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Climate change and human infectious diseases: A synthesis of research findings from global and spatio-temporal perspectives

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ABSTRACT

The life cycles and transmission of most infectious agents are inextricably linked with climate. In spite of a growing level of interest and progress in determining climate change effects on infectious disease, the debate on the potential health outcomes remains polarizing, which is partly attributable to the varying effects of climate change, different types of pathogen-host systems, and spatio-temporal scales. We summarize the published evidence and show that over the past few decades, the reported negative or uncertain responses of infectious diseases to climate change has been growing. A feature of the research tendency is the focus on temperature and insect-borne diseases at the local and decadal scale. Geographically, regions experiencing higher temperature anomalies have been given more research attention; unfortunately, the Earth's most vulnerable regions to climate variability and extreme events have been less studied. From local to global scales, agreements on the response of infectious diseases to climate change tend to converge. So far, an abundance of findings have been based on statistical methods, with the number of mechanistic studies slowly growing. Research gaps and trends identified in this study should be addressed in the future.

1. Introduction

Although the evidence of climate change has grown significantly during recent years, the level of confidence varies among different climatic variables owing to availability of homogeneous long-term data records (IPCC, 2013). The Intergovernmental Panel on Climate Change's 2014 report has stated that warming of the climate system is unequivocal, with each of the past three decades being successively warmer than any preceding decade since 1850. Confidence in global average precipitation change over land areas since 1901 is low prior to 1951 and medium afterwards, but is estimated high for increased number of heavy precipitation events in more regions than it has decreased. It is very likely that global near surface and tropospheric air specific humidity has increased since the 1970s. However, the conclusions on changes of extreme events, such as drought, tropical cyclone activity, storminess, hail, and thunderstorms, remain less clear at a global scale (Hartmann et al., 2013).

The nonlinear and chaotic nature of the climate system imposes more residual uncertainties about the rate and magnitude of future climate change (Kirtman et al., 2013). However, there is little doubt that a fundamental global climate change presents a threat to human health in a variety of ways (McMichael et al., 2006; Costello et al., 2009; Watts et al., 2015). Globally, 23% of all deaths in 2012 were attributable to the environment and an additional 250,000 potential deaths annually from 2030 to 2050 for well understood impacts of climate change (Hales et al., 2014). The causal pathways between climate change and health outcomes are operated in both direct and indirect mechanisms. Human infectious diseases are affected by both mechanisms and thus their interactions and the estimates of exposure to climate health risks is particularly complex.

Heat wave, storms, drought, and flood present direct risk to human infectious disease (Watts et al., 2015). Temperature affects the survival rates of pathogens. Some population and certain regions are more vulnerable to infectious disease due to their lack of the ability to effectively respond to the stresses imposed by elevated temperature (Wei et al., 2012). Excessive bursts of precipitation could cause sanitary sewer overflow and promote the emergence and spread of infectious disease ranging in severity from mild gastroenteritis to life-threatening ailments such as cholera, dysentery, infections hepatitis (EPA, 1996).

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Glossary of terms

Climate change a general term used here to indicate major changes in climate properties, such as temperature, precipitation, extreme events, or wind patterns, among others, that persist for an extended period of time, typically decades or longer.

Climate variability variations in the mean state and other statistics of the climate on all temporal and spatial scales, beyond individual weather events (World Meteorological Organization). Climate variability is mostly due to natural oscillations in the Earth systems.

Drought a period of abnormally dry weather long enough to cause a serious hydrological imbalance.

Positive climate change-infectious disease relationship a positive relationship signifies a higher probability of disease outbreak with the increased magnitude of climatic variables.

Temperature anomaly a departure from long-term temperature averages.

Temperature variability the change in standard deviation in detrended annual temperature, comparing against the periods before and after a certain year.

Indirect risks are mediated through changes in the biosphere (e.g., the life cycles and shifting distribution of vectors) and other through social processes (e.g., human-vector contacts). For diseases transmitted by vectors, such as Lyme disease and West Nile virus, greater pathogen transmission is tried closely with biodiversity loss—a well-established consequence of climate change. High pathogenic avian influenza virus that caused serious outbreaks in Europe and North American poultry farms came from migrant wild fowls—the avian flu virus's natural reservoir whose migration timing is heavily controlled by temperature (Lycett et al., 2016). Long-term warming and temperature anomalies can mediate the bacterial communities of *Vibrio* infections, as seen in costal Chile, Israel, and the U.S. Pacific Northwest (Baker-Austin et al., 2013; Vezzulli et al., 2016).

Nonetheless, although human infectious diseases have gained considerable attention in discussions about climate change, many details remain controversial (Altizer et al., 2013). This uncertainty can be exemplified by the controversial responses of malaria to rising temperatures reported in different studies (e.g., Akinbobola and Omotosho, 2013; Alonso et al., 2011; Omumbo et al., 2011). A critical necessity to maintain and enhance human health in the face of increasingly changing climate trends is to identify knowledge gaps and trends in this field. In spite of many existing climate change and infectious disease (CC-ID) review efforts, the question of how the scientific consensus towards their relations has shifted over time, location and variables has been overlooked. Such questions are of critical importance to public and environmental health because they address the design of site-specific and disease-dependent proactive mitigation and reliable projections of vulnerability. Given their importance, nonetheless, some obstacles hinder the investigation of the complex CC-ID relations that involve many interacting socio-environmental components over space and time.

First, the feedback mechanism of CC-ID is subject to different climate variables, disease types, and environmental settings. The richness in the types of exploratory and response variables confine the comparability of studies that probed on distinct diseases or risk factors. Second, inconsistencies in the spatial scale and time range can result in discrepancies between correlation and causation. Depending on the study objectives and data availability, individual studies range from hospital level to global assessments and span from days to hundreds of years. Although local cases can afford in-situ measurements with fine details, large-scale studies tend to use aggregated and coarse resolution data to link with disease incidence cases. Spatial aggregation errors can significantly alter the coefficient values and inferences drawn from models. Meanwhile, considering the time lag effects in many phenomena or processes, differences in the length of study duration could also impair the comparability of results. Third, knowledge generalization is further complicated by the disciplinary diversity inherent in CC-ID research, as reflected by the wide spectrum of the background of researchers and methods ranging from questionnaire-based interviews to laboratory experiments, statistical analyses, and process-based modeling. The discrepancies in the degree of causality and quality of evidence of these methodologies impose challenges in information synthesis.

To achieve a general understanding towards the CC-ID feedback mechanism, identify research gaps to date, and offer prospects for future research, a synthesis of knowledge on the current research progress over various spatio-temporal scales and a diversity of analytic approaches is presented. Specifically, this review is driven by the following four questions:

1) How do scientific opinions change towards the CC-ID relations over space and time?
2) To what level do current CC-ID research hotspots correspond to regions undergoing large climate change?
3) Do we have a better understanding on the mechanisms of the interaction between climate change and infectious diseases?
4) Will the direction and certainty of research findings shift as the spatial and temporal scales of CC-ID studies change?

An overview of current CC-ID research was provided in a data-intensive meta-discovery manner. The literature database construction and the classification scheme for climatic variables and disease types are described in Sections 2 and 3. A meta-data analysis was then conducted to address the above questions, and the main findings are presented in Section 4. Finally, we summarize the key messages synthesized in this research and include case study discussions.

2. Search strategy and selection criteria

A comprehensive search was conducted in several mainstream bibliographic databases including the ISI Web of Science, Scopus, ScienceDirect, and PubMed. Our approach first involved performing searches of article abstract/title/keywords using strings of [(‘climate change’ or ‘climate’) and ‘infectious disease’]. After a first round of search, papers focusing on human-related infectious disease were retained and the information on climatic and disease type was extracted to have a crude knowledge about their themes. To add missing articles that were not identified by the initial search, another round of search was conducted. We applied all keyword combinations from one climatic variable and one disease type to bind the population of cases under consideration. Specifically, search string for climatic variables include [‘climate change’ or ‘temperature’ or ‘climate variability’ or ‘extreme events’ or ‘humidity’ or ‘precipitation’] and disease groups include [‘infectious disease’ or ‘communicable disease’ or ‘Fecal oral’ or ‘food borne’ or ‘water contact’ or ‘airborne’ or ‘insect borne’ or ‘vector’ or ‘zoonoses’].

The search was applied to publications before 2015 and articles published before 2000 were combined because relatively few references were published on the topic prior to this year. The initial literature database was further manually screened with the following rules: 1) duplicated and non-English papers were removed; 2) non-peer reviewed articles were not considered to be of a trustworthy scholarly validity; 3) articles that did not report a health outcome related to climate change were not considered, such as review, editorial, or commentary articles; and 4) non-human infectious disease-related articles were