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Perspectives on climate change and infectious disease outbreaks: is the evidence there?

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Gina E. C. Charnley[1,2,3] ✉ & Ilan Kelman[3,4,5]

The accelerated warming of the planet caused by anthropogenic climate change is very concerning, as its impacts have the potential to be broad and its effects widespread. One climate change impact with significant interest from scientists, politicians, the media and the general public, is the proposed changes to infectious disease dynamics. Climate change has the potential to alter disease transmission through expansion to naive populations or by worsening risk factors. However, limitations exist in our ability to forecast the climate and disease, including how we incorporate changes in human behaviour and how we attribute climate/weather events solely to an infectious disease outcome. Broad statements about the impact of the climate on infectious disease may not be helpful, as these relationships are highly complex and likely lead to an oversimplification. The interdisciplinary field of climate-health research has the attention of those outside of science, and it is the responsibility of those involved to communicate attribution on an evidence basis, for better scientific communication and public spending. The uncertainty around the impacts of climate change is a call for action, to prevent pushing the Earth's systems into the unknown.

Climate change is a natural phenomenon of the planet, moving through natural cycles of ice ages and warmer periods over millions of years. These changes occur through alterations in the Sun and the Earth's orbit, emissions from volcanos and changes to atmospheric greenhouse gas (GHG) levels (e.g., carbon dioxide, methane, nitrogen oxides, water vapor), which can be seen in geological records[1]. Since the onset of the Industrial Revolution (late 18th century) and the subsequent burning of fossil fuels coupled with land use alterations, the climate has been changing at rates not documented in the Earth's natural history[2].

The human influenced warming of the Earth has led to changes to temperatures, precipitation, natural hazards, sea level and ecosystems[3]. However, climate change is a highly complex process, involving interaction between land, oceans, the atmosphere, and the biosphere. The impact of climate processes on regional weather can be heterogenous, with the presence of large water bodies, topography and proximity to coast being highly important[4].

The impact of anthropogenic climate change on society, in terms of food, migration, weather and health, is a rapidly evolving field. The complexity of the Earth's climate makes attributing climate change to changes in society very challenging. Climate change has gathered a significant amount of interest beyond the scientific community in recent decades, particularly in the media and politics. Therefore, how the science is communicated in these highly complex and evolving fields is important[5].

Here, we offer perspectives on the role of climate change on infectious diseases, and the projected changes that may occur in the future. Recent increases in investment and funding for climate-related epidemiology has led to an uptick in the number of studies being published and a significant research landscape on the subject now exists[6]. Additionally, the topic has been picked up by the media, politicians and non-governmental organisations, often stating the catastrophic impacts the climate will have on infectious disease transmission and distribution, globally[7].

Terminology

In a rapidly evolving and complex field, language is important, particularly in terms of using definitions in a uniform way to allow for better comparison. This can present challenges due to disagreement over definitions. For example, the "pre-industrial era" is discussed throughout climate research, but a definition of this era is still ambiguous[2]. Some key definitions for this work are stated here.

[1]Bloomberg School of Public Health, Johns Hopkins University, Baltimore, MD, USA. [2]School of Public Health, Imperial College London, London, United Kingdom. [3]Institute for Global Health, University College London, London, United Kingdom. [4]Institute for Risk and Disaster Reduction, University College London, London, United Kingdom. [5]University of Agder, Kristiansand, Norway. ✉e-mail: g.charnley19@imperial.ac.uk

The World Health Organization (WHO)[8] defines an infectious disease as a pathogenic microorganism (e.g., bacteria, virus, parasite or fungi) that can be spread, either directly or indirectly. We base our understanding of an infectious disease on the WHO definition and describe transmission types to include direct contact, food-borne, water-borne, vector-borne and via fomites. Some commonly suggested mechanisms through which climate change may increase infectious diseases include:

1. via changes to transmission risk factors – such as water, sanitation, poverty and housing, leading to higher case numbers, morbidity and mortality.
2. via changes to distribution – changing the range in which an infectious disease can be epidemic or endemic, e.g., changes in vector distribution and behaviour[6].

The weather is defined as the state of the atmosphere (particularly, pressure), which governs conditions such as cloudiness, wind, temperature and precipitation, fluctuating on regional and hourly to weekly scales. Alternatively, the climate is long term changes to weather patterns, typically on time scales of 30 years or longer[9]. Climate change, according to the Intergovernmental Panel on Climate Change (IPCC) is "a change in the state of the climate that can be identified by changes in the mean and/or the variability of its properties, and that persists for an extended period, typically decades or longer"[10], covering natural and human influences.

Challenges in climate change projections

Climate data and reconstructions include station data, satellite data and paleo-climate data from tree rings, ice cores and lake and ocean sediment. These data are highly important as both a method of validating climate models and to better understand historical climate change[11]. For example, the Pliocene and Eocene epoch could be excellent analogies for some climate scenarios, providing a glimpse into what the future climate might look like[12].

General Circulation Models (GCMs) are mathematical representations of the Earth's climate systems and are powerful tools for climate change projections. GCMs are continuously being improved with computational advances and validated by new data. Recent improvements have been made in simulating continental-scale surface temperature patterns and multi-decadal trends. However, the models continue to perform less well for precipitation and representing the processes involving clouds and aerosols. The ability to simulate ocean thermal expansion, glaciers and ice sheets, and thus sea level, has improved, but significant challenges remain in representing the dynamics of the Greenland and Antarctic ice sheets[13].

Climate change scenarios used in projections are largely based on suggested future emissions of greenhouse gases. The Representative Concentration Pathways (RCPs) are perhaps the most widely used set of emissions scenarios set out by the IPCC and cover a wide range of projected pathways and uncertainties (see Table 1 for more details)[14]. Emissions' release and uptake are largely governed by societal changes, such as changes in economics, population, lifestyle, technology and policy, which are fundamentally uncertain[13].

Challenges in attributing climate change to infectious disease

Infectious diseases have a huge global burden, particularly among those most vulnerable, and increases in transmission are highly concerning. Some key fears to changes in disease range, are that populations will have little understanding about the spread or preparedness to respond to the disease and a naive population immunity would lead to higher morbidity and mortality[7]. A positive outcome for exploring the relationships between climate, weather and disease is to create early warning systems and plan for future changes. For example, if a disease has a strong environmental link, then weather forecasts could be informative for disease transmission risk[15,16]. If these relationships are not accurate, or potentially inaccurate due to residual confounding, then this could lead to wasted resources, such as vaccinations.

Similarly to climate data, infectious disease data are rife with challenges and inconsistencies. Infectious disease data are sparse, with issues in reporting gaps, lags, testing, overreporting and underreporting. Therefore, identifying a true increase/decrease in a disease or change in transmission is at the mercy of the reporting systems[17]. Furthermore, attributing these changes to climate change needs caution. For example, the WHO recently confirmed a global upsurge in cholera and stated that climate change is playing a key role, due to an increase in droughts, floods and cyclones[18]. However, climate change is expected to decrease cyclone frequency (but increase intensity) and not all extreme weather can be attributed to climate change, as even without any anthropogenic warming, droughts, floods and cyclones would still occur[19,20].

Climate is very rarely the only variable that impacts the distribution and transmission of infectious diseases. Bruce-Chwatt and De Zulueta[21] not only discuss future projections in vector-borne disease transmission changes, but also use lessons from historical transmission of malaria to exercise caution in how they communicate climate-related malaria changes. For example, malaria was common in Britain during the Medieval Warm Period but did not decrease during the Little Ice Age. Instead, later declines were largely related to changes in land use and the destruction of wetlands[21]. Furthermore, there is a wider variety of diseases at low latitudes compared to high latitudes, related to both the environment and the vulnerability of the population including poverty, access to clean water and sanitation and healthcare[22]. All these factors will continue to change and evolve in the future and are difficult to project or predict.

Important economic forces are at play in the burden of infectious diseases and will likely continue to do so into the future. For example, since the 1980s, there has been a trend towards degradation of Sub-Saharan African healthcare, mainly due to armed conflicts and conditions imposed by international financial institutions having largely damaging consequences[22]. How the global economy and development aid will change in the future is highly contentious (with economic crises often difficult to project or predict), such as the rate of development or conflict in middle-income countries and the financial stability of low-income countries, all of which will impact health, healthcare, and health systems[23].

One way climate change may impact behaviour is through perception of risk. If people see or perceive infectious disease risk due to climate change as something that could impact their lives, this could improve health-related behaviours such as vaccination uptake, handwashing and mask wearing[24,25]. For example, if a coronavirus vaccine had been offered in January 2019, it is very likely that uptake would have been low. When vaccines were available (from December 2020), uptake in many countries with availability was high, partly because people perceived their risk and inconvenience as high[26]. Improving our understanding of people's behavioural changes due to climate change could be highly beneficial for all climate-related impact studies. Until we have a greater evidence base, our interpretations should not be overstated, as already suggested in the field of climate-related migration[27].

The impact of future climate on vector-borne disease ranges is a highly studied area, potentially due to the clearer link between the vectors and the climate (e.g., via thermal response curves from laboratory studies), and concerns over the difficulties in controlling vectors[28,29]. All animals and plants sit within an ecosystem, and therefore their survival and range largely depend upon what occurs in the wider ecosystem. Studies examining the distribution of vectors in isolation, as a simple insect-climate relationship may not be fully informative, unless the results are put into the context of how all other aspects of the ecosystem will behave and adapt. Previously, animals have shifted their ranges and behaviours to account for natural climate variation; however, we know we are altering the climate at accelerated rates, so species might not be able to adapt at the pace needed[30]. Others could adapt by moving, but are restricted by cities, fences, or have reached maximum elevation. Furthermore, the biodiversity loss expected due to climate and global changes may reduce some zoonotic infectious diseases, although not all animals have the same zoonotic potential[31].

Table 1 | Key characteristics of the four Representative Concentration Pathways (RCPs), including the greenhouse gas emissions relating to each scenario (2.6, 4.5, 6.0 and 8.5) and the likelihood of reaching certain temperatures above pre-industrial [adapted from: Ref. 47]

CO_2-eq Concentrations in 2100	RCP	Change in CO_2-eq emissions compared to 2010 (in %)		Likelihood of staying below a specific temperature level during the 21st century (relative to 1850–1900)			
		2050	2100	1.5 °C	2 °C	3 °C	4 °C
<430	Only a limited number of individual studies have explored levels below 430 ppm CO_2-eq						
430–480	RCP2.6	−72 to -41	−118 to −78	More unlikely than likely	Likely	Likely	Likely
480–530		−57 to −42	−107 to −73	Unlikely	More likely than not		
>530		−55 to −25	−114 to −90		About as likely as not		
530–580		−47 to −19	−81 to −59		More unlikely than likely		
>580		−16 to 7	−183 to −86				
580–650	RCP4.5	−38 to 24	−134 to −50				
650–720		−11 to 17	−54 to −21		Unlikely	More likely than not	
720–1000	RCP6.0	18 to 54	−7 to 72			More unlikely than likely	
>1000	RCP8.5	52 to 95	74 to 178			Unlikely	More unlikely than likely

Evidence that climate change has impacted infectious disease

There are several vector-borne, water-borne and air-borne pathogens that are considered climate-sensitive and therefore affected by climate change[32]. Meningitis is projected to worsen with climate change, with some evidence that meningococcal meningitis has strong environmental links, particularly along the meningitis belt. Increases in desertification in the future, due to increasing temperatures could see a rise in meningitis transmission[33]. However, wind speed is also important for meningitis transmission and the IPCC has projected a global "stilling", with wind speeds slowing in the coming decades and by 2100, average global wind speed dropping by 10%, potentially decreasing the distribution of air-borne dust and meningitis transmission[34].

Influenza transmission often increases in cold and dry conditions and so climate change could see a direct relationship with a decrease in the disease. However, many studies which evaluate weather and influenza look at temperature[35], whereas climate change is projected to increase precipitation in several areas, including in Europe. The potential for longer wet spells could increase indoor activity and therefore the spread of respiratory pathogens[36]. Additionally, the impacts of climate on influenza largely revolve around human transmission, and few studies investigate the role of climate on viral biology and animal hosts, research which would also be useful for many other diseases[35].

Links have been made between disease and large patterns of ocean circulation and sea surface temperatures, particularly for water-borne diseases, due to rainfall patterns being partially driven by the El Niño-Southern Oscillation in some areas[37,38]. These studies are often done in isolation, without considering other basins/ocean-atmosphere teleconnections, salinity, or, sea surface height leading to potentially spurious relationships. Teleconnections are highly complex natural systems, and how they impact weather and climate variability across a continent is highly spatially heterogenous, not least because regional factors play a crucial role in how any teleconnection translates to local weather and therefore disease risk[4]. Furthermore, there is evidence that underlying vulnerabilities e.g., lack of water and sanitation, are far more important than environmental factors when it comes to water-borne disease transmission, as a breakdown in these services is needed for pathogen exposure[39].

There are several projections for vector-borne diseases, including malaria and dengue, suggesting that with climate change, there will be an overall net increase in climate suitability and therefore the population at risk, but these projections come with high uncertainty[29,40]. From a biological perspective, higher temperatures mean higher metabolic rates for vectors, leading to higher biting and development rates. A higher metabolism can result in greater vector mortality, as their energy reserves are exhausted much quicker[22]. Additionally, an increase in storm intensity could see the destruction of vector-breeding grounds[41] and increasing salinity from storm surges and coastal erosion may cause some pathogens to proliferate and some to regress[42].

Ways forward

We have presented many complexities and challenges which the scientific community faces in attributing infectious disease transmission to climate change. Given how specific changes may result in both increases and decreases in infectious disease transmission for different areas of the world, caution is needed when communicating climate-related risks. There are several ways in which the evidence base could be further improved and strengthened, to create more meaningful and comprehensive science which can be used for preparedness, as summarised in Table 2.

Conclusion

The impacts of climate change are a highly relevant scientific field for contemporary society and more inter-disciplinary research is vital. Projections of infectious diseases into the future with climate scenarios and global change contribute to development-related decision-making including financing, especially for health systems and land use. However, over-attributing infectious disease transmission to climate or to climate change could lead to a waste and diversion of public resources, which could be better spent in addressing underlying vulnerabilities. Furthermore, making broad statements about unevidenced impacts of climate change on infectious disease causes issues within the public, contributing to rising action fatigue in climate change mitigation and climate change adaptation[43] and the scientific community, leading to inaccuracies and a lack of nuances in the scientific evidence base.

An ethical issue emerges, already pointed out by disaster and conflict scientists[44,45]. Does blaming a social breakdown on climate change shift the blame and therefore potential action away from those who can do something about it? Does it present these issues as acts of nature, albeit human-altered nature, outside of our control and therefore decreasing our incentive to prepare in the long-term and invest in a sustainable future? Actions to lift people out of poverty and provide them with basic services will improve all aspects of health and give people greater agency to mitigate and adapt to climate change. These broader preparedness and mitigation techniques

Table 2 | Summary of the issues, limitations and challenges in climate-health research suggested here and ways forward to improve the evidence base and communication

Issue/limitation	Way forward
Projection uncertainties	Focus on more short-term forecasting (<2050), which has less uncertainty and provide recommendations which should be prioritized for the near future.
Resource allocation	Spend more broadly on health and sustainable development, rather than targeted techniques. More generic improvements in health and equity are likely to have wider-ranging benefits.
Historical climate-related disease transmission changes incorporated into future projections, including climate-related behavioural changes	Rather than focusing solely on historical data and incorporating these into mathematical models, additional emphasis is needed on how pathogens/vectors and people have behaved historically with climate change, even if these may contradict modelling predictions. For instance, vectors require suitable habitats to increase their range with increasing temperatures.
Improved weather and disease data capabilities	No matter how accurate the mathematical algorithm or computational power, regions lacking data inhibit predictions and forecasts. Weather and disease data collection should be scaled up, particularly in Africa where stations are sparse.
Innovation in health data collection	Rather than waiting for patients to present at health care facilities and assuming that a test is available, more innovative methods are needed to collect and anonymise health data. For example, develop more rapid/at-home testing and utilising mobile reporting.
Interdisciplinarity	Seen throughout the climate change-related health literature is research authored by those working in the same discipline. More inter-disciplinary teams are needed, with reciprocal knowledge sharing, to make sure that the optimal data are used, results are interpreted correctly, and model assumptions are the best available.
Better communication of climate-related health risks	Adopt a pragmatic approach to climate-related health risks, particularly when an inter-disciplinary team has not been involved. Fully explore the limitations of the data and forecasting tools while discussing the bidirectionality of many of these relationships.

offer far more benefits compared to specific actions for one climate-sensitive disease.

It is not about pitting those who believe in the importance of climate change-related narratives against those who do not[46]. Instead, it is about taking a more evidence-based approach to attributing these large scale and highly complex processes to a variety of inputs, particularly when specialists from all fields have not been included in every aspect of the research. Fundamentally, we do not know for certain what will happen in the future, nor its effects, and that is why we should act on climate change now, because we are knowingly pushing the Earth's systems into the unknown.

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Competing interests

The authors declare no competing interests.

Additional information

Correspondence and requests for materials should be addressed to Gina E. C. Charnley.