from the operational community of practice (i.e. representatives from cholera and vector-borne disease control programmes) as well as selected experts on the use of climate information in modelling of these diseases.

The aims of the meeting were to:

- Articulate a common approach, functions and steps for integration of climate information into IDSR, led by user-needs.
- Gather examples of relevant applied modelling initiatives, discuss feasibility of implementation within the current projects.
- Outline objective criteria for evaluating and promoting policy-relevant, evidence-based and replicable initiatives in the field.
- Synthesize common needs for training and capacity development materials, guide to existing resources, opportunities to fill gaps.

The expected outcomes of the meeting were:

- Recommendations for technical support to implementation of the projects.
- Revision and update of overall guidance on integrating climate information into disease surveillance and response.

To achieve these aims, the meeting was structured around user needs and functions required to integrate climate information into surveillance systems, rather than individual modelling initiatives. The key steps included in the draft WHO/WMO guidance on climate-informed health early warning systems was used

to frame the sessions of the meeting, as these were considered to be representative of the process to be followed by countries aiming to develop early warning systems for health.

Meeting Summary: DAY ONE

Introductory Presentations

Opening remarks and Introduction of the DFID-funded project on “*Delivering Climate Resilient Water and Sanitation in Africa and Asia*”

Diarmid Campbell-Lendrum (CCH Coordinator, WHO HQ) gave the opening remarks and presented the objectives of the meeting. The overall goal of the meeting was to promote the sharing of experiences and technical inputs from participants to inform next steps for two DFID-funded projects (i.e. DFID-funded projects on “Delivering climate resilient water and sanitation in Africa and Asia” led by WHO and “Predicting and preparing for Cholera in Yemen” led by the UK Met Office), as well as to contribute to the field in general. The sessions were therefore ordered to follow the process of bringing climate information into health surveillance, allowing participants to reflect on their own experience and expertise on these different stages.

Diarmid Campbell-Lendrum then provided a brief background on the DFID-funded project on “*Delivering Climate Resilient Water and Sanitation in Africa and Asia*”. This project supports Ethiopia, Malawi, Mozambique, Bangladesh and Nepal to develop health surveillance systems to identify and respond to climate-related changes in the incidence of water- and sanitation-related disease. This is linked to preventative action and development of more effective early warning systems that will enable better and quicker responses to disease outbreaks, particularly cholera and severe diarrheal disease, and vector-borne illness. The programme outcomes will contribute to better global health security, and the tools developed will have wide application in developing countries.

For this project, the needs and next steps at the country level were outlined, as these will determine short- and mid-term follow-up actions:

- Better characterize climate/weather data/analysis needs for selected products;
- Identify mechanisms for data access, and alternative climate/weather data sources if required;
- Map and assess disease surveillance information flow (DHIS2/other, process map, individuals responsible for data integration and visualization)
- Understand available models, feasibility of implementation, and support requirements;
- Consolidate protocols around disease surveillance for different CSDs.

WMO-WHO Collaboration on Health, Environment, and Climate

Joy Shumake-Guillemot (Officer-in-Charge, WMO) presented a background of the WMO Integrated Health Services, which aims to promote the development and use of climate/weather services to enhance the management of climate related health risks and improve health outcomes. The initiation and background of the WHO-WMO Joint Office was described, and the collaborative objectives outlined:

- i) Promote the alignment of relevant policies and raise awareness of environmental and climate related risks and solutions to protect human health;
- ii) Promote the generation and application of scientific evidence;
- iii) Develop appropriate technical mechanisms and partnerships to facilitate the development, delivery, access to and use of data and tailored information products on weather, climate, and environmental hazards to health;
- iv) Develop and disseminate technical and normative guidance, scientific publications and tools, and other actions to support capacity development;
- v) Monitor progress on the access and use of reliable and relevant weather, climate, and environmental information.

Joy Shumake-Guillemot finally discussed the new Climate and Health Science Portal that is currently in development. This online tool aims to be open-access and quality-controlled portal providing users with climate/ environment/health science data and application resources to complement the WHO and WMO's existing policies and action.

UK Met Office programme on climate services for health and briefing on UNICEF project on *"Predicting and preparing for Cholera in Yemen"*

Rosa Barciela (Strategic Head of Health Science Integration, UK Met Office) provided a background on UK Met Office initiatives on climate change and health. The UK Met Office aims to translate weather/climate science into useful products and services (for both non-communicable and infectious disease). It was highlighted that a lot of climate/weather data is being generated, but most of it goes unused. The goal is therefore to enable users to work with this data, to build partnerships, and to develop useful tools and resources. Some tools were shown as examples, including the Global Hazard Map (summarizes where high impact weather is forecast across the globe out to seven days) and the Medical and Environmental Data Mash-up Infrastructure (MEDMI; connects diverse databases to improve understanding of the links between climate, environment, and health).

Rosa Barciela described the DFID-funded project on *"Predicting and preparing for Cholera in Yemen"*, implemented by the UK Met Office in partnership with the University of West Virginia, University of Maryland, and UNICEF. The project builds on the initiative established through DFID in 2018 that supported in-country cholera prevention activities in Yemen. The desired outcome of the project is to enhance the capability to use forecast-based interventions for cholera, up to 8 weeks ahead, and in 5-10 countries.

- The key point discussed after the presentations was the feasibility of scaling-up the model used to forecast cholera risk in Yemen to additional 5-10 countries when the model has not been validated. Participants recommended to validate it prior to expanding it. Furthermore, it was suggested to distinguish between evaluating the impact on where cholera already is, and areas where it could spread (current vs. prospective impact).
- It was explained that there has been a poor understanding of cholera hotspots in Yemen, so this project was largely 'operational' and based on the limited information available.

The three presentations provided during this session highlighted: the public health importance of tackling climate-sensitive diseases; the strong political interest to tackle them, both in terms of epidemics and long-term climate change; the increasingly good institutional alignment; and the growing availability of technical capacity in this area of work.

Presentations provided in the following sessions provide a wide range of examples and approaches on the use of climate and weather information for predicting and preparing for cholera and vector-borne diseases and are organized around the suggested key steps to develop climate-informed early warning systems.

Session 1: Initial problem characterization and health sensitivity review and analysis

Joacim Rocklöv (Professor of Epidemiology, Umeå University) gave a presentation entitled: *"Health Sensitivity to Weather and Climate Variability"*. The presentation described methods used to better understand the etiology of diseases and the sensitivity of a disease to weather, season and climate variability. Aspects to be considered when modelling disease were described (e.g. latencies, non-linearities, exposure-response functions, effect-modification, heterogeneity) and different methods covered. First, process-based (mechanistic) models were described, which are representations of the processes that characterize the functioning of biological, dynamic systems (aiming to describe system behaviour). Examples shown were process-based models for dengue vectorial capacity (percentage by year), and suitability for outbreaks of *Vibrio* spp (coastal area suitability by year). Second, empirical models were described, which are typically less complex and aim to describe the statistical relationships among data (e.g. time series regression), without necessarily modelling all of the underlying processes determining overall system behaviour. An example shown was a time series regression for Ocean Nino Index (ONI) and dengue incidence.

Finally, common space-time issues were highlighted, including quality of data (especially re-modelled or remotely sensed data), confounders and impact of other drivers, granularity, hazard vs. exposure, and notified vs. confirmed cases.

Discussion points:

- The complexity of understanding the nature of climate- sensitivity of disease was raised by participants. There are a lot of things to understand to decompose the sensitivity of disease – understanding the process, and necessary lead times and level of certainty necessary to deploy different public health interventions.
- Furthermore, the need to consider non-climate drivers that could act as confounders or modifying factors in the analyses (mobility, socioeconomic factors, environment) , or introduce statistical noise, should be included in the design.
- Participants also discussed about the different data needs depending on geographical resolution and the additional data needs necessary to reach finer spatial resolution.
- Participants highlighted that in the absence of perfect data, data of lower spatial resolution or quality may still give useful information, and that the level of spatial and temporal resolution of the analysis may be influenced by available data, the transmission ecology of the disease (e.g. space-time variations are more important for vectors and diseases with faster life or transmission cycles) and the public health decision in question.
- The complexity of the issue of mobility of populations, vectors and pathogens, and its different nature depending on the disease (e.g. transmission of malaria generally being localized to where humans while they sleep, whereas other diseases may be contracted in other locations such as workplace, in transit, etc.)
- When assessing the feasibility of developing a climate-informed health early warning system the strength of the relationship between the disease and external factors (weather/climate) could inform decisions on which diseases are best to forecast. Time-scale for interventions and lead time for prediction are also important considerations.
- Ethical issues regarding the purpose of the model, inclusion of stakeholders in designing the decision-making process, and informing them of uncertainties and consequences of acting on model outputs, were discussed. It is recommended not to over commit to actions based on model predictions, and to continuously re-examine their validity.
- The importance of understanding what you are using the EWS for was highlighted. This should be better reflected in the WHO guidance on climate-informed health early warning systems. It is recommended to start with the user needs and consider the associated health response, which will in turn inform the kind of sensitivity analysis undertaken.
- The fact that when dealing with EWS there are chances of getting a prediction but not an outbreak or the opposite was raised. Consequences of Type 1 errors (prediction for a false outbreak) – even though you may be providing communities with helpful services, this would lead to poor distribution of resources and medications, which could in turn have a negative health impact in other areas where resources are needed but not allocated. Users may also lose confidence in the tool.

- Consequences of Type 2 errors (no prediction and there is an outbreak) as much bigger as poor preparation for an outbreak could have devastating impacts.
- Issues around data quality, availability and access were highlighted as well as potential opportunities. Current global initiatives to bring together data could help to calibrate and validate models. It was suggested to promote the use of new technologies such as earth observation data for forecasting and satellite data for decades, and the possibility of using crowdsourcing data. WMO restructuring efforts, may present an opportunity to unlock some of the data ownership issues (e.g. charging for data from meteorological services). , and encourage more opportunities to clean data so as to increase usability.
- Data and model ownership issues were raised by participants – sometimes countries have the data but don't want to share it if they are not the owners of the tool. More effort could be put on communicating how datasets are going to be used.
- The potential role for WHO/WMO to support accessing new technologies was mentioned.

Session 2: Feasibility assessment

Hannah Nissan (Associate Research Scientist, Columbia University) presented on the second recommended step to develop a climate-informed health early warning system: *“Feasibility Assessments: When is climate information useful for disease early warnings?”*. This considered situations in which there is sufficient lag time between an environmental observation and a health outcome (e.g. between observed rainfall and increased transmission of vector-borne disease), and where it is necessary or useful to use meteorological forecasts, which give longer lead times, but add complexity and uncertainty. The need to consider the plausibility of associations was stressed, as statistical associations may not imply casualty without a plausible mechanism. The proposed way forward is to identify which aspects of the relationship between climate and malaria are predictable (on which spatial and temporal scales) while being aware of the less predictable effects. The presentation emphasized the need to strengthen ecological surveillance versus disease surveillance for EWS when possible, and to use weather or climate forecasting only when the lags are insufficient to use monitoring data.

Next, Fekri Dureab (Heidelberg Institute of Global Health) gave a presentation covering *“Cholera in Yemen”*. Between Oct 2016 and June 2019, the accumulative number of suspected cholera cases was more than 1.8 million (with a case fatality rate of 0.2%). The cholera outbreak in Yemen has been largely driven by years of conflict, so potential risk factors were categorized as conflict-related (security, population movement) and non-conflict related (e.g. water and sanitation, infrastructure, biological, behavioral, environmental, etc.). The Electronic Disease Early Warning System (eDEWS) was outlined, which has a mean time between reporting and verification (contact either by visit, phone, SMS) of 2.85 days. eDEWS covers more than 80% of functional healthcare facilities in Yemen, yet there are still capacity weaknesses in disease surveillance, community engagement and prevention efforts.

Discussion points:

- The importance of being aware about the limitations of models, and that we don't over commit to the outcomes predicted by the models was raised;
- The different reasons why lags can occur were mentioned (e.g. delay in manifestation of disease after infection; delays in seeking medical attention; lags in climate/medical information being relayed to authorities);
- Discussion covered the necessity, or otherwise, of always having a plausible mechanism explaining an observed association between meteorological or climate information and disease outcomes, or interventions and disease outcomes. In certain cases it is well documented that an intervention works but it is not clear why, and we should not refrain from using them because of this.
- The case was made that developing EWS for associations without a full biological understanding may be acceptable for actions that build institutional capacity (and lessons learned), and when used to implement "no or low regret" interventions, but should be avoided when they could increase vulnerability of populations, increase other risks, or cause large diversions of resources.
- The point was raised that not only can models can be wrong, but that too much trust can be placed in them, leading to dismantling of decision-making frameworks that have been successfully used for years. It is important to be transparent about what is the failsafe threshold and consider the consequences of taking a decision based on unreliable models.
- The importance of communication and interpretability, as well as forecast reliability was emphasized, in order for them to be used as decision -support tools.
- The importance of considering the transferability of a model to different areas (how to integrate models into prediction frameworks, looking at similar geographical characteristics, vulnerabilities, decision making contexts etc.) was emphasized;

Session 3: Developing integrated risk forecasting and monitoring

Jan Semenza gave the first presentation on developing integrated risk forecasting and monitoring (European example). The presentation covered the European Centre for Disease Prevention and Control (ECDC) mandate for Infectious diseases, which conducts monitoring and surveillance for reportable diseases and emerging events that could arise in Europe. Environmental sensing data is used for prediction of disease emergence (conditions are published in the communicable disease threat report (CDTR) publication).

As an example, the ECDC Vibrio Map Viewer model was presented, which predicts the environmental suitability for *Vibrio* spp (rather than predicting risk of disease). The Vibrio Viewer is a real-time model that uses daily updated remote sensing data to study environmental suitable conditions including sea

surface temperature and salinity (within a 30m band around the coast of the Baltic sea). Favourable conditions for *Vibrio* occur most frequently in the summer when water temperatures exceed 15°C and salinity is low. Exposure can pose significant health risks and be life threatening. *Vibrio* infections are not a reportable disease across Europe, (voluntarily monitored in Baltic states which are surrounding the Baltic Sea). Since it is not reported, States have to monitor environmental conditions, which is followed by active surveillance in high risk regions. When suitability is detected, outreach efforts are implemented to communicate with local authorities and advise protective actions such as beach closures. Dr. Semenza confirmed that the model scale can be adjusted to suit the context (regarding generalizability of the model).

Another example was presented describing the monitoring of passenger volumes into Europe from disease active zones (Zika, Chikungunya) plus vectoral capacity calculated as functions of temperature and vector data. Hotspots where local vectors exist that could contract VBD from travelling passengers are carefully monitored.

Next, Nicholas Ogden (Public Health Agency of Canada) presented on *“Predicting and forecasting infectious disease emergence and re-emergence: what does public health need?”* (Canadian example). Emerging diseases are defined as those whose incidence in humans has increased in the past (~2 decades) or threatens to increase in the near future. This increase could be due to a variety of factors, such as geographic spread, increased adaptive capacities in hosts, or even increased awareness. Climate change and variability can impact the emergence of disease through: i) Reservoir host dynamics; ii) Agriculture dynamics; iii) Vector biology; and iv) Host infection and transmission dynamics. Understanding vector ecology and lifecycles are critical to understanding how the climate affects their life cycles (e.g. tick-borne disease vs. mosquito-borne diseases).

The different examples in two different continents presented showed some level of convergence with regards to the process followed. They both assessed: the public health context; the sensitivity of the disease to weather/climate; the feasibility (based on sensitivity); the reliability; and then developed the model.

Discussion points:

- The importance of understanding the disease in the context of other socio-economic drivers was emphasized.
- There is a concern that environmental signals for disease outbreaks are often not taken seriously, as public health officials traditionally consider “early warning” to be early detection of cases, and do not consider environmental triggers as real epidemiological signals, irrespective of how reliable the model may be.
- The need to strengthen environmental surveillance, including vector surveillance was emphasized.
- The fact that there needs to be greater explanation/messaging to the users and the public when it comes to forecasting or early warning systems (also to ensure sustained use of these systems)

was emphasized. A common perception and barrier to model implementation is that these models are too complex. More in-depth communication and training of end-users with respect to public health action can help to increase the literacy and open-mindedness of the public health community.

Meeting Summary: DAY TWO

Session 3 Cont'd: Developing integrated risk forecasting and monitoring

Laith Hussain (University of Gothenburg) presented on “*Web-based Early Warning and Response System (EWARS) for Arbovirus Disease Outbreaks*”. The history of EWARS from its initiation in 2011 to country implementation starting in 2016 was described. It was designed to be deployed during emergency settings as an adjunct to national disease surveillance systems (for dengue, chikungunya, and zika). It can be set up within 24 hours and is also operational in remote settings or in areas without reliable internet or electricity. EWARS indicators include outbreak (probable, confirmed and hospitalized cases), meteorological data - weekly (temperature, precipitation, humidity); epidemiological/demographic data; and entomological data.

Laith Hussain described the structural design of EWARS, specifically Dashboard I (retrospective) that uses run-in data to create the prediction model, and Dashboard II (prospective surveillance) which uses evaluation data to assess how the derived parameters from the run-in data would predict an outbreak. Officers at the national/provincial level use Dashboard I to validate the model (parameters are automatically linked to district via the web), and officers at the district/municipality level use Dashboard II (weekly data) for interpretation and action. There is an [Operational Guide](#) for more information on how to use EWARS.

Next, Albert Chen (Senior Research Fellow at Exeter University) gave a presentation on “*Hybrid weather prediction for smart water disease protection*”. The presentation covered the methodology used to produce 2D simulations of the transport/mixing of pollutants from overflowing/damaged sewers to surface flood water, resulting in the increase of various pathogens. The methodology consists of determining (sequentially): 1) Water quality/concentration of pollutants (through measurements or literature); 2) Exposure/ingestion (e.g. during wading, cleaning); 3) Vulnerability and dose-response relationships; 4) Monte Carlo simulations (risk analysis by building models that perform risk analyses of possible results by substituting a range of value (a probability distribution) for any factor that has inherent uncertainty); 5) Probability of infection; and 6) the number of people affected.

Discussion points:

- Further details of the EWARS model were requested. A strength of EWARS is that it can be easily integrated into existing national surveillance programs and is not designed to replace existing systems. EWARS requires a set of 3-years records of surveillance data for calibration and 2 years data for evaluation of the tool. The most significant predictors (derived through sensitivity analyses) vary per country although mean temperature was commonly found to be a good predictor. There was also an unexplained correlation with mean age of patients, which is interpreted as change in serotype, although this has not been formally tested.

- A survey was conducted after the use of EWARS. The most striking result is that countries have reported better communication and coordination between district and national level actors. With regards to mitigation of outbreaks the major problem is to decide when to start with vector control in large districts. For this reason, future work is planned on risk mapping to identify hotspots.
- Some limitations of EWARS were mentioned: temporal variation of some variables (monthly instead of weekly information), spatial variation of data (state instead of district information), paucity/absence of data/variables, varied data sources (independent online systems), multiple non-verifiable data sources, and inconsistent sampling (entomological indices). Accessibility of meteorological data to include in the tool is often a problem due to high costs. Ideally real-time observation data is used but in the case of the *“Hybrid weather prediction for smart water disease protection”* in Bangladesh, scenario-based analysis was used to build the database. Questions about how to evaluate data quality in this case were raised.
- Ensuring sustainable use of the tools requires a lot of capacity building to transfer the skills to on-site workers and users.

Participants requested WMO for support to facilitate access to meteorological data.

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- Another proposal was to focus on the process rather than on minimum guidance for each model. Ensuring that the community knows what the goals or outcomes are for the models are important.
- Whether or not enough guidance or quality standards exist for data and models was questioned. As the field expands the number of models is also increasing. WHO stated that, in order to effectively support countries in their efforts to integrate climate/weather information within their surveillance systems and or develop climate-informed early warning systems, there needs to be some guidance and criteria against which models can be evaluated. The field appears to be at an inflection point, with quite a lot of practical experience and the need to develop objective criteria to be able to recommend countries to go a specific model. The question of how this community of practice could help WHO to develop these criteria was raised.
- Getting different groups comparing the models including data quality assessment was proposed. Modelling challenges as a way to identify strengths of the models was also proposed. The development of tutorials was also discussed.
- Since each model has a unique purpose it was raised that it may be difficult to develop strict guidance or run direct comparison to compare models. Nonetheless, it was considered very useful to develop minimum standards for the process to assess models, and guidance on their performance. While doing this there is a need to give special attention to capacity building as the user community is increasingly interested to engage in development and use of models. Participants stresses the important of leadership from WHO/WMO to bring together the science and the community of practice.

Session 4: Operationalization: designing warnings and response plans, establishing communication mechanisms with communities, and pilot-testing EWS

David Olson (High Threat Pathogens, WHO-HQ) gave an overview of the Global Task Force for cholera control in his presentation: “*Cholera Control and Role of Forecasting*”. Global disease burden estimates for cholera include 3 million cases and 95,000 deaths annually. Cholera infection can lead to severe dehydration and death (case fatality for untreated cholera can reach as high as 50%). Heavy rainfall is an important predictor for cholera transmission for a variety of reasons including worsening sanitary conditions, overload of under-maintained (non-resilient) municipal water and sanitation systems, infrastructural damage, and washout of open defecation sites and latrines. However, there *can* be cholera transmissions in the absence of rainfall (e.g. decreased pressure in municipal piped systems creating sewage backflow/crossflow, changing behaviours such as farmers using untreated water during drought).

The Global Task Force on Cholera Control (GTFCC) was established in 2017 and Operationalizes the new global strategy for cholera control at the country level. It has three strategic blocks: 1) Early detection and immediate response to contain outbreaks; 2) Multi-sectoral cholera elimination interventions in targeted cholera hotspots; and 3) GTFCC partnership as a coordination and country support mechanism.

It was emphasized that context is very important due to variation in climate/geographical factors and population susceptibility. Each cholera at-risk context (and subsequent outbreak) is unique, depending on setting, population characteristics and behaviours. With regards to forecasting and EWS, several efforts are ongoing. In order to translate warning into feasible action with impact in the ground, time-lead and ability to forecast location where response can occur are essential. The EWS has to provide a signal that allow us to be prepared. In places where there are not regular outbreaks it is important to establish a response system. Given context specificity and need for timeliness in turning information into action, predictive modeling capacity should be developed locally.

Next, Ahlam Al Mutawakel (UNICEF Yemen) gave an overview of the “*Yemen WASH Cholera Response*”. In Yemen, 73% of districts are in acute need of improved water, sanitation, and hygiene (WASH) services. This has doubled since 2014, mostly due to the conflict in Yemen over the past years. The conflict has had a major impact on the movement of people, health supplies equipment, medications, etc. – often delayed or they do not arrive at all. The approach to WASH interventions include targeted preparedness, response and prevention activities (targeted mostly for communities most impacted by the conflict).

Discussion points:

- There are several efforts/models being developed for cholera forecasting/EWS. Short-term predictive models have been most accurate. Translating predictions into impactful action remains a work in progress.

- The complexity of the climate cholera link was highlighted: relationships vary by location and are non-linear.
- The need to identify risk areas using different factors (e.g. incidence, water and sanitation, population concentration) was highlighted as important to identify target districts for cholera vaccination. Although vaccines are required to stop the transmission, there are not enough vaccines available globally to protect whole populations. For this reason, forecasting and identifying risk areas are extremely important.
- To effectively manage cholera, capacity has to be built in different areas ranging from better understanding its seasonality to advancing the lead-time of forecast. Furthermore, WASH interventions have to accompany any cholera prevention work as a way to ensure longer term population health.
- Representatives from countries also expressed that there are also challenges to access meteorological data in their country. More information on how to combine WASH/cholera data and overlay it with climate/weather datasets was requested.

Session 5: Monitoring, evaluation and iterative improvement

Antarpreet Jutla (University of Florida) presented *“Monitoring, evaluation and iterative improvements: a curious case of cholera in Yemen”*. Various classifications of cholera were explained: 1) Epidemic cholera consists of a sporadic deadly outbreak that typically occurs inland and after a disaster, such as a flood or hurricane (single seasonal peak); 2) Endemic cholera consists of cholera that persists throughout the year, usually in coastal regions or in areas of seawater intrusion from coasts to inland (single seasonal peak); and 3) mixed-mode cholera is a contribution of both (usually two seasonal peaks). The major functions for epidemic cholera were and used in the model described were temperature, precipitation and water insecurity. Finally, the presentation highlighted that too much emphasis is placed on statistical significance (some useful models or associations may be ignored for very small differences).

Anton Camacho (LSHTM) presented on “Monitoring, evaluation and iterative improvement”. Addressing cholera epidemics in different countries must include exploring what factors drive outbreaks locally, and determine the magnitude of risk and location of future outbreaks. Examples of outbreaks in Haiti (2011-14) and Yemen (2016-17) showed associations and lag between rainfall events and cholera outbreaks. Findings on the association between cholera and rainfall were presented (transmission increased by 42% following a week with 25 mm of rainfall compared with no rainfall), and in Yemen, a ‘Ramadan effect’ was detected (transmission increased by 19% during Ramadan compared to the preceding month, after adjusting for rainfall) possibly related to behaviour change during this period.

Discussion points:

- It is important to differentiate between explanatory and predictive models (and observational data should be used to retrospectively evaluate predictive models).
- Disease transmission in context: the more complex the transmission route, the more complex the model will have to be (this is true especially for water-borne diseases).
- There are many contributing factors to take into consideration for disease risk monitoring which can make it complex (and threaten accuracy), for example:
 - Climatic and geographic factors;
 - Population factors (socio-demographic, immunity build up, behavioural changes, mobility and displacement);
 - Conflict (direct and indirect effects);
 - Access to improved water and sanitation;
 - Phenotypical changes in cholera strain;
 - Control interventions;
 - Data quality.
- Questions were raised about how a model can be validated without using quantitative measures rather than qualitative approaches that don't include cholera data.
- Participants agreed that criteria for evaluation of models should be developed by the expert community.

Session 6: Training packages and capacity building tools

Rachel Lowe and Felipe Colon (LSHTM) led the final presentation on “*Modelling tools and capacity building in climate and public health*”. The relationship between lead time and forecast certainty was discussed (climate forecasts have greater lead time but less certainty of accuracy vs. short-term forecasts based on reported cases have short lead time but greater certainty). An example was shown of a map displaying a dengue forecast using the rank probability skill scale (RPSS) method (which gives a rank of 0 to 1, with 1 being the value for a perfect forecast).

The presentation also covered some training initiatives that the presenters have organized, including the School on Modelling Tools and Capacity Building in Climate and Public Health in collaboration with, the International Centre for Theoretical Physics (ICTP)). The course teaches skills in statistical and dynamical disease modelling and provided tools to analyze climate, environmental and public health data.

Discussion points:

- Representatives from countries questioned the ability to transfer the model shown in the presentation to their countries. Rachel Lowe confirmed that the methodology is transferable, but the model does need to be fitted to the country. Country representatives emphasized that tools/models must be accompanied by training and capacity building initiatives for users (in-country).
- It was emphasized that it should be institutional members (from Ministries) who express their needs and receive capacity building opportunities.
- Capacity building should include not only education on climate-sensitive diseases, but also training on science-based and informed decision-making processes.
- When training health professionals in the use of climate data, it is important that training and course-designs are tailored to the decision and capacity needs of the users instead of centered around the available processes or tools meteorological services or academic partners make available (prioritizing user needs instead of selling products).
- It is less effective to develop a model and go straight to the user to implement – there needs to be a supportive process of co-design throughout, with a clear understanding of the final application context.

Key Points and Next Steps

A summary of key points derived from the meeting were provided by Dr Campbell-Lendrum (CCH Coordinator, WHO-HQ) and Rosa Barciela (Strategic Head of Health Science Integration, UK Met Office).

Common themes:

- Validation that there are commonalities in scope, functions, process, from humanitarian response to cholera in Yemen, to Lyme disease in Canada;
- There is a need to start and base whole process on the public health response – decisions on products, model validation etc. iterate from there;
- Particular attention should be paid to data governance/ownership, quality and access, for both health and climate/meteorological data;
- Importance and need for clearer guidance on principles and best practice (rather than prescriptive rules) for the essential step of model validation;
- Need for sustained dialogue and co-development to bridge the gap between traditional epidemiology and predictive approaches;

WHO - Short term needs for the project on “Delivering Climate Resilient Water and Sanitation in Africa and Asia”:

- Ensure completion of needs/readiness assessment in project countries;

- Develop clear criteria for model and product selection where there is more than one available option;
- Ensure technical support for model and product development in country while strengthening the institutional capacity to implement those (including partnerships with relevant experts and the NMHS);
- Clarify connections between the two projects, to span the spectrum from the humanitarian response to the cholera epidemic to sustained country-owned systems, and resilience to climate change.

Early Action for Cholera (UK Met Office) - Next steps:

- Lessons learnt from the Yemen case study: model evaluation & context (e.g. political, institutional, etc.);
- Enhance cholera risk prediction model;
- Spatial coverage (4 km) and lead time (up to 8 weeks);
- Scaling the model up to 10 cholera-prone countries: quantitative evaluation & context;
- Consideration of whether this approach be extended to other environmentally-driven infectious diseases.

Establishment of a “Cholera Hub” should be based on an honest & equal partnership in terms of: Access to models, datasets, tools and knowledge that is mutually beneficial; and impact, mainly in relation to building

- relevance to operational decision-making (e.g. UNICEF, WHO (GTTF), UN CERF), co-designed, co-developed and underpinned by user-driven demand, and distributed ownership.

Next steps to advance the field overall:

An overall summary of the key agreements reached by the community of practice and experts attending the meeting to advance the overall field was given by Diarmid Campbell-Lendrum:

- Review and inputs to draft WHO/WMO guidance on developing climate-informed early warning systems for health;
- Review and inputs to capacity development /training package planned between PAHO, WHO-SEARO and WHO-HQ;
- Identify the most effective convening forum to carry on building this community of practice, with engagement of health and meteorological actors at national and international level.

- Development of quality criteria for model validation.

Finally, participants were thanked for their presentations and discussions, which demonstrated a high level of expertise and a rapidly growing community of practice in the field.

Annex I: Meeting Agenda

DAY 1: Tuesday 25 June 2019

Time	Activity	Presenter / Facilitator
9.00		
9.10	Opening remarks and introduction of participants Meeting objectives, overall WHO programme on climate change and health and DFID-funded project on <i>“Delivering Climate Resilient Water and Sanitation in Africa and Asia”</i>	Diarmid Campbell-Lendrum
9.35	WMO/WHO joint Office on Health and Climate and workplan on climate change and health	Joy Guillemot
9.45	UK Met Office programme on climate services for health and briefing on UNICEF project on <i>“Predicting and preparing for Cholera in Yemen”</i>	Rosa Barciela
10.00	Coffee break	
10.30	Session 1: Initial problem characterization and health sensitivity review and analysis Open discussion: <ul style="list-style-type: none"> • Defining sensitivity analysis; • Data needs, availability and access; • Data quality assessment and metadata; • Different types of analysis: challenges and opportunities; 	Joacim Rocklöv
12.30	Lunch break	
14.00	Session 2: Feasibility assessment Open discussion: <ul style="list-style-type: none"> • Strength and uncertainty of the associations; • Plausibility of the associations; • Lag time of the associations 	Hannah Nissan and Fekri Dureab
15.30	Tea break	
16.00	Session 3: Developing integrated risk forecasting and monitoring Open discussion: <ul style="list-style-type: none"> • Risk forecasting models; • Model uncertainty; • Integrated risk monitoring; • Setting thresholds; • Data visualization; • Applicability to other countries and diseases 	Jan Semenza and Nicholas Ogden
17.00	End of first day	

DAY 2: Wednesday 26 June 2019

Time	Activity	Presenter / Facilitator
9.00	Summary of key points from Day 1	Diarmid Campbell-Lendrum
09.10	Continuation session 3: Developing integrated risk forecasting and monitoring Open discussion: <ul style="list-style-type: none"> • Risk forecasting models; • Model uncertainty; • Integrated risk monitoring; • Setting thresholds; • Data visualization; • Applicability to other countries and diseases 	Laith Hussain and Albert Chen
10.30	Coffee break	
11.00	Session 4: Operationalization: designing warnings and response plans, establishing communication mechanisms with communities and pilot-testing EWS Open discussion: <ul style="list-style-type: none"> • Challenges and opportunities; • Lessons learned 	David Olson and Ahlam Al Mutawakel
12.30	Lunch break	
14.00	Session 5: Monitoring, evaluation and iterative improvement Open discussion: <ul style="list-style-type: none"> • Technical evaluation; • Community uptake; • Health outcome evaluation; • Cost-effectiveness evaluation 	Antarpreet Jutla and Anton Camacho
15.30	Tea break	
16.00	Existing training packages and capacity building tools on integration of health within health surveillance systems and climate-informed health early warning systems	Rachel Lowe and Felipe Colon
16.30	Summary of key points discussed and next steps	Diarmid Campbell-Lendrum and Rosa Barciela
17.00	Closure of the meeting	

Annex II: Participants List

PARTICIPANTS	AFFILIATION	CONTACT
AZMAN, Andrew	Johns Hopkins Bloomberg School of Public Health; Baltimore, USA	azman@jhu.edu
BHATTACHAN, Anuj	Vector Borne Disease and Research and Training Centre; Hetauda, Nepal	ipdlah@gmail.com
CAMACHO, Anton	The London School of Hygiene & Tropical Medicine; London, UK	Anton.Camacho@lshtm.ac.uk
CHADO, Edward	Ministry of Health (Epidemiology Officer); Lilongwe, Malawi	edchado71@gmail.com
CHEN, Albert	University of Exeter Exeter, UK	A.S.Chen@exeter.ac.uk
COLON-GONZALEZ, Felipe	The London School of Hygiene & Tropical Medicine; London, UK	felipe.colon@lshtm.ac.uk
DHIMAN, Ramesh Chand	National Institute of Malaria Research; Delhi, India	dhiman.rc.nimr@gov.in; r.c.dhiman@gmail.com
DUREAB, Fekri	Heidelberg Institute of Global Health; Heidelberg, Germany	fekridureab@yahoo.com
DUTTA, Shanta	National Institute of Cholera and Enteric Diseases; Kolkata, India	shanta1232001@yahoo.co.in; shanta.dutta@gov.in
HUSSAIN, Laith	University of Gothenburg Gothenburg, Sweden	laith.hussain@gu.se
JNAWALI, Shambhu Prasad	Department of Health Services Kathmandu, Nepal	jnawalisp@gmail.com
JUTLA, Antarpreet	University of Florida Gainesville, USA	Antarpreet.Jutla@mail.wvu.edu
KEBEDE, Mandefro	Bacterial Disease Surveillance and Response; Addis Ababa, Ethiopia	mandekebede@gmail.com
KEBEDE, Tilahun	Ministry of Health (National Malaria Program) Addis Ababa, Ethiopia	tilahun.kebede@moh.gov.et
LEANG, Rithea	National Dengue Control Program Phnom Penh, Cambodia	rithealeang@gmail.com
LOWE, Rachel	London School of Hygiene & Tropical Medicine; London, UK	Rachel.Lowe@lshtm.ac.uk
LUIS, Maimuna	Ministry of Health (Cholera Surveillance) Maputo, Mozambique	maimunaluis@gmail.com
LUQUERO, Francisco	Epicentre MSF Paris, France	Francisco.luquero@epicentre.msf.org
McBEAN, Fergus	Department for International Development (DFID); London, UK	F-McBean@dfid.gov.uk
MULEIA, Rachid	Eduardo Mondlane University Maputo, Mozambique	rmuleia@gmail.com

MULENGA, Shadreck	Malaria Control Program Lilongwe, Malawi	shadmulenga@yahoo.com
NISSAN, Hannah	Associate Research Scientist, Columbia University Palisades, USA	hannah@iri.columbia.edu
OGDEN, Nicholas	Public Health Agency of Canada Ottawa, Canada	nicholas.ogden@canada.ca
PEDRO, Silvia	Ministry of Health (Malaria Vector Control); Maputo, Mozambique	silviamourinhop@gmail.com
ROCKLÖV, Joacim	Umeå University Umeå, Sweden	joacim.rocklov@umu.se
SEMENZA, Jan	Scientific Assessment Section European Centers for Disease Control	JanC.Semenza@ecdc.europa.eu
SENG, Heng	Ministry of Health (Comm. Disease Control); Phnom Penh, Cambodia	senghengmoh@gmail.com
SHACKLETON, Deborah	University of Exeter Exeter, UK	dms228@exeter.ac.uk
THORPE, Joel	ACAPS, Yemen Amman, Jordan	jt@acaps.org
REMOTELY CONNECTING	AFFILIATION	CONTACT
AMONE JR, Felimone	VillageReach Maputo, Mozambique	felimone.amone@gmail.com
JOSELIN, Anne	Department for International Development (DFID); London, UK	a-joselin@dfid.gov.uk
RODO, Xavier	IS Global Barcelona, Spain	xavier.rod@isglobal.org
UK MET OFFICE	AFFILIATION	CONTACT
BARCIELA, Rosa	UK Met Office Exeter, UK	rosa.barciela@metoffice.gov.uk
OLIVIER, Stephen	UK Met Office Exeter, UK	stephen.oliver@metoffice.gov.uk
UNITED NATIONS	AFFILIATION	CONTACT
AL MUTAWAKEL, Ahlam	UNICEF Sana'a, Yemen	aalmutawakel@unicef.org
CHAVES-GONZALES, Juan	Programme Advisor, OCHA	chavesj@un.org
GRIMSICH, Greg	Humanitarian Affairs Officer, OCHA	grimsich@un.org
MILANO, Leonardo	Senior Data Scientist, OCHA	
WHO/WMO	AFFILIATION	CONTACT
ANDERSON, Laura	Global Malaria Programme, WHO Geneva, Switzerland	andersonla@who.int

APONTE VARON, John	Global Malaria Programme, WHO Geneva, Switzerland	apontej@who.int
CAMPBELL-LENDRUM, Diarmid	Climate Change and Health, WHO Geneva, Switzerland	campbelllendrumd@who.int
GREEN, Annika	Climate Change and Health, WHO Geneva, Switzerland	greenann@who.int
KROEGER, Axel	Research & Training in Tropical Diseases, WHO; Geneva, Switzerland	kroegera@who.int
LACKRITZ, Eve	Global Malaria Programme, WHO Geneva, Switzerland	lackritze@who.int
LEGROS, Dominique	High Threat Pathogens, WHO Geneva, Switzerland	legrosd@who.int
MAIERO, Marina	Climate Change and Health, WHO Geneva, Switzerland	maierom@who.int
MATHIS, Margeaux	Infectious Hazard Management, WHO; Geneva, Switzerland	mathism@who.int
MERLE, Corinne	Intervention and Implementation Research, WHO; Geneva, Switzerland	merlec@who.int
NEVILLE, Tara	Climate Change and Health, WHO Geneva, Switzerland	nevillet@who.int
OLSON, David	High Threat Pathogens, WHO Geneva, Switzerland	olsond@who.int
SALUJA, Manjeet Singh	NPO, WHO India New Delhi, India	salujam@who.int
SHUMAKE-GUILLEMOT, Joy	WHO/WMO Climate and Health Office Geneva, Switzerland	jshumake- guillemot@wmo.int
TSACHOUA, Luc	Health Emergency Preparedness, WHO; Geneva, Switzerland	tsachoual@who.int
VELAYUDHAN, Raman	Vector and Ecology Management, WHO Geneva, Switzerland	velayudhanR@who.int
VILLALOBOS PRATS, Elena	Climate Change and Health, WHO Geneva, Switzerland	villalobose@who.int
WARREN, Taylor	Monitoring and Evaluation, WHO Geneva, Switzerland	warrenk@who.int