Editorial

Climate Change and Infectious Diseases: The Next 50 Years

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Introduction

It is accepted that the world is warming and driving most of "climate change"; but while the science is "in", the reasons and required interventions sadly remain debated and political. The relationship between climate change and its environmental and social manifestations is complex and brings about diverse adverse risks to human health. Global Climate Change Week—from October 15 to 21—is a time to promote awareness and discussion between academics, policymakers and broader communities to address future climate change actions and solutions.[1]

Projected increases in annual temperatures, rainfall and the frequency of extreme weather events will have direct and indirect repercussions on the environment in which pathogens, vectors, and hosts interact. Directly, infectious pathogens require suitable environments to thrive and ultimately cause human disease. Changes to the environment can further support pathogen survival and with that, the frequency and severity of disease (Fig. 1). Human-induced climate change is just one of the numerous global-scale changes that will affect human health. Indirectly, human factors such as unplanned urbanisation will result in a significantly higher proportion of populations in the urban setting, providing a more favourable environment for pathogens to thrive and for subsequent transmission to humans—whether it be from other humans, animals, vectors or directly from the environment.

Climate Change in Southeast Asia

By 2080, sea levels are expected to rise by as much as 40 cm.[2] Southeast Asia is particularly vulnerable due to its low-lying terrain and long coastlines. More than 100 million people—mostly in East and Southeast Asia—currently live within 1 m of sea level[3] and several large cities including Bangkok, Manila, Ho Chi Minh City and Jakarta are at risk as sea levels rise. In Vietnam, 18 million people currently reside on the Mekong River Delta. The Intergovernmental Panel on Climate Change (IPCC) Fourth Assessment Report predicted that by 2050, rising sea levels could directly displace 7 million of these residents.[4]

In Southeast Asia, surface air temperatures are expected to increase by 2°C by 2060 and as much as 5°C by 2098. In Singapore, the annual mean temperature has increased from 26.6°C in 1972 to 27.7°C in 2014. Rainfall has intensified with an increase in annual average rainfall from 2192 mm in 1980 to 2727 mm in 2014.[5] A rise in average precipitation will result in wetter climates spreading over larger land masses.[6] In Indonesia—which experiences a monsoon wet season and a dry season—there is projected increased rainfall during the rainy seasons and up to a 75% decrease during the dry season,[7] increasing the chances of both flooding and droughts.

Vector-borne Disease

The epidemicity of disease vectors, such as mosquitoes and sand flies are highly climate sensitive so alterations to the geographical and seasonal distribution of diseases they transmit could change considerably. Malaria, dengue, Zika, and Japanese B encephalitis are among some of the more common infectious diseases of Asia likely to be affected.

Warmer and wetter weather will see areas previously uninhabitable for mosquitoes provide favourable breeding grounds, potentially leading to a geographical redistribution of diseases transmitted by mosquitoes. Theoretical modelling—which amalgamates predicted climate changes with the known climate suitability for *Anopheles*—suggests malaria-endemic regions will expand to cover larger geographical areas both north and south of the equator, including South China and Taiwan.[8] Conversely, the range of malaria may contract in areas of India and Southeast Asia, where temperatures will likely exceed 40°C and become unsuitable for *Anopheles* mosquitoes.[9]

Dengue, transmitted via *Aedes* mosqitoes, has seen a 30-fold incidence increase over the last 50 years globally, with an estimated 50 to 100 million annual cases worldwide and almost half the world's population living in countries

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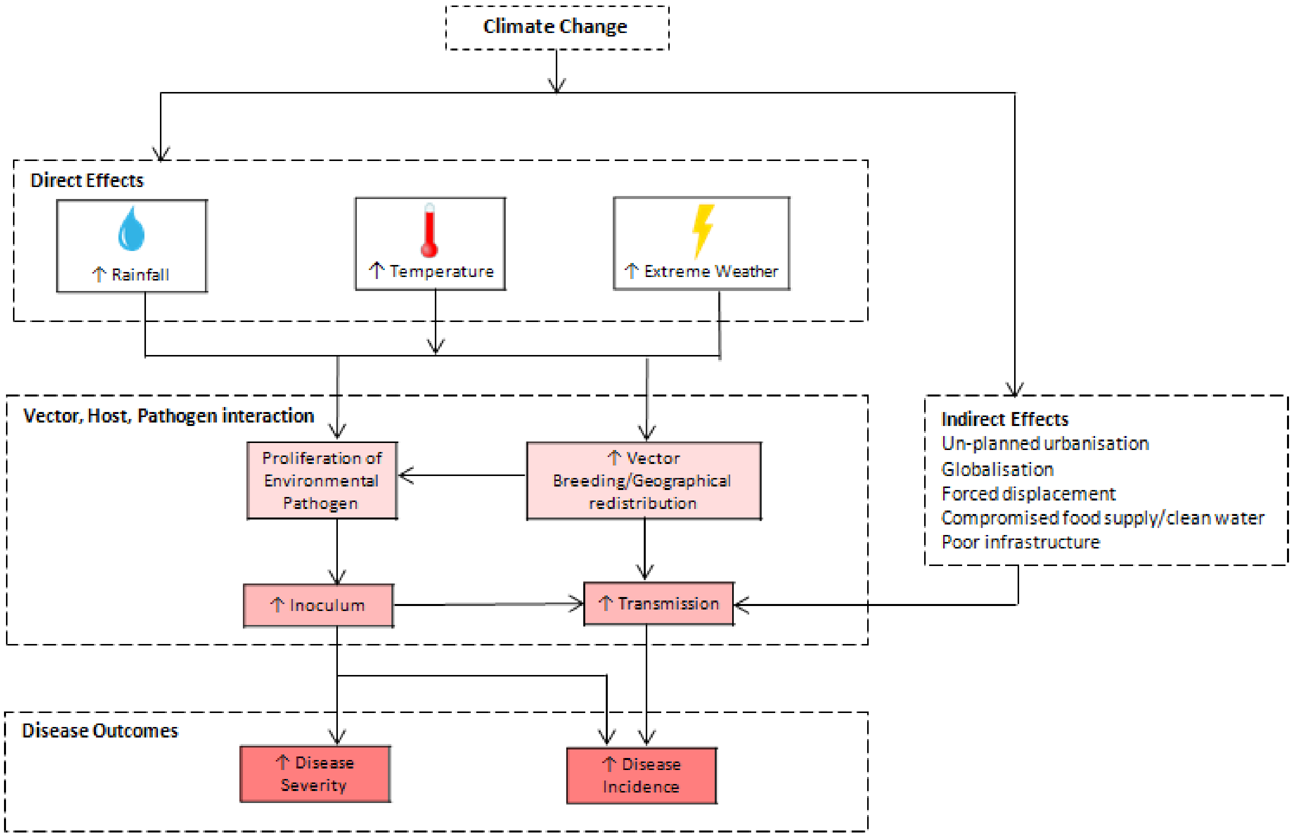

Fig. 1. Chart showing the potential direct and indirect consequences of climate change on the severity and incidence of infectious diseases.

where dengue is endemic.[10] In addition to the accelerated breeding and maturation cycle in warmer and more humid conditions, *Aedes* will proliferate faster as climate change coincides with increasing urbanisation; the increased density of human populations and abundant mosquito breeding sites, such as in household waste which encourages higher rates of infection. Singapore experienced an unprecedented dengue disease outbreak in 2005 with over 14,000 cases.[11] Kalimuddin et al[12] looked into the forecasting of dengue disease patterns in Singapore utilising mathematical modelling. The paper concluded that whilst the forecasting tool can predict future outbreaks, for it to be of any benefit, it requires coordinated local policymaking and international collaboration.

Water-borne Disease

Poor sanitation and shortages of clean drinking water increase the likelihood of waterborne disease outbreaks especially in countries with vulnerable infrastructure. With the expected increase in the frequency and intensity of precipitant-related weather events, flooding will occur more often. The subsequent increase in water runoff from surrounding areas may lead to cross-contamination of the water supply, especially if drainage is inadequate. Following heavy rainfall, a global systematic review by Cann et al[13] identified that *Vibrio* spp. and *Leptospira* spp. account for 45% of the pathogens found to infiltrate water supplies.

Moreover, higher temperatures are known to be associated with the amplification of enteric pathogens in the environment, including *Vibrio cholera*.[14] Higher inoculums of *V. cholerae* positively correlates with increased incidence of disease as well as more severe clinical manifestations.

Airborne and Droplet-Spread Disease

Environmental factors influence the transmission of airborne diseases—temperature and relative humidity both being important. Increasing urbanisation and globalisation facilitate human-to-human transmission, meaning the spread of disease will occur more readily, thereby increasing the chance of outbreaks.

The vast majority (95%) of all cases of tuberculosis (TB) occur in the tropics but a direct correlation to climate change is only speculative.[15] The estimated incidences of TB in the Philippines and Indonesia are 270 and 187 per 100,000 population, respectively.[16] More than half of all new cases of TB occur within Southeast Asia and the Western Pacific regions;[16] these cases tend to occur within densely populated cities where ongoing rapid and unplanned urbanisation is common—a potentially indirect result of climate change.

Influenza viruses in temperate climates exhibit strong seasonal patterns, favouring winter epidemics. With this, one could theorise that cooler, less humid conditions are favourable to influenza and therefore forecasted climate changes may actually reduce the incidence of influenza. The tropics, however, experience significant influenza activity all-year round, with additional fluctuations correlating to neighbouring temperate seasonal changes.[17] The congregation of humans indoors may be an important factor to influenza epidemics, with adverse weather events being a driving factor.[18] It is conceivable that with increased rainfall and higher population densities, we may actually observe an increase in influenza across all climates.

Unlike seasonal influenza, human avian influenza virus outbreaks such as H5N1 and H7N9 occur sporadically and result from the direct interaction of humans with wild or domestic birds. Changing wild bird migration patterns and human proximity to infected birds will impact incidence rates. H7N9 infections have been strongly correlated with temperature and also with relative humidity of between 70% to 80%.[19]

A Prevalent Environmental, Climate-Sensitive Pathogen

Melioidosis, caused by the bacterium *Burkholderia pseudomallei* is endemic to Southeast Asia, Northern Australia and other tropical regions; it is estimated to cause 89,000 deaths per year worldwide.[20] Pneumonia is the most common clinical presentation but the variation in presentation and severity can make melioidosis difficult to diagnose, varying from acute fulminant sepsis to chronic non-specific symptoms. Rainfall and extreme weather events show a strong correlation with acute clinical infections.[21,22] *B. pseudomallei* is easily isolated from soil and surface water in endemic regions during these weather conditions. During heavy rainfall, the bacterium is aerosolised and inhaled. Moreover, heavy rainfall in the 14 days prior to presentation is independently associated with more severe illness and increased mortality. Climate change will likely have a profound impact on both the incidence of melioidosis in current endemic areas and its emergence in new areas.

Conclusion

Climate change will undoubtedly impact the geographical distribution of infectious diseases as well as affect incidence and in some cases, severity of disease. Expected effects of climate change on human health are largely negative and will be compounded by other social and human factors. Changes may be subtle and many may argue that human populations will adapt; however, failure to consider how these changes in infectious disease patterns will emerge and develop mitigating strategies is not acceptable. As always, neglect affects the most vulnerable populations disproportionately especially those with scarce resources and poor infrastructure, making combating the effects of climate change all the more challenging.

While this discussion focuses on infectious diseases, the direct impact of climate change on other health outcomes should not be overlooked. A World Health Organization (WHO) assessment concluded that climate change is estimated to cause 250,000 additional deaths per year between 2030 and 2050; 38,000 from the direct effects of heat-exposure in the elderly, and 95,000 due to childhood malnutrition.[23] Aero-allergen levels and pollution are increasing and will result in more cardiopulmonary illnesses including asthma. Furthermore, the psychological impact of extreme weather events and the associated stresses on individuals and communities are difficult to quantify. Arguably, mental health concerns relating to climate change may have the largest impact worldwide with devastating effects on human health.[24]

Public health decisions and necessary adaptive strategies require proactive implementation. Accurate forecasting and monitoring of climate change and its impact on infectious diseases is critical. Effective and robust forecasting can help influence government policies and social behaviours, which will be critical to combat some of the most important issues relating to climate change such as population displacement, increased urbanisation and poor sanitation. If direct associations between adverse weather events and communicable diseases can be established, we may be able to develop weather-based early warning systems to improve surveillance and predict the risk of outbreaks.

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