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Planning for climate change: The need for mechanistic systems-based approaches to study climate change impacts on diarrheal diseases

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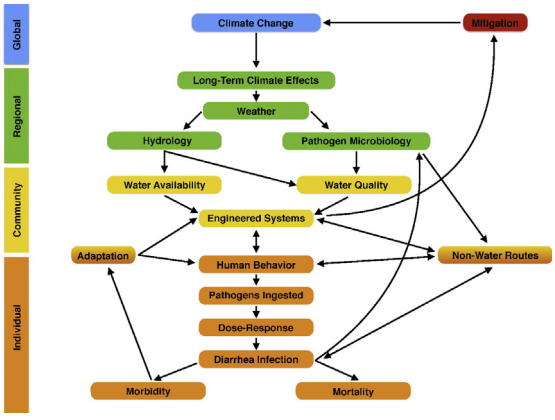
HIGHLIGHTS

- Diarrhea rates are affected by ambient temperature, precipitation, extreme weather.
- Pathogen taxa, socioeconomics, and antecedent weather modify these relationships.
- Climate change likely to increase diarrhea rates but complexity makes impacts unclear
- Current methods to study climate change impacts on diarrhea are inadequate.
- Mechanistic systems methods can predict impact and help design adaptation strategies.

GRAPHICAL ABSTRACT



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ABSTRACT

Increased precipitation and temperature variability as well as extreme events related to climate change are predicted to affect the availability and quality of water globally. Already heavily burdened with diarrheal diseases due to poor access to water, sanitation and hygiene facilities, communities throughout the developing world lack the adaptive capacity to sufficiently respond to the additional adversity caused by climate change. Studies suggest that diarrhea rates are positively correlated with increased temperature, and show a complex relationship with precipitation. Although climate change will likely increase rates of diarrheal diseases on average, there is a poor mechanistic understanding of the underlying disease transmission processes and substantial

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uncertainty surrounding current estimates. This makes it difficult to recommend appropriate adaptation strategies. We review the relevant climate-related mechanisms behind transmission of diarrheal disease pathogens and argue that systems-based mechanistic approaches incorporating human, engineered and environmental components are urgently needed. We then review successful systems-based approaches used in other environmental health fields and detail one modeling framework to predict climate change impacts on diarrheal diseases and design adaptation strategies.

1. Introduction

Enteric infections caused by inadequate drinking water supplies, sanitation and hand hygiene currently kill an estimated 842,000 children worldwide annually with the greatest number of deaths occurring in Sub-Saharan Africa and South-East Asia (Prüss-Ustün et al., 2014). They also frequently lead to stunted growth, impaired cognitive development and malnutrition — the effects of which can last into adulthood (Guerrant et al., 2013). It has been estimated that anthropogenic climate change will increase the relative risk of diarrhea by 22–29% by the end of the century (Kolstad and Johansson, 2011) possibly negating recent progress in reducing the global burden of diarrhea (Walker et al., 2012). The approximately 748 million people worldwide without an improved water supply (Bartram et al., 2014) and the additional 1.8 billion without consistent access to water free of microbial contamination (Bain et al., 2014) may bear the heaviest share of this additional disease burden. Their reliance on microbially contaminated or unreliable water supplies reduces their adaptive capacity to sufficiently respond to regional climate impacts. Furthermore, the nearly 2.5 billion who lack access to improved sanitation (Bartram et al., 2014) or who have other risk factors such as poor nutrition, hygiene or access to healthcare — are also at risk of increased incidence of diarrhea due to climate change impacts.

Predicting diarrhea incidence is complicated by the number of relevant risk factors and layers of complexity even when not accounting for climate change impacts (Mellor et al., 2012). This complexity includes factors such as individual genetics and physiology, personal behaviors, engineered infrastructure, local disease etiology and environmental factors as well as geographical, political, socioeconomic and cultural elements (Rehfuess and Bartram, 2014). In particular, the effects of environmental conditions such as temperature and precipitation might be modified by different factors, such as underlying social conditions, available infrastructure, and antecedent environmental conditions.

Epidemiological analyses have helped build our understanding of the relationships between weather-related drivers of diarrheal diseases. However, given the imminent threat of climate change, there is now a need for alternative approaches to augment our understanding of the risk of increased incidence of diarrhea, and to work towards designing effective interventions to improve adaptation strategies.

We propose that mechanistic, transdisciplinary systems-based methods that couple empirical field-based measurements with computational approaches incorporating human, engineered and environmental components are needed to better quantify this disease risk under diverse climate scenarios for disparate regions. These types of methods will enable engineers, scientists and policymakers to design "no regrets" adaptation strategies that reduce both current and future risk against a backdrop of generally improving economic conditions in many developing countries. Such an approach can help improve resiliency which is the tendency to maintain integrity when subject to disturbance. Here, we first review the epidemiological literature on weather and climatic drivers of diarrheal diseases. We then assess the relevant weather and climate-affected transmission mechanisms that should be considered in improved approaches. Finally, we discuss examples of successful systems-based approaches and propose a way forward.

2. Discussion

2.1. Epidemiological literature on climate drivers of diarrheal diseases

A number of epidemiological studies correlate all-cause diarrhea incidence to ambient temperature differences. In particular, studies have shown increases in diarrhea incidence of 3–11%, per degree Celsius ambient temperature increase in Fiji (Singh et al., 2001), Bangladesh (Hashizume et al., 2007), Peru (Checkley et al., 2000; Lama et al., 2004) and Japan (Onozuka et al., 2010). These regional results are corroborated by a recent global meta-analysis indicating a 7% increase in all-cause diarrhea per degree Celsius temperature increase based on the 10 studies that met the inclusion criteria (Carlton et al., 2015). While some of this research has shown a linear relationship between temperature and diarrhea rates (Hashizume et al., 2007), these associations can be non-linear and depend on local climatic conditions and pathogens. For example, in Peru, Checkley et al. (2000) found that a 5 °C temperature increase in the winter was associated with a 77% increase in diarrhea-related hospital admissions, while the same temperature increase led to only a 21% increase in the summer (Checkley et al., 2000). Research in Botswana found that hospital admissions for diarrhea were associated with minimum temperature but not average or maximum temperature. Furthermore, increases in minimum temperatures corresponded with higher rates of diarrhea in the dry season, but lower rates in the wet season (Alexander et al., 2013).

Rainfall has likewise been shown to be an important driver of diarrheal diseases across diverse climatic regions. Research in Botswana found a bimodal cyclical pattern with peaks in the incidence of diarrhea in the wet and dry seasons. However, diarrhea incidence was only correlated to rainfall during the wet season (Alexander et al., 2013). Studies in Fiji (Singh et al., 2001) and Bangladesh (Hashizume et al., 2007) have shown that diarrhea incidence can increase above or below threshold rainfall amounts. Carlton et al. (2014) found that heavy rainfall events following dry periods increased the risk of diarrhea by 39%, while the risk decreased by 26% when the heavy rainfall event followed a wet period (Carlton et al., 2014). Furthermore, the exacerbation of diarrhea rates has been associated with severe flooding in Bangladesh (Hashizume et al., 2008) which can affect vulnerable regions (Christenson et al., 2014).

Studies have also investigated whether social and environmental conditions such as socioeconomic status or improved water and sanitation facilities modify the effect of weather or climate on diarrheal diseases. Research in Bangladesh indicated that effects of temperature on diarrhea rates were greater for those with lower educational attainment, households without a concrete roof and unsanitary toilets (Hashizume et al., 2007). The risk of diarrhea during severe flooding in Bangladesh was increased for individuals with lower education levels and non-concrete roofs, those drinking from a tube-well as opposed to tap water, and those with a distant water source or unsanitary toilets (Hashizume et al., 2008). Researchers in Ecuador found that unimproved sanitation increased the risk of diarrhea after one day of rainfall, but the effect was insignificant after five days of rainfall. Moreover, having an unimproved water source increased the risk of diarrhea, but only after several days of rainfall (Bhavnani et al., 2014). Despite the importance of such factors in modifying risk in these studies, other researchers have reported that sanitation, social cohesion and hygiene