OPEN LETTER

REVISED Climate change and health in Southeast Asia – defining research priorities and the role of the Wellcome Trust Africa Asia Programmes [version 3; peer review: 2 approved]

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v3 **First published:** 18 Oct 2021, **6**:278
https://doi.org/10.12688/wellcomeopenres.17263.1
Second version: 26 Aug 2022, **6**:278
https://doi.org/10.12688/wellcomeopenres.17263.2
Latest published: 05 Sep 2022, **6**:278
https://doi.org/10.12688/wellcomeopenres.17263.3

Abstract

This article summarises a recent virtual meeting organised by the Oxford University Clinical Research Unit in Vietnam on the topic of climate change and health, bringing local partners, faculty and external collaborators together from across the Wellcome and Oxford networks. Attendees included invited local and global climate scientists, clinicians, modelers, epidemiologists and community

Open Peer Review

Approval Status ✓ ✓

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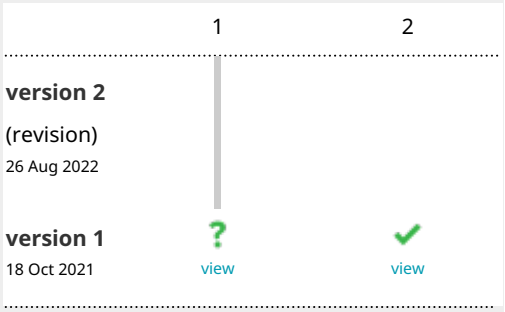
version 3 (revision) 05 Sep 2022	✓ view	

engagement practitioners, with a view to setting priorities, identifying synergies and fostering collaborations to help define the regional climate and health research agenda. In this summary paper, we outline the major themes and topics that were identified and what will be needed to take forward this research for the next decade. We aim to take a broad, collaborative approach to including climate science in our current portfolio where it touches on infectious diseases now, and more broadly in our future research directions. We will focus on strengthening our research portfolio on climate-sensitive diseases, and supplement this with high quality data obtained from internal studies and external collaborations, obtained by multiple methods, ranging from traditional epidemiology to innovative technology and artificial intelligence and community-led research. Through timely agenda setting and involvement of local stakeholders, we aim to help support and shape research into global heating and health in the region.

Keywords
climate change, global warming, global heating, southeast asia, vietnam, thailand, laos, myanmar, indonesia,



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Any reports and responses or comments on the article can be found at the end of the article.

This article is included in the Oxford University Clinical Research Unit (OUCRU) gateway.

This article is included in the Mahidol Oxford Tropical Medicine Research Unit (MORU) gateway.

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Author roles: Choisy M: Conceptualization, Writing – Original Draft Preparation, Writing – Review & Editing; **McBride A**: Conceptualization, Project Administration, Writing – Original Draft Preparation, Writing – Review & Editing; **Chambers M**: Conceptualization, Writing – Original Draft Preparation, Writing – Review & Editing; **Ho Quang C**: Writing – Original Draft Preparation; **Nguyen Quang H**: Writing – Original Draft Preparation; **Xuan Chau NT**: Writing – Original Draft Preparation; **Thi GN**: Project Administration; **Bonell A**: Writing – Original Draft Preparation; **Evans M**: Writing – Original Draft Preparation; **Ming D**: Writing – Original Draft Preparation; **Ngo-Duc T**: Conceptualization, Writing – Review & Editing; **Quang Thai P**: Writing – Review & Editing; **Dang Giang DH**: Writing – Original Draft Preparation; **Dan Thanh HN**: Writing – Original Draft Preparation; **Ngoc Nhung H**: Writing – Original Draft Preparation; **Lowe R**: Conceptualization, Writing – Review & Editing; **Maude R**: Conceptualization, Writing – Original Draft Preparation, Writing – Review & Editing; **Elyazar I**: Conceptualization, Writing – Original Draft Preparation, Writing – Review & Editing; **Surendra H**: Writing – Review & Editing; **Ashley EA**: Conceptualization, Writing – Original Draft Preparation, Writing – Review & Editing; **Thwaites L**: Writing – Original Draft Preparation; **van Doorn HR**: Conceptualization, Writing – Original Draft Preparation, Writing – Review & Editing; **Kestelyn E**: Writing – Original Draft Preparation; **Dondorp AM**: Conceptualization, Writing – Original Draft Preparation, Writing – Review & Editing; **Thwaites G**: Conceptualization, Writing – Review & Editing; **Vinh Chau NV**: Writing – Review & Editing; **Yacoub S**: Conceptualization, Supervision, Writing – Original Draft Preparation, Writing – Review & Editing

Competing interests: No competing interests were disclosed.

Grant information: This work was supported by Wellcome [106680].
The funders had no role in study design, data collection and analysis, decision to publish, or preparation of the manuscript.

How to cite this article: Choisy M, McBride A, Chambers M *et al.* **Climate change and health in Southeast Asia – defining research priorities and the role of the Wellcome Trust Africa Asia Programmes [version 3; peer review: 2 approved]** Wellcome Open Research 2022, **6**:278 https://doi.org/10.12688/wellcomeopenres.17263.3

First published: 18 Oct 2021, **6**:278 https://doi.org/10.12688/wellcomeopenres.17263.1

REVISED **Amendments from Version 2**

This update corrects a labelling error in the legend of Figure 1.

Any further responses from the reviewers can be found at the end of the article

Introduction

In November 2021, 120 world leaders attended the 26th UN Climate Change Conference (COP26) in Glasgow (UK), alongside more than 40,000 other stakeholders. This 12-day summit was dubbed as the 'world's best last chance to get runaway climate change under control'[1]; 153 participant countries agreed new 2030 emissions targets, and agreed plans to protect vulnerable communities and natural habitats, mobilise finances to make these goals achievable, and work together under the terms of the Paris agreement.

As the global community united to tackle this crisis, the Wellcome Trust also defined its research priorities around climate change and health; these are 1) to improve understanding of the effects of climate change on human health and 2) define the interventions and policies that can respond to the climate crisis in a way that protects and improves human health[2].

The Wellcome Trust Africa and Asia programmes

The Wellcome Trust Africa and Asia programmes (AAP) are embedded in the world's regions most affected by global heating, and most exposed to the impact of further climate disruptions. Southeast Asia is one of the most vulnerable regions of the world, with over 600 million people at risk of the results of global heating in the form of extreme weather events, flooding, droughts and fires, resulting in changing disease patterns, forced migration, food and water insecurity and climate refugees.

The AAPs in Southeast Asia already[3] have extensive research expertise on climate-sensitive infections including vector-borne diseases like malaria and dengue, as well as diarrheal diseases, respiratory and novel emerging infections. A further strength lies in the long-standing academic relationships in the region and being embedded within local hospitals and public health institutions in Southeast Asia; these links render the AAPs well positioned to help set the regional research agenda to ensure that we and our partners are equipped to measure, respond to, and eventually develop mitigation strategies to minimise the impact of climate change on the health of the local population over the coming decades.

The AAPs have public engagement and policy teams with strong partnerships with communities, and well-established engagement platforms– for example networks to engage with school children and youth and long-standing community advisory boards, which will enable us to partner with the public and local communities to develop a grounded and locally relevant research agenda.

The meeting (7th April 2021)

To complement global efforts through COP26, and in parallel with the Wellcome Trust defining their climate change and health agenda, a virtual meeting was organised by the Oxford University Clinical Research Unit (OUCRU) in Vietnam, which aimed to set priorities for the regional research agenda on climate and health, identify synergies in pre-existing work and future research interests, and foster collaborations between the faculty of the Wellcome and Oxford Networks and local partners. Attendees included 59 invited local and global climate scientists, clinicians, modelers, epidemiologists and community engagement practitioners. In this summary paper, we outline the major themes that were identified and what will be needed to take forward this research for the next decade. All attendees, whether attending in person or online, were welcomed to share opinions, ask and answer questions, or offer comments during the meeting.

The meeting began with overviews of pre-existing research which has relevance to climate change and health presented by each of the units in the Asian AAP. This is summarised in the section 'Climate and infectious disease research in the Asian Oxford Tropical network'. Once an inventory of research experience and opportunities had been achieved, the discussion moved on to setting the direction and agenda for future research. This is summarised in the section 'Future directions and suggested research agenda for the Asian AAPs'.

Meeting outcomes

1) Summarizing existing climate and infectious disease research in the Asian Oxford Tropical network

Over the last four decades, the Oxford Tropical Network in Southeast Asia has developed large research programmes in Vietnam, Thailand, Nepal, Indonesia, Cambodia, Myanmar and Laos, which have included a diverse portfolio of work on climate-sensitive diseases such as dengue, malaria, rickettsioses, diarrheic illnesses, respiratory and emerging infections[4–7]. The research has spanned both hospital-based and community studies (including long-term cohort studies, sentinel and passive surveillance), using various approaches ranging from clinical, microbiology and molecular epidemiology work through to entomology and mosquito-viral dynamics as well as mathematical modelling, innovative monitoring technologies and use of artificial intelligence. Although, until now, the interaction between meteorological factors and infectious diseases has not been a major research focus for these programmes, a number of important findings have been made, which, combined with decades of detailed datasets allows for more in-depth research on the interaction between climate and infectious diseases, to understand and predict changing disease burdens in the future.

Researchers at OUCRU-Vietnam are ideally placed to investigate the relationship between climate and infectious diseases, as Vietnam has a geographical range spanning almost the entire inter-tropical region (8° to 21° latitude) and an elevation ranging from sea level on the coast to more than 3,000 m in the central and northern highlands and hosts a

high diversity of ecosystems. This, combined with a large population of almost 100 million (populating all the ecological regions equally), as well as a high intensity of infectious diseases in circulation (particularly influenza, dengue and diarrhoeal diseases), has enabled detailed modelling studies of these pathogens[4,8,9].

Researchers at Eijkman-Oxford Clinical Research Unit (EOCRU), Indonesian universities and international partners are investigating the association between agricultural land-use drivers and malaria. Changing patterns of human land use, particularly related to agricultural expansion and deforestation, are suggested to be the primary drivers behind the recent spread of *Plasmodium knowlesi* in humans[10]. Strengthened practices for zoonotic malaria surveillance will assist in providing a local evidence base for policy makers to reduce disease transmission, facilitate sustainable agricultural development and enhance research capacity related to One Health methodologies.

With smaller units in Cambodia, Lao PDR, Myanmar and northern Thailand and study sites across the region, Mahidol Oxford Tropical Medicine Research Unit (MORU) in Bangkok, Thailand has led research on locally prevalent infectious diseases including malaria, melioidosis and scrub typhus over more than 4 decades. This has included working with national disease control programmes on analysis of routine malaria and dengue surveillance data to study the relationship between climate and disease patterns. Ongoing exploration of data from climate stations and satellite remote sensing together with case data at different spatial and temporal scales has revealed complex relationships that vary between locations. Data quality of climate, geographic and disease data are key determinants of the strengths of, and confidence in, these relationships. This learning is feeding into thinking about development of future analyses and predictive models of disease outbreaks and trends to help inform policy decisions.

This existing experience in investigating climate sensitive diseases, albeit not in dedicated climate studies, with the research infrastructure, and understanding of infectious disease dynamics and pathogenesis, sets the AAPs up well to further develop this into a firm and dedicated agenda for climate change studies. Their presence embedded in local health systems and experience so far shows the importance of long-term studies, the combination of data of multiple nature (entomology, epidemiology, environment, anthropology) and integrative analyses involving modelling, experiments and observational studies, all this at various spatial and temporal scales. In order to forge a dedicated research agenda for climate change within the Asia Network, the major climate-sensitive diseases currently investigated within the network (dengue, malaria, rickettsial infections, influenza and infectious diarrhoea) were discussed and areas were outlined upon which to build future research. We will also investigate whether other climate-sensitive infections currently not investigated by the network may should be added to our research agenda.

Vector-borne diseases

Dengue

The most notable example of the effect of meteorological conditions on infectious diseases concerns vector-borne infections such as dengue and malaria, which have been a major focus of research at OUCRU and MORU/EOCRU, respectively, over the last 20 years[11]. Temperature, rainfall, humidity and changing land use affect the habitat availability of many arthropods, as well as various developmental stages of their life cycle. This has allowed us to understand and predict both the geographical range and the seasonality of many vector-borne diseases[12]. In the past two decades several models have been developed for these two purposes. The most sophisticated ones explicitly account for the effect of climate change on the vector population dynamics, integrating data from entomological surveys[13]. Researchers in OUCRU-Vietnam have assembled one of the largest dengue syndromic databases in the world (monthly dengue cases in 273 provinces of 8 countries of southeast Asia over 18 years), and were able to define in great detail how high temperature drives the spatial hierarchy in dengue epidemics across the region[8].

In addition to these modelling studies, OUCRU has a large translational programme of dengue research including clinical trials, innovative monitoring systems and pathogenesis studies, as well as investigations into the susceptibility of mosquitoes to dengue virus under various environmental conditions and manipulated treatment. The capacity of commensal intracellular *Wolbachia* bacteria to block dengue virus infection of mosquitoes has been a major theme at OUCRU, with studies comparing multiple *Wolbachia* strains, evolution of dengue virus in the presence of *Wolbachia*, and assessing *Wolbachia* to block vertical transmission of dengue[14].

With encouraging results from a randomised controlled trial in Indonesia, the world mosquito programme is now investigating the feasibility to mitigate the transmission of dengue virus using large scale release of *Wolbachia*-infected *Aedes aegypti* mosquitoes in Vietnam, Indonesia and Brazil[15]. *Wolbachia* strains are sensitive to temperature, so the sustainability of this approach in a warming world will need to be continually evaluated. In that context, we are conducting experiments to assess the robustness of the *Wolbachia* effect under various temperatures and fluctuation regimens.

Recently, MORU Epidemiology Department has been working to develop models of the association between climate and dengue in Thailand and Myanmar working with the national disease control programmes using data from government climate stations and satellite remote sensing. Aiming to improve predicted trends in dengue incidence over time, including locations and timing of dengue outbreaks, these models incorporate a range of factors including reporting lags[16] and human mobility[17]. Increasingly, MORU is also collecting diagnostic and demographic data on a wide range of infectious diseases, in projects across hundreds of villages in rural areas, for example

through the South and Southeast Asian Community-based Trials Network (SEACTN)[18]). These data can improve estimates of true disease incidence and distribution which will help to improve the predictive models.

Malaria

Malaria has been a major research theme for MORU, with ongoing work on clinical trials, elimination interventions, pathogenesis trials, molecular biology, pharmacology, as well as epidemiology and mathematical modelling. MORU has a large and growing network of malaria study sites across Asia and Africa which provides access to a large quantity of high-quality clinical data. It also provides health services for malaria in several countries including in Myanmar by Medical Action Myanmar and Shoklo Malaria Research Unit and clinics in Thailand through the Borderland Health Foundation. These permit largescale collection of high-quality surveillance data to study patterns and trends and assess the impact of population level interventions. Data from Kayin State in Myanmar have been used to develop predictive models of malaria using climate data from satellite remote sensing. MORU has been working to support national malaria control programmes (NMCP) across the region. Under the Enhanced modelling for NMCP Decision-making in the Greater Mekong Subregion to Accelerate Malaria Elimination (ENDGAME) project these include development of models to answer specific policy questions[19]. With a range of climate classes and seasonality across the region and variety of mosquito vector species, these relationships are complex and there is enormous scope for future research towards optimally incorporating current and future climate trends into predictive models of malaria trends to better predict timelines to elimination and identify locations at high risk of outbreaks.

Researchers at EOCRU along with their local collaborators have extensive experience in the zoonotic malaria parasite *P. knowlesi* and understanding its geographical distribution in terms of disease risk by human, animal and vector interaction[10]. *P. knowlesi* is transmitted among macaques in a sylvatic cycle and zoonotically to humans by anopheline mosquitoes. EOCRU uses case data, climate variables, and land cover categories to generate fine-scale distribution maps for the three macaque host species (*Macaca fascicularis*, *nemestrina* and *leonina*) and two mosquito vector complexes (Dirus and Leucosphyrus Complex). Conversion of intact forest into disturbed forest or the creation of vegetation mosaics, increases the probability that Leucosphyrus Complex will thrive at these locations, as well as bringing humans into these areas.

Rickettsial infections

Rickettsial infections are widely distributed globally and transmitted by ticks, mites, lice, and fleas. Climate change may lead to changes in the environment which affect host and vector abundance and as a result impact on disease incidence. In a longitudinal study (2003 to 2017) from the Lao PDR, trends of murine and scrub typhus incidence were associated with temperature and rainfall respectively, suggesting that global heating and increased precipitation may expand the distribution and burden of these diseases[20].

Other climate-sensitive diseases

Influenza

In addition to vector-borne and environmental infectious diseases, meteorological conditions can also affect the transmission of human-to-human transmitted respiratory infectious diseases such as measles[21] or influenza[22,23]), either by affecting the survival of the virus in the air, or by changing the behaviour of the human host. Controlled experiments coupled with epidemiological modelling allow to decipher these effects. A model developed and calibrated at OUCRU-Vietnam showed that absolute humidity is the main driver of the intensity of seasonal variation of influenza-like illness (ILI)[9]. The model calibrated on Vietnamese data successfully predicted the epidemiological regimen of influenza in over 75 locations around the world. This was possible because of the large diversity of climatic conditions in Vietnam, representing a substantial proportion of the diversity of climates.

Infectious diarrhoea

Another class of infectious diseases that have been shown to be influenced by meteorological variables are those with (partial) environmental transmission. *Vibrio cholerae* is a bacterium that lives on the surface of copepods in estuaries. When such bacteria are ingested by humans, they cause cholera. This can then initiate human-to-human orofecal transmission chains and outbreaks among human populations, even in locations remote from the coast. An increase in estuary / sea surface temperature can trigger a demographic explosion of copepod populations on the surface on which *V. cholerae* thrive, thereby dramatically increasing the probability of human ingestion and triggering an outbreak. The risk of cholera outbreaks have been successfully predicted from monitoring sea surface temperature that can easily be achieved in real-time from satellite measurements[24].

A study combining epidemiology, hydrology, microbiology, and anthropology to investigate the seasonal epidemiology of diarrheal infections in northern Laos found that enteric bacteria concentration in river water was higher during flooding. However, paradoxically, the incidence of diarrhea was higher in the dry season than the rainy season, likely driven by the population forced to use highly contaminated surface water instead of clean naturally filtered well water, highlighting the importance of community and behavioural studies and engagement[4].

Challenges of climate change models and infections

Disease models are increasingly used to tackle the more challenging task of anticipating the consequences of climate change on the burden of infectious diseases[25,26]. The challenge comes from the fact that we are dealing with an extrapolation exercise for conditions that have never been experienced before and thus have no data available yet. Mathematical models explicitly accounting for the biological mechanisms of each life-cycle step are expected to produce more robust predictions than classical black-boxes approaches, such as classical statistical analysis or even more sophisticated machine learning approaches[27]. Difficulties when exploring the link between meteorological conditions and infectious diseases are

that transmission also depends on a myriad of human factors such as population density, susceptibility, age structure and mobility etc., which makes the identification of the exact effects of meteorological variables more complicated[28,29].

Furthermore, the effects of meteorological conditions are often non-linear[30,31]. In general, biological processes have an optimal range rather than a linear relationship with temperature[32]. Effects can also be multiple, partially contradictory, with various delays, and also more or less direct. Heavy rainfalls may for example wash-up mosquito populations in the short term but prepare for optimal breeding sites and humidity conditions in the longer term[33]. As for assessing the epidemiological impact of climate change, an additional complication relates to the fact that the host, the pathogen and the vector can adapt to these changes, and this has already been documented[34]. Such adaptations clearly add a large degree of uncertainty to any prediction that can be made. So far, we have discussed the effect of meteorological variables on the vector only, but it is also well documented that the development time of the etiologic agent in the vector (extrinsic period) is highly dependent on temperature too[35].

2) Future directions and suggested research agenda for the Asian AAPs

1) The need for high quality long-term longitudinal data

Climate change and its effects occur over multiple years and decades, and our previous research has shown the necessity of data collected over long periods of time to be able to conduct attribution studies. Furthermore, to support accurate understanding of the impact of global heating, it is important that the data used are accurate at multiple spatial scales (global, regional, local). We discussed several different mechanisms of obtaining data to complement clinical and laboratory studies; these include data collection systems based on satellite technology incorporating meteorological, topological, ecological data, downscaling data from global models to produce local, high-resolution data and using mHealth/drones for data gathering at the local level.

A crucial part of recognizing the potential health impacts of climate related hazards is identifying changes in disease patterns over time and linking these to climate related parameters, land-use change/ecology changes/biodiversity loss. This then allows development of accurate models to predict future health threats, and can result in health system and policy changes to prepare for these. However, for this to be possible, data collection with sufficient geographical density at different levels of the health system is required. The Wellcome AAPs in Asia are well positioned to capture such data in their wide network of intensive care units (ICUs), hospitals, and community-based health workers. Wellcome Innovations supports a large Asian ICU Flagship programme, jointly led by OUCRU and MORU. Part of the programme has been the establishment of an electronic ICU registry, which captures information on diagnosis and disease severity. The registry is currently running in 15 Asian (as well as 9 African) countries, including 231 hospitals, and still expanding. A parallel Wellcome Innovations Flagship programme supports the Southeast Asia Community-Based Trials Network[36], which comprises large networks of community health workers in Myanmar, Laos, and Cambodia. In Vietnam and Indonesia, networks encompass both human and animal health monitoring at community level. In addition, OUCRU and MORU research units together have an extensive network of over 100 clinical trial sites across 11 Asian countries (Figure 1).

With this infrastructure in place, we plan for the next five years to systematically capture the changes in disease burden and disease patterns, as well as climate related data. This will deliver an invaluable data source for interrogation with the aim to identify specific climate hazard related health impacts. This will then serve as a starting point to design interventions to counter these adverse health outcomes.

Another challenge regarding investigation of the climate effects on health in general is that climatic and health data are often produced at different spatial and temporal scales and resolutions[37]. In order to address this issue, we will explore the combination of (i) mechanistic models of the effect of climatic variables on the biological processes of these epidemiological systems and (ii) more agnostic machine-learning-type of modelling in order to identify relevant proxies across scales. The general approach is inspired from methodologies currently developed in downscaling research.

2) The need for local and international interdisciplinary collaboration

To supplement high quality clinical and epidemiological data obtained by traditional research methods, cross-disciplinary collaboration will be required to mount the broad approach for a such a challenge such as climate change. Internal collaboration between clinicians, data scientists and mathematical modelling teams should be supplemented by cross discipline work with anthropology, microbiology, entomology and public health. Collaboration between the Wellcome AAPs in both continents will help to optimise use of resources, align data collection and linkage across diverse datasets to provide a more regionally holistic picture.

In addition, obtaining and processing high quality meteorological and climate data will require collaboration outside of our established network. We have identified several projects underway by local and international research groups using advanced mapping technologies, early warning systems and artificial intelligence to model accurate impacts of climate change on both local, regional and national level. For example, a dengue warning system from London School of Hygiene and Tropical Medicine (LSHTM)[38], and the Vietnam space mapping technology. Working with meteorologists, hydrologists, environmental scientists, engineers and anthropologists may also be key to implementing sustainable interventions.

3) The need for innovation - mhealth

Climate related data are collected through a variety of methods, including weather stations and satellites. Recent technological innovations offer novel and improved approaches to both the surveillance and response to climate-driven health challenges. Mobile Health (often abbreviated to mHealth) incorporates the use of mobile devices, patient monitoring devices, and other wireless technologies. Use of such devices enable a

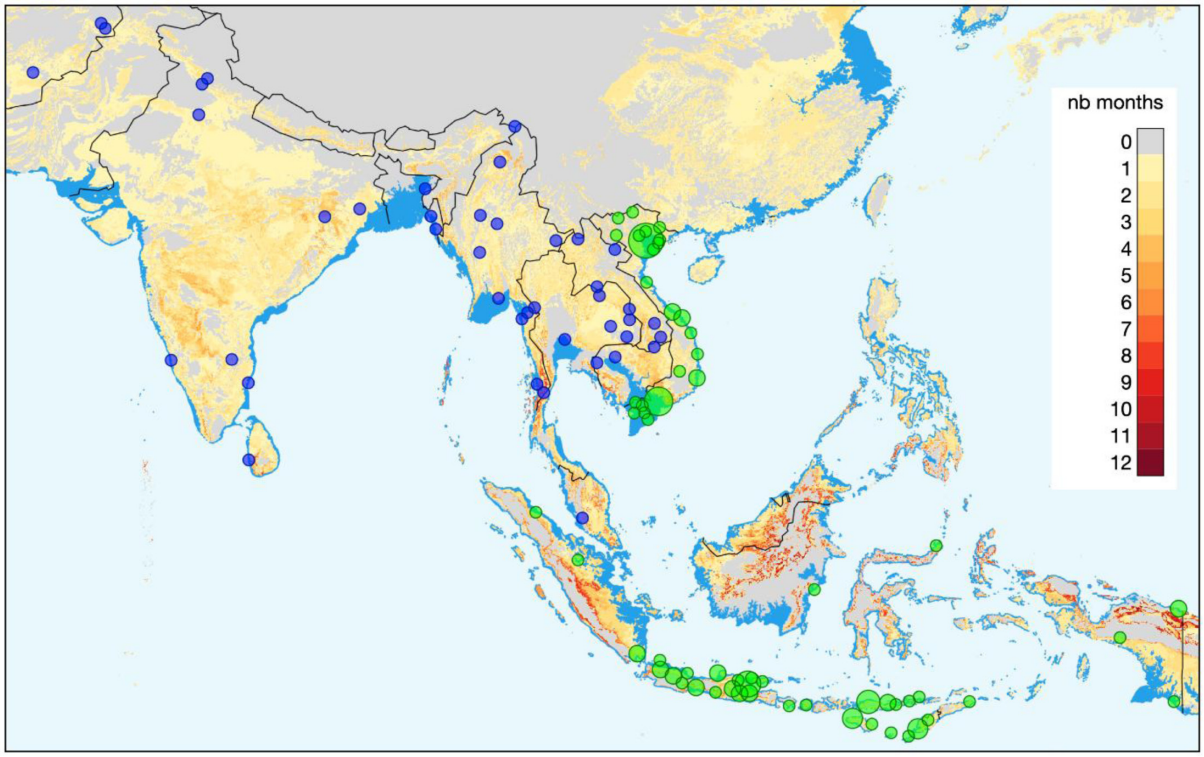

Figure 1. Locations of the Oxford University Clinical Research Unit (green) and Mahidol Oxford Tropical Medicine Research Unit (MORU) (blue) study sites. MORU additionally has study sites in Eastern Africa that are not shown here. The background colours of the map represent the additional number of months per year that are predicted to have a monthly average maximum temperature above 30°C over the 2081–2100 time period (based on data simulated by the CNRM-CM6-1 GCM model with the SSP 126 and obtained from WorldClim. The dark blue color shows the coastal area lost to sea by 2100.

range of functions, such as sending and receiving messages, as well as more advanced technologies, including Global Positioning Systems (GPS). Such devices and technologies enable more timely and accurate collection of data, particularly in remote regions, and offer many potential applications with regards to health promotion and protection. Satellite systems monitor the meteorological, environmental, and physiological status that may influence the transmission of certain infectious diseases. This data can be used to augment meteorological data collected at regional or national level and enable the development of effective surveillance and early warning systems. When combined with pattern recognition and disease trends, satellite data may enable disease outbreaks to be predicted in advance[39].

We plan to integrate these unique approaches to both the surveillance and response to climate-driven health challenges, incorporating novel digital technologies, remote patient monitors, mHealth initiatives, artificial intelligence (AI) methodologies with satellite-assisted data systems. For example, we intend to integrate AI algorithms into existing surveillance systems, which will enable faster and more accurate processing of large amounts of data, resulting in more precise detection and prediction of disease outbreaks.

4) Need for individual as well as population level research

Changes in weather patterns and increasing frequency of extreme weather events exert important, diverse effects at an individual patient level. Increased hospitalisations and mortality are directly attributable to human-induced global heating[40,41]. In regions experiencing higher ambient temperatures (i.e. temperatures that people are experiencing, as opposed to temperature from weather stations that are measured in very specific controlled conditions), heat stress causes many health impacts including deranged physiological processes such as water handling and electrolyte balance. Direct heat stresses also affect cardiovascular[42] and renal health[43], and exacerbate dehydration and shock in infections. Southeast Asia and other tropical regions are already experiencing the health impacts of extreme heat, but are predicted to be more severely affected in coming years[40,44]. Estimations of the impact of occupational heat (e.g., in outdoor workers) in South East Asia by 2050 are extreme[45,46]. Research from the military and sports medicine indicate that wearable technology and ingestible core telemetry pills can be used to identify heat strain early, allowing mitigation strategies such as active cooling[47]. A priority area for research going forward is identifying at-risk groups like outdoor workers, pregnant women, children and the elderly and tailoring solutions to individual patients[48].

For hospitalised patients, clinical decision-making is affected by climate variables. Established relationships between seasonality and prevalence of infections are implicit knowledge taken into account by clinicians: for example, in wet season the increased prevalence of dengue in SE Asia has implications on the diagnosis and management of acute febrile illnesses and affects effectiveness of treatment and diagnostics as a function of positive and negative predictive value. Changing climatic variables can present challenges for vector-borne diseases by establishing new areas of autochthonous transmission, as well as changing seasonal epidemiology. The development of data-driven tools such as clinical decision support systems (CDSS) aimed at providing support in the management of illness will increasingly need to explicitly acknowledge and account for these variables, and integrate with outbreak models. Thus, we envisage that CDSS of the future would be tailored and contextualised to geographic location, season and climate.

5) The need for public and policy engagement

The final area identified as a key component of the future AAP programme is that of public and policy engagement, with the goals of (1) better understanding the potential impact of climate change on wellbeing and mental health, (2) learning the research priorities of vulnerable communities in relation to climate change, and (3) expanding our collaborations outside of the scientific community (4) Engaging with government and key policy-makers.

Although climate change is recognised as a health emergency, this is predominantly referred to as a physical health emergency, often with little reference to mental health. However, there is increasing evidence that both the drivers and consequences of climate change can threaten emotional wellbeing[49]. In addition, eco-anxiety (worry about the environment) can cause psychological distress. Eco-anxiety, defined by the American Psychological Association as "a chronic fear of environmental doom", is not recognised as a disorder and in fact, may be an appropriate reaction to the climate emergency. Indeed, when linked to increased activism and a sense of empowerment, it can have positive impacts on mental health[50]. Research on the psychological effects in young people is scarce although they are likely to be disproportionately affected, and the few published studies have focused on youth in the Global North or amongst indigenous peoples[51–53]. However, an increase in online discussions and posts on this topic from Asian and African young people suggest that despite the lack of data, this anxiety isn't a uniquely first world problem and is likely to be linked to the rising cases of poor mental health in children and youth in low and middle income countries[54–56].

Engagement activities will need to be tailored to sociocultural settings across the networks – and therefore need to be designed and driven in collaboration with the community. We plan to engage with the public, particularly youth, who are major stakeholders in climate change and empower them to take action, advocate for change and develop solutions. Climate change and mental health are priority areas already identified by the OUCRU facilitated Youth Engagement with Science (YES) group – a collective of over 800 Vietnamese young people.

In addition to community engagement, we also have an active policy engagement team within the AAPs. In Vietnam we are currently working with various government institutions including; the ministry of Health (MoH), department of health (DoH) provincial CDCs, national, provincial and district hospitals, national public health agencies (Pasteur Institute, NIHE in Hanoi), and the National Bureau of Meteorology and of Natural Resources and Environment (MONRE and DONRE). Going forward we plan to increase engagement and discussion around our climate and health research with these key stake-holders and policy-makers at national and provincial levels

Finally, we do not wish to limit our collaboration to the scientific community. Through collaboration with other stakeholders such as non-governmental organisations, community-based organisations and embassies, we aim to expand our reach and encourage action to be taken in local and national policy-making spheres.

Summary

Going forward, we aim to take a broad, collaborative approach to including climate science in our current portfolio where it touches on infectious diseases now, and more broadly in our future research directions. Box 1 summarises our next steps and research priorities. We will focus on building our research upon climate-sensitive diseases with which we already have considerable experience, and supplement this with high quality data obtained from internal studies and external collaborations, obtained by multiple methods, ranging from traditional epidemiology to innovative technology and artificial intelligence and community-led research. Through timely agenda setting and involvement of local stakeholders, we aim to help support and shape research into global heating and health in the region.

Box 1. Next steps and priorities

- To build a regional network of climate and health collaborators/stakeholders
- Identify local and regional climate-sensitive infectious disease risk, with the eventual aim of enabling the design and testing of interventions.
- Develop innovative solutions to climate-driven health challenges, through integration of novel digital technologies, remote patient monitors, mHealth initiatives and artificial intelligence (AI) methodologies, including:
  - AI-assisted surveillance /satellite-assisted data systems for geospatial risk mapping of climate-sensitive diseases (including vector-borne and water-borne diseases)
  - Incorporate meteorological data into clinical decision support systems for individual management of acute febrile illnesses.
- Develop engagement activities with vulnerable communities to understand their priorities and the potential impact of climate change on mental health, facilitated by the OUCRU Youth Engagement with Science programme.
- Expand our communication and engagement with government and non-governmental organisations, community-based organisations and embassies to develop action to be taken in local and national policy-making spheres.

Data availability

No data are associated with this article.

Acknowledgments

Meeting attendees

OUCRU Ho Chi Minh City

Sophie Yacoub

Guy Thwaites

Marc Choisy

Mary Chambers

Angela McBride

Trieu Huynh Trung

Louise Thwaites

Vuong Nguyen Lam

Nhat Phung Tran Huy

Duyen Huynh Thi Le

Nguyet Nguyen Minh

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Jo Millar (Oxford University)

Rachel Lowe (London School of Hygiene and Tropical Medicine (LSHTM))

Ana Bonell (LSHTM and MRC Gambia)

Megan Evans (Leicester University)

Damien Ming (Imperial College London)

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Open Peer Review

Current Peer Review Status: ✔ ✔

Version 3

Reviewer Report 21 September 2022

https://doi.org/10.21956/wellcomeopenres.20348.r52243

✔ **Hannah Nissan**
[1] Grantham Institute for Climate Change and the Environment, London School of Economics and Political Science, London, UK
[2] Climate and Resilience Hub, Willis Towers Watson, London, UK

No further comments.

Competing Interests: No competing interests were disclosed.

Reviewer Expertise: Climate science and modelling; climate information and its use for public health control programmes; climate change.

I confirm that I have read this submission and believe that I have an appropriate level of expertise to confirm that it is of an acceptable scientific standard.

Version 1

Reviewer Report 04 July 2022

https://doi.org/10.21956/wellcomeopenres.19080.r51313

✔ **Paul Lester Chua**
Department of Global Health Policy, Graduate School of Medicine, The University of Tokyo, Tokyo, Japan

This open letter is a timely piece to disseminate and encourage efforts in conducting climate change and health research in Southeast Asia (SEA), wherein most countries are vulnerable to climate change impacts. The Asian Oxford Tropical network is indeed in a good position to perform this work with the good quality data they collected or can collect to the benefit of climate change and health researchers (e.g. modelers). One concern I have in this open letter is the message of “exclusivity” within the network they have (presumably driven by Western counterparts) rather than consider expanding collaborations with existing efforts from all nations in SEA (i.e. ASEAN countries). The authors did mention local collaboration but seem like they only refer to cross disciplines and community engagement. The proposed directions may leave out certain research efforts (e.g. existing local work or datasets) in and outside the SEA countries they work with. This message may be a personal observation and was never intended since this open letter solely reflects the discussions that came out from the participants of the virtual meeting. Nonetheless, the authors' pursuit of climate change and health research in SEA is still a commendable endeavour making this open letter relevant.

Some specific comments:

Introduction

- The first sentence in the first paragraph needs to be updated: "*At the end of 2021, more than 190 world leaders will attend the 26th UN Climate Change Conference (COP26) in Glasgow (UK), alongside thousands of other stakeholders".*

- In the first sentence of the second paragraph, does Wellcome Trust intend to carve its own rather than align to the global efforts? "*the Wellcome Trust is defining its own research priorities and agenda around climate change and health".*

- If possible, please include citations in the third and fourth paragraphs like a webpage summarising AAP work.

- It may be better to mention the date of the virtual meeting and the number of participants.

Climate and infectious disease research in the Asian Oxford Tropical network

- As mentioned in the last sentence of this section, how were major climate-sensitive diseases selected in SEA? Were they selected based on the perceptions or expertise of the participants? There is a possibility there are other “major” climate-sensitive diseases being missed out.

- In Figure 1, why use SSP 1-RCP 2.6? Would it be closer to reality using SSP2-RCP 4.5? Why also limit to temperature? Would climate categories or precipitation be created as well?

Future directions and suggested research agenda for the Asian AAPs

- Would the authors be confident to say that the AAP's wide network of intensive care units (ICUs), hospitals, and community-based health workers will be able to capture the major climate-sensitive infectious diseases? Are governmental health facilities excluded from this AAP work?

- In the last paragraph (and in the entirety of the piece), there was no mention of collaborating or interacting with governments. It is understandable that SEA governments

are usually not open to research collaboration because of many reasons, but translating research into policy requires their cooperation. It may be good to consider how to interact with them in the future.

Explanation on some of the set questions:

- ***Does the article adequately reference differing views and opinions?***
  The point of view of the open letter only reflects the discussion in the virtual meeting and there are no opposing views/opinions.

- ***Are all factual statements correct, and are statements and arguments made adequately supported by citations?***
  The strong statements on the achievements of the AAP and/or Asian Oxford Network would be better to be fully referenced like in the third and fourth paragraphs of the "Introduction" and first, third, fourth, and fifth paragraphs of "Climate and infectious disease research in the Asian Oxford Tropical network".

Is the rationale for the Open Letter provided in sufficient detail?
Yes

Does the article adequately reference differing views and opinions?
Partly

Are all factual statements correct, and are statements and arguments made adequately supported by citations?
Partly

Is the Open Letter written in accessible language?
Yes

Where applicable, are recommendations and next steps explained clearly for others to follow?
Yes

Competing Interests: No competing interests were disclosed.

Reviewer Expertise: Climate change and health

I confirm that I have read this submission and believe that I have an appropriate level of expertise to confirm that it is of an acceptable scientific standard.

Author Response 18 Aug 2022

Angela McBride, Oxford University Clinical Research Unit, Ho Chi Minh City and Hanoi, Vietnam

Many thanks for taking the time to review this open letter.

This open letter is a timely piece to disseminate and encourage efforts in conducting climate change and health research in Southeast Asia (SEA), wherein most countries are vulnerable to climate change impacts. Thea Asian Oxford Tropical network is indeed in a good position to perform this work with the good quality data they collected or can collect to the benefit of climate change and health researchers (e.g. modelers). One concern I have in this open letter is the message of "exclusivity" within the network they have (presumably driven by Western counterparts) rather than consider expanding collaboration with existing efforts from all nations in SEA (i.e. ASEAN countries). The authors did mention local collaboration but seem like they only refer to cross disciplines and community engagement. The proposed directions may leave out certain research efforts (e.g. existing local work or datasets) in and outside the SEA countries they work with. This message may be a personal observation and was never intended since this open letter solely reflects the discussions that came out from the participants of the virtual meeting. Nonetheless, the authors' pursuit of climate change and health research in SEA is still a commendable endeavour making this open letter relevant.

Author response: Thank you for your comment. Our network is by no means 'exclusive'; we have extensive local collaborators within Vietnam and other ASEAN countries (as explained on p8). This initial meeting included our current local partners, but one of the outcomes of the meeting, (as stated in Box 1) and one of our first priorities is 'to build a regional network of climate and health collaborators/stakeholders.'

Some specific comments:
Introduction
The first sentence in the first paragraph needs to be updated: "At the end of 2021, more than 190 world leaders will attend the 26th UN Climate Change Conference (COP26) in Glasgow (UK), alongside thousands of other stakeholders".

Author response: Good point. Updated.

In the first sentence of the second paragraph, does Wellcome Trust intend to carve its own rather than align to the global efforts? "the Wellcome Trust is defining its own research priorities and agenda around climate change and health".

Author response: No, Wellcome certainly aligns to the global efforts. What we meant here is that Wellcome is developing a research agenda within that global effort and that this agenda is focused on the consequences of climate change on health. Hopefully, the text reflects this more clearly now.

If possible, please include citations in the third and fourth paragraphs like a webpage summarizing AAP work.

Author response: A link has been provided to the Wellcome Trust overview of the Africa Asia Programmes.

It may be better to mention the date of the virtual meeting and the number of

participants.

Author response: This has been added.

Climate and infectious disease research in the Asian Oxford Tropical network
As mentioned in the last sentence of this section, how were major climate-sensitive diseases selected in SEA? Were they selected based on the perceptions or expertise of the participants? There is a possibility there are other "major" climate-sensitive diseases being missed out.

Author response: These diseases were selected based on the diseases that AAP is currently working on and for which climate sensitivity has been shown by us or others. It is certainly not exhaustive and it is possible that some key infections are missed out; if this is the case, then it is also one of our goals to identify and potentially develop new research on them.

In Figure 1, why use SSP 1-RCP 2.6? Would it be closer to reality using SSP2-RCP 4.5? Why also limit to temperature? Would climate categories or precipitation be created as well?

Author response: Good point. The new version of Figure 1 now shows both temperature change and rise in sea level which is expected to be of primary concern given that most of the population actually lives by the sea in this part of the world. As for the choice of the scenario, that could indeed be argued. SSP2-RCP 4.5 is indeed closer to reality unfortunately. We chose SSP1-RCP 2.6 for the figure in order to provide a conservative projection.

Future directions and suggested research agenda for the Asian AAPs
Would the authors be confident to say that the AAP's wide network of intensive care units (ICUs), hospitals and community based health workers will be able to capture the major climate-sensitive infectious diseases? Are governmental health facilities excluded from this AAP work?

Author response: No, government health facilities are not excluded, in fact, many of the AAPs are based within government hospitals (e.g. the Hospital for Tropical Diseases in Ho Chi Minh City) and our network covers the full range of healthcare settings from ICUs through to community health care centers. So we should be well placed to capture changing patterns of climate-sensitive diseases presenting to these healthcare facilities.

In the last paragraph (and in the entirety of the piece), there was no mention of collaborating or interacting with governments. It is understandable that SEA governments are usually not open to research collaboration because of many reasons, but translating research into policy requires their cooperation. It may be good to consider how to interact with them in the future.

Author response: Thank you for highlighting this, as this is an extremely important area of work for the AAPs and we have a very active engagement and policy team. In Vietnam, we are currently working with various government institutions including; the Ministry and

Department of Health (MoH and DoH), provincial CDCs, national, provincial, and district hospitals, national public health agencies (Pasteur Institute, NIHE in Hanoi), and the National Bureau of Meteorology and of Natural Resources and Environment (MONRE and DONRE). We have updated the manuscript on p15.

Competing Interests: No competing interests were disclosed.

Reviewer Report 20 June 2022

https://doi.org/10.21956/wellcomeopenres.19080.r50668

?

Hannah Nissan
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[2] Climate and Resilience Hub, Willis Towers Watson, London, UK

Detailed explanation for the answers to the set questions

Is the rationale for the Open Letter provided in sufficient detail?
The article could be improved by providing more comprehensive background information about the rationale for the meeting it describes and what it achieved (see below).

Does the article adequately reference differing views and opinions?
The article does not cite differences of opinion; perhaps none were raised in the meeting. I am not sure exactly of the makeup of the team involved, but it appears that some perspectives may be absent – e.g. climate and meteorological expertise/services, and operational disease control programmes. It would be advisable to engage these communities in a genuine dialogue before finalising a research agenda and way forward.

Are all factual statements correct, and are statements and arguments made adequately supported by citations?
To the best of my knowledge, yes, except for a few statements which require citations (see below).

Is the Open Letter written in accessible language?
Yes. In general, the paper would benefit from more precise language in a few places.

Where applicable, are recommendations and next steps explained clearly for others to follow?
Recommendations are clearly included, but these should be more precisely described, and an explanation given for how they will be achieved.

Report

Introduction
In addition to improving the overall framing of the paper and providing more detail about the rationale for the meeting (see Q1 above), the paper would benefit from a description of the process that was followed to engage participants before and during the meeting to elicit responses? How were differing viewpoints reconciled? The article does not express any differences of opinion. Was everyone in agreement?

A point about structure: it is not currently clear where the description of the outcomes of the meeting begin (until one arrives at the section “Future directions and suggested research agenda for the Asian AAPs” on page 6). The section 'climate and infectious disease research in the Asian Oxford Tropical Network' could be describing the outcomes of the meeting or part of the background literature. Some clarity over the different sections of the article would make it easier for the reader. I would also suggest including an overview of the article structure in the introduction for further clarity.

Could the relationship between the AAPs and the Oxford Tropical Network be clarified?

Climate and infectious disease research in the Asian Oxford Tropical network
A reference is needed for the statement: “Changing patterns of human land use, particularly related to agricultural expansion and deforestation, are suggested to be the primary drivers behind the recent spread of *Plasmodium knowlesi* in humans.”

First paragraph on page 5: “Data quality of climate, geographic and disease data are key determinants of the strengths of these relationships.” Wouldn’t data quality be a key determinant of confidence in an assessed relationship, not just its strength?

Some claims in the second paragraph of page 5 require substantiation: “Their presence embedded in local health systems and experience so far shows the importance of long-term studies, the combination of data of multiple nature (entomology, epidemiology, environment, anthropology) and integrative analyses involving modelling, experiments and observational studies, all this at various spatial and temporal scales.” Where do these findings come from?

Vector-borne diseases
The structure is not clear. This section reads as a summary of existing work on these topics rather than a research agenda. The reader expects a research agenda, given the framing in the abstract and introduction. Please clarify where the background literature review ends and the research agenda begins.

Challenges of climate change models and infections
This section provides a thorough discussion of the challenges from the perspective of infectious disease modelling, but there are major challenges around the uncertainties arising from the boundary conditions that are not discussed (i.e. the climate forcings used for these types of modelling studies). Appropriate expertise within the research team is essential adequately to account for the complexities of climate modelling and its uncertainties. I cannot tell for sure, but the absence of a discussion of the strengths and limitations of climate models implies that this expertise is not represented in the author team. This imbalance should be addressed before

finalising any research agenda, in particular before deciding on experimental designs and analytical approaches.

Future directions and suggested research agenda for the Asian AAPs

1) The need for high-quality, long-term, longitudinal data

The authors discuss the need for data at multiple spatial scales and densities. Another major challenge with using longitudinal population data for climate-health research is that the two datasets are often sampled at inappropriate temporal frequencies to capture the relationships between climate/weather drivers and health outcomes. Did the participants discuss these challenges and how to overcome them to achieve their research agenda? They may wish to consult a recent report produced for the Wellcome Trust on this topic[1].

2) The need for local and international interdisciplinary collaboration

Has the author team considered including the relevant National Meteorological Services, not just researchers? This would be advisable.

4) Need for individual as well as population level research

“In regions experiencing higher ambient temperatures, heat stress causes many health impacts including deranged physiological processes, such as water handling and electrolyte balance.” What is meant by 'ambient' in this sentence? Deaths occur from the heat at relatively moderate temperatures, not only extremes.

5) The need for community engagement

The participants identified three goals of community engagement. Supporting operational disease control programs was not mentioned. Did the participants discuss this? Supporting operational disease programming would surely represent an important perspective when setting the research agenda if the intention is to reduce climate-related disease burdens (see also comments below).

Box: Next steps and priorities

This box is a useful addition to the article but would benefit from being specified more precisely. How will these be achieved? The second point, in particular, is very far-reaching. It seems that you have already prioritised climate-sensitive diseases in this paper, and by the topics that you chose to discuss during the meeting. Is this point more about better understanding and quantifying the risks from these diseases?

This is the first place where interventions are mentioned. If the ultimate aim is to reduce climate-related disease risks, surely supporting practical disease programming and operations should be important to the research agenda. It is of course necessary to understand climate-health associations via traditional epidemiological research, but also to understand both where the entry points are for designing new interventions and (often overlooked) how climate could interfere with existing disease control and elimination efforts. Reducing these risks will involve some use of climate data and potentially forecasts, and research questions can be designed with these interventions in mind. Failing to include them at this stage would miss an important opportunity to ensure that the research outcomes are useful for developing effective interventions.

One further question/clarification: why are youth groups specifically the focus of the engagement about climate and mental health?

References
1. Nissan H, Diggle PJ, Fronterre C: Combining climate and health data: challenges and opportunities for longitudinal population studies. *Wellcome Trust*. 2022. Reference Source

Is the rationale for the Open Letter provided in sufficient detail?
No

Does the article adequately reference differing views and opinions?
Partly

Are all factual statements correct, and are statements and arguments made adequately supported by citations?
Yes

Is the Open Letter written in accessible language?
Yes

Where applicable, are recommendations and next steps explained clearly for others to follow?
Partly

Competing Interests: No competing interests were disclosed.

Reviewer Expertise: Climate science and modelling; climate information and its use for public health control programmes; climate change.

I confirm that I have read this submission and believe that I have an appropriate level of expertise to confirm that it is of an acceptable scientific standard, however I have significant reservations, as outlined above.

Author Response 18 Aug 2022

Angela McBride, Oxford University Clinical Research Unit, Ho Chi Minh City and Hanoi, Vietnam

Many thanks for taking the time to review this open letter.

In addition to improving the overall framing of the paper and providing more details about the rationale for the meeting (see Q1 above), the paper would benefit from a description of the process that was followed to engage participants before and during the meeting to elicit responses? How were differing viewpoints reconciled? The article does not express any differences of opinion. Was everyone in agreement?

Author response: A broad range of opinions were aired at the meeting, mostly relating to the variety of participant backgrounds (infectious disease doctors, mathematical modellers, climate scientists, etc.), but the overarching goals certainly appeared to be aligned, and complementary rather than contradictory.

We will continue to make sure that a broad range of perspectives and expertise is represented within our collaborative projects. For example, within Vietnam, we will be working with the Vietnam Institute of Meteorology, Hydrology and Climate Change (IMHEN), the National Institute of Hygiene and Epidemiology (NIHE), the Pasteur Institute of Ho Chi Minh City, and the Centers of Disease Control at provincial levels (in particular, Hanoi and Ho Chi Minh City).

A point about structure: it is not currently clear where the description of the outcomes of the meeting begin (until one arrives at the section "Future directions and suggested research agenda for the Asian AAPs" on page 6). The section 'climate and infectious disease research in the Asian Oxford Tropical Network' could be describing the outcomes of the meeting or part of the background literature. Some clarity over the different sections of the article would make it easier for the reader. I would also suggest including an overview of the article structure in the introduction for further clarity.

Author response: Regarding clarity of structure, the revised article introduction includes an overview as suggested. To clarify, the Asian AAP is a very broad programme (more than 1000 staff) spread over six countries in Southeast Asia. This is clearly an asset for us, as highlighted in the article. But it also represents a challenge to maintain cohesion in research programmes across the AAP. Since the intersection between climate change and infectious diseases is a new research topic for the Asian AAP, the first part of the meeting actually focused on making an inventory of opportunities for the Asian AAP to work on the topic – this is what is transcribed in the article until the section "Future directions and suggested research agenda for the Asian AAPs".

Could the relationship between the AAPs and the Oxford Tropical Network be clarified?

Author response: AAP is a funding programme of The Wellcome Trust, whereas the Oxford Tropical Network (OTN) is a research network of the University of Oxford. A substantial part of the research done in the OTN is funded by the AAP, but the AAP also funds research carried out by other institutions outside of the University of Oxford (e.g. LSHTM, University of Liverpool).

A reference is needed for the statement "Changing patterns of human land use, particularly related to agricultural expansion and deforestation, are suggested to be the primary drivers behind the recent spread of Plasmodium knowlesi in humans".

Author response: This is reference 17.

First paragraph on page 5: "Data quality of climate, geographic and disease data are key determinants of the strengths of these relationships.". Wouldn't data quality be a key determinant of confidence in an assessed relationship, not just its strength?

Author response: Certainly, thanks for the comment. We will alter the text accordingly.

Some claims in the second paragraph of page 5 require substantiation: "Their presence embedded in local health systems and experience so far shows the importance of long-term studies. The combination of data of multiple nature (entomology, epidemiology, environment, anthropology) and integrative analyses involving modelling, experiments and observational studies, all this at various spatial and temporal scales." Where do these findings come from?

Author response: This comes from our past research experience in the region.

Vector-borne diseases

The structure is not clear. This section reads as a summary of existing work on these topics rather than a research agenda. The reader expects a research agenda, given the framing in the abstract and introduction. Please clarify where the background literature review ends and the research agenda begins.

Author response: Yes, this is a summary of past and existing work in the Asian AAP. This is the case not only for this paragraph but all the paragraphs until the "Challenges of climate models and infections" section. As said above, the meeting that we are reporting in this article had two goals: (1) making an inventory of opportunities and past research on the topic of climate change and infectious diseases, and (2) identifying key points to research further in the future (which is the last section of the article: "Challenges of climate models and infections"). We have now made this structure clearer in the introduction. Of note though, what you refer to as "background literature" is mostly about the past research conducted in the Asian AAP, in particular.

Challenges of climate models and infections

This section provides a thorough discussion of the challenges from the perspective of infectious disease modelling, but there are major challenges around the uncertainties arising from the boundary conditions that are not discussed (i.e. the climate forcings used for these types of modelling studies). Appropriate expertise within the research team is essential to adequately account for the complexities of climate modelling and its uncertainties. I cannot tell for sure, but the absence of a discussion of the strengths and limitations of climate models implies that this expertise is not represented in the author team. This imbalance should be addressed before finalising any research agenda, in particular before deciding on experimental designs and analytical approaches.

Author response: Thank you, this is an important point. Assoc Prof Rachel Lowe from LSHTM and Prof Thanh Ngo-Duc from Hanoi University of Science and Technology were present at the meeting and have expertise in climate models. However, we recognised that this was an under-represented and key area, so we have now expanded our collaboration to climate scientists in the department of Physics at Oxford University and in the European Centre for Medium-Range Weather Forecast (ECMWF) which provides the world's leading operational global numerical weather prediction on time scales from days, weeks, months, and seasons.

Future directions and suggested research agenda for the Asian AAPs

1) The need for high quality, long term, longitudinal data
The authors discuss the need for data at multiple spatial scales and densities. Another major challenge with using longitudinal population data for climate-health research is that the two datasets are often sampled at inappropriate temporal frequencies to capture the relationships between climate/weather drivers and health outcomes. Did the participants discuss these challenges and how to overcome them to achieve their research agenda? They may wish to consult a recent report produced for the Wellcome Trust on this topic.

Author response: That is an excellent point that we have indeed identified and discussed extensively after the meeting. In fact, this specific point was listed in our research agenda that we presented to Wellcome in March during their evaluation of our research agenda to begin October 2022. One line of investigation we want to develop in order to address this issue involves the combination of (i) mechanistic models of the effect of climatic variables on the biological processes of these epidemiological systems, and (ii) more agnostic machine-learning-type of modelling in order to identify relevant proxies across scales. The general approach is inspired by methodologies currently developed in downscaling research.

2) The need for local and international interdisciplinary coloration
Has the author team considered including the relevant National Meteoroligcal Services, not just researchers? This would be advisable.

Author response: Yes, we have.

4) Need for individual as well as population level research
"In regions experiencing higher ambient temperatures, heat stress causes many health impacts including deranged physiological processes, such as water handling and electrolyte balance." What is meant by 'ambient' in this sentence? Deaths occur from the heat at relatively moderate temperatures, not only extremes.

Author response: Ambient temperature is the temperature to which people are exposed to or are directly experiencing. These temperatures could be quite different from temperatures from meteorological stations that are measured in very specific controlled conditions. We have added this explanation to the manuscript.

5) The need for community engagement
The participants identified three goals of community engagement. Supporting operational disease control programs was not mentioned. Did the participants discuss this? Supporting operational disease programming would surely represent an important perspective when setting the research agenda if the intention is to reduce climate-related disease burdens (see also comments below).

Author response: Certainly. But this specific aspect has already been one of our key research agendas for many years in the AAP. What we wanted to focus on in the meeting and this article are the aspects that are specifically related to climate change and that are new to our research agenda.

Box: Next steps and priorities
This box is a useful addition to the article but would benefit from being specified more precisely. How will these be achieved? The second point, in particular, is very far-reaching. It seems that you have already prioritised climate-sensitive diseases in this paper, and by the topics that you chose to discuss during the meeting. Is this point more about better understanding and quantifying the risks from these diseases?

Author response: Yes, and possibly identifying others that we may have missed in our meeting. Again, the diseases identified in this article are informed by our past research in the programme (which was not climate change oriented). For that reason, it is very possible that we currently have a biased view of the situation. The second point is to fix such a potential issue.

This is the first place where interventions are mentioned. If the ultimate aim is to reduce climate-related disease risks, surely supporting practical disease programming and operations should be important to the research agenda. It is of course necessary to understand climate-health associations via traditional epidemiological research, but also to understand both where the entry points are for designing new interventions and (often overlooked) how climate could interfere with existing disease control and elimination efforts. Reducing these risks will involve some use of climate data and potentially forecasts, and research questions can be designed with these interventions in mind. Failing to include them at this stage would miss an important opportunity to ensure that the research outcomes are useful for developing effective interventions.

Author response: Thank you, and we very much agree with this point. Specific interventions were not discussed at this meeting, but the need to design and test future interventions to reduce climate-related disease was included in the meeting outputs (P12-13). Since the meeting, we have started work on various projects on climate and health interventions, including assessing early action protocols in heat-vulnerable populations in Vietnamese cities. We are also working on facilitating dengue control measures by developing a dengue forecasting tool that will combine probabilistic forecasts of weather and near-term climate conditions with mathematical models of dengue transmission.

One further question/clarification: why are youth groups specifically the focus of the engagement about climate and mental health?

Author response: It is well established that climate anxiety is a prominent issue for children and young people; they stand to suffer the worst consequences but have little formal power to limit the damage. Since the OUCRU public engagement group has built up well-established and fruitful links with young people via schools and online platforms over the past decade, we have identified this as a network upon which engagement work can build. Other age groups will not be excluded from wider engagement projects.

Competing Interests: No competing interests were disclosed.