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Influences of heatwave, rainfall, and tree cover on cholera in Bangladesh

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A R T I C L E I N F O

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A B S T R A C T

Cholera is a severe diarrheal disease and remains a global threat to public health. Climate change and variability have the potential to increase the distribution and magnitude of cholera outbreaks. However, the effect of heatwave on the occurrence of cholera at individual level is still unclear. It is also unknown whether the local vegetation could potentially mitigate the effects of extreme heat on cholera outbreaks. In this study, we designed a case-crossover study to examine the association between the risk of cholera and heatwaves as well as the modification effects of rainfall and tree cover. The study was conducted in Matlab, a cholera endemic area of rural Bangladesh, where cholera case data were collected between January 1983 and April 2009. The association between the risk of cholera and heatwaves was examined using conditional logistic regression models. The results showed that there was a higher risk of cholera two days after heatwaves (OR = 1.53, 95% CI: 1.07–2.19) during wet days (rainfall > 0 mm). For households with less medium-dense tree cover, the heatwave after a 2-day lag was positively associated (OR = 1.80, 95% CI: 1.01–3.22) with the risk of cholera during wet days. However, for households with more medium-dense tree cover, the association between the risk of cholera and heatwave in 2-day lag was not significant. These findings suggest that heatwaves might promote the occurrence of cholera, while this relationship was modified by rainfall and tree cover. Further investigations are needed to explore major mechanisms underlying the association between heatwaves and cholera as well as the beneficial effects of tree cover.

1. Introduction

Cholera is an acute diarrheal disease caused by the bacterium *Vibrio cholerae* (*V. cholerae*) (Reidl and Klose, 2002). It is extremely virulent and can lead to death within hours if untreated (Glass and Black, 1992; Reidl and Klose, 2002). Poor environmental conditions, such as shortage of safe water and poor sanitation, have long been recognized as the illuminating factors for spread of the disease (Glass and Black, 1992). Cholera incidence has been greatly reduced due to improved environmental conditions and implementation of intervention measures (Ali et al., 2012; Tappero and Tauxe, 2011). However, it remains a global threat to public health and has emerged in some areas, such as Haiti (Barzilay et al., 2013), and recently in Yemen (Qadri et al., 2017). It is estimated that cholera cases range from 1.3 million to 4.0 million each year worldwide, resulting in 21,000 to 143,000 deaths (Ali et al., 2015).

Evidence suggests that climate change and variability play an important role in the emerging and reemerging of cholera (Colwell, 1996; Constantin De Magny and Colwell, 2009; Islam et al., 2009; Lipp et al., 2002). Specifically, factors including rainfall patterns, sea surface temperature, and El Niño Southern Oscillation (EÑSO) are linked to the occurrence of cholera (Colwell, 1996; Constantin De Magny and Colwell, 2009; Eisenberg et al., 2013; Emch et al., 2010; Hashizume et al., 2008; Lipp et al., 2002; Lobitz et al., 2000; Pascual et al., 2000). EÑSO has showed a positive effect on cholera incidence with a 2-month lag in the fall period in Bangladesh (Pascual et al., 2000), while the effect may change at different time periods (Rodo et al., 2002). In Haiti, a significant positive correlation was found between rainfall and cholera incidence 4–7 days later (Eisenberg et al., 2013). The increase in the number of cholera cases was also observed with high and low rainfall in Bangladesh (Hashizume et al., 2008). While another study showed that rainfall had no influence on the variation of cholera incidence in Matlab area during 1988–2001 (Ali et al., 2013). Several studies identified a positive association between temperature and

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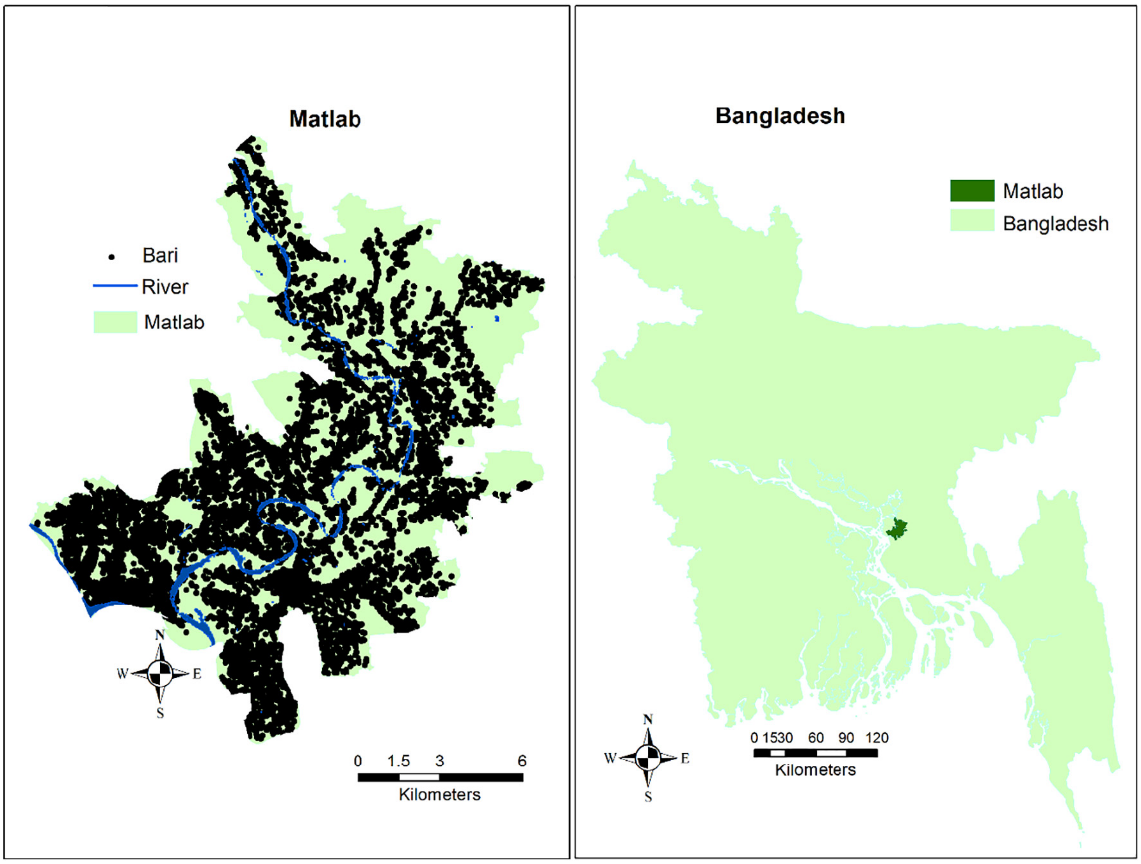

Fig. 1. The study area of Matlab, Bangladesh.

cholera incidence (Ali et al., 2013; Lobitz et al., 2000). It was reported that the increase in minimum temperature by 1 °C was associated with 6% increase in cholera incidence in Matlab, Bangladesh (Ali et al., 2013). It was also observed that cholera outbreaks had a significant association with the annual bimodal cycle of sea surface temperature (Lobitz et al., 2000). However, no significant association between the sea surface temperature and cholera incidence was observed in another study (Emch et al., 2010). Seasonality patterns also indicate an association between cholera occurrence and climatic factors (Ali et al., 2013; Emch et al., 2008; Hashizume et al., 2010). The outbreaks of cholera are more frequently observed in warmer seasons while vary in different latitudes (Emch et al., 2008), suggesting the need to further investigate the effect of climate on cholera transmission (Lipp et al., 2002).

It is projected that surface temperature will rise in the 21st century under all assessed emission scenarios (IPCC, 2014). For example, temperature may increase by 1.4–3.1 °C by the end of the century under medium emission scenarios. It is likely that heatwaves will become more frequent and extreme precipitation will become more intense. Evidence shows that extreme weather events and climatic variations have a profound influence on human health and infectious disease transmission (Patz et al., 2005; Wu et al., 2016b). Heatwaves are expected to lead to an increase in cholera outbreaks because *V. cholerae* population may increase as temperature rises (Baker-Austin et al., 2013; Levy, 2015). Baker-Austin et al. (2016) reported that non-cholera Vibrio species infections were substantially higher in summer 2014 in northern Scandinavia during an extreme heatwave compared to previous years in the summer, suggesting heatwaves were associated with the emergence of vibrios in that area. Studies in the Baltic Sea area, the Chesapeake bay, and the coast of Bangladesh also demonstrated that climate factors, such as temperature and rainfall have driven the prevalence of *V. cholerae* both geographically and temporally (Baker-Austin et al., 2013; Constantin De Magny and Colwell, 2009; Huq et al., 2005; Levy, 2015). The connection between temperature and cholera risk is expected because the increase of the abundance of *V. cholerae* has been linked to increased water temperature in several coastal areas (Heidelberg et al., 2002; Huq et al., 2005; Louis et al., 2003). A positive association between temperature and cholera risk has also been observed (Reyburn et al., 2011). Therefore, future climate change will likely increase the risk of cholera outbreaks.

Greenspace, referred to land partly or completely covered by trees, grass or other vegetation, is expected to lower heat-related health risks (Gunawardena et al., 2017; Hondula et al., 2018). Studies showed that greenspace, particularly trees, could effectively mitigate the effects of heatwaves and urban heat islands (Hondula et al., 2018; Lee et al., 2016). By shading and evapotranspiration, trees reduce the exposure to heat hazards and exert cooling effects on the ambient temperature (Hondula et al., 2018; Lee et al., 2016; Qiu et al., 2013). Given the effect of tree cover on extreme heat, it is likely that tree cover can effectively mitigate the risk of cholera associated with heatwaves.

To date, several studies have shown how temperature, rainfall and EÑSO are linked to cholera outbreaks (Ali et al., 2013; Eisenberg et al., 2013; Emch et al., 2010; Hashizume et al., 2008; Hashizume et al., 2010; Islam et al., 2009; Ohtomo et al., 2010; Pascual et al., 2000; Reyburn et al., 2011). However, the association between extreme heat (e.g., heatwaves) and the occurrence of cholera has scarcely been examined (Baker-Austin et al., 2016), and it is also unknown how tree cover might modify the effect of heatwaves on the occurrence of cholera. Additionally, most of the existing studies are based on time series analysis using population-level data (Ali et al., 2013; Hashizume et al., 2010; Islam et al., 2009; Ohtomo et al., 2010; Reyburn et al., 2011), the results of which could not reflect the effect of climate factors on cholera at the individual scale. Herein, we designed a case-crossover study and evaluated long-term (1983–2009) cholera data of a rural area of