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

Jianyong Wu[1], **Mohammad Yunus**[2], **Mohammad Ali**[3], **Veronica Escamilla**[4], **Michael Emch**[5]

[1]Department of Environmental Sciences and Engineering, Gillings School of Global Public Health, University of North Carolina at Chapel Hill, NC 27599, USA

[2]International Centre for Diarrhoeal Disease Research, Bangladesh

[3]Department of International Health, Bloomberg School of Public Health, Baltimore, Johns Hopkins University, MD 21205

[4]Carolina Population Center, University of North Carolina at Chapel Hill, NC 27599, USA

[5]Department of Geography, University of North Carolina at Chapel Hill, NC 27599, USA

Abstract

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=l.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.

Competing Interest Statement
The authors declare they have no conflicts of interest related to this study.

Keywords

temperature; infectious disease; climate extreme; greenspace; case-crossover

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 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 Bangladesh at the individual level. First, we investigated the association between heatwaves and cholera occurrence. We then examined the co-effects of rainfall and tree cover on the association between heatwave and cholera.

2. Methods

2.1. Study area

The study area, Matlab, is located approximately 57 km southeast of the capital city Dhaka, Bangladesh (Figure 1). During the study period, Matlab had a population of approximately 220,000, and the majority of people worked in agriculture or fishing. Matlab is also a field site of International Centre for Diarrhoeal Disease Research, Bangladesh (icddr, b), which maintains one of the most comprehensive population-based databases through a longitudinal Health and Demographic Surveillance System (HDSS) (Alam etal., 2017), providing a unique opportunity to study the relationship between climate and cholera.

2.2. Cholera data

Cholera data were obtained for individuals living in the Matlab HDSS area who were treated between January 1983 and April 2009 at the icddr, b hospital. We selected this study period because cholera incidence was lower post 2009 due to several interventions implemented in the study area. A cholera case was identified by isolating *Vibrio cholerae* O1 or O139 from the fecal specimen of a patient seeking treatment for diarrhea at the icddr,b hospital. For each case, patient's age, sex, the household identification number, and the date of hospital visit were recorded. The data collection procedures were approved by the ethical review committee of icddr, b.

2.3. Climate data and heatwave definition

Daily temperature and rainfall data near Matlab (Chandpur station) from 1982-2001 were obtained from the Bangladesh Meteorological Department (BMD). Since climate data from BMD were unavailable after 2001, we obtained daily temperature data during 2002-2011 from the National Climatic Data Center (NCDC), USA. Pearson correlation was performed using data from both sources from 2000 and 2001 to ensure consistency. Data from the two sources are highly correlated ($r=0.953$, $p<0.001$). Missing data (219 data points, ~ 2% of total data points) were replaced by averaging data from two neighboring time points. Daily rainfall data from 2001-2009 were obtained from the TRMM (Tropical Rainfall Measuring Mission) online visualization and Analysis System (TOVAS). Similarly, Pearson correlation analysis shows that the 2000 and 2001 rainfall data from both sources are significantly correlated ($r=0.312$, $p<0.001$).

To define a heatwave, we used the 30-year (1982-2011) daily mean temperature data as a reference and calculated the 95th percentile of the distribution as the threshold (30.5 °C). A heatwave is defined as two or more consecutive days with daily mean temperatures above the threshold (Wu et al., 2014). Therefore, the heatwave variable is a binary variable. Considering the potential lag effect of heatwaves, we also created 5 heatwave lag variables by shifting times by 1 to 5 days.

2.4. Tree cover data

Tree cover data were obtained from the Landsat Forest Cover Change dataset (http://glcf.umd.edu/data/landsatFCC/) for years 2000, 2005 and 2010. The tree cover datasets were originally created by classification of Landsat satellite images with a spatial resolution of 30 m (Hansen et al., 2013). Each pixel in the tree cover data layer (excluding water areas) was given a tree coverage value ranging from 0 to 100%. We further reclassified the free cover into four categories: no free cover (free coverage=0%), sparse free cover (free coverage=l-20%), medium free cover (tree coverage=21-40%), and dense free cover (free coverage > 40 %) (Figure SI).

The percentage of household free coverage was estimated using the geographic location of each *bari* (a patrilineally-related cluster of households with an average of 5 households) obtained via a global positioning system survey, and the tree cover classification data for the year 2000. We placed a 250 m buffer around each *bari* and calculated the percentage of free coverage within the buffer using ArcGIS 10.1 (ESRI Inc, CA, USA). We selected the 250 m buffer distance based on study area characteristics, and previous studies using 100 m to 2000 m buffers to examine the relationship between greenspace and health outcomes (Astell-Burt et al., 2013; Browning and Lee 2017; Dadvand et al., 2014; Wolch et al., 2011). Because of the dense population in Matlab area, the distance between two neighbor *baris* is relatively small. The buffers of neighbor *baris* are largely overlapped when the buffer distance is 500 m or above (Figure S2). In contrast, a smaller distance (e.g., ≤100 m), in most instance, would not cover a *bari*, because a *bari* is comprised with several patrilineally related households living in a compound. Thus, the percentage of tree cover would likely to be under represented. Considering the size of our study area and the spatial distribution of the population, we assumed that a 250 m buffer is ideal for evaluating the relationship between green space and cholera transmission in our study setting.

2.5. Case-crossover design

We designed a case-crossover study to investigate the association between heatwaves and cholera. A unique characteristic of the case-crossover design is that cases are used as their own controls at a different time point (before or after the cases are diagnosed) (Maclure 1991). This self-matching design has advantages when studying the associations between transient exposures and acute effects because it controls for potential individual confounders (e.g., sex, race and socio-economic status) that do not vary considerably over the case-control match periods (Carracedo-Martínez et al., 2010). We used a semi-symmetrical bi-directional approach to select control days (Mittleman and Mostofsky 2014). Each case is supposed to have two control days which are the days one week before and one week after the hospital visit. In addition, the control days were selected in the same calendar month as the case was recorded. For cases that were recorded early or late in the month, only one control day might be selected. For instance, if a case was presented in the earlier part of the month, then the control days were one week after presentation of the case, and if the case was presented in the later part of the month, then the control days were one week before the presentation of the case. The one-week time interval was chosen because cholera is an acute disease. The transmission of cholera normally starts when people ingest water or food contaminated with *V. cholerae.* Direct transmission among people is rare. When a person is infected with the pathogen, it may take a few hours to 5 days to show symptoms because the pathogen has an extremely short incubation period.

2.6. Statistical analysis

A conditional logistic regression model was applied to identify the climatic risk factors for cholera. Since a case and its control were the same individual, they were assigned the same identification number, which was used as the strata in the model. The climatic variables included temperature, heatwave, heatwave in 1-day lag, heatwave in 2-day lag, heatwave in 3-day lag, heatwave in 4-day lag, heatwave in 5-day lag, and rainfall. The heatwave variables were binary: days meeting the heatwave definition (value = 1) and days not meeting the heatwave definition (value = 0). Both bivariate and multivariable models were used to measure the association between climatic factors and cholera. We used Pearson correlation to identify highly correlated predictors. Amongst the highly correlated predictors (e.g., $r > 0.6$, $p < 0.001$), only one was included in the multivariable model (Wu et al., 2016a). For example, since heatwave in a 1-day lag was highly correlated with heatwave ($r = 0.71$, $p < 0.001$), we included only heatwave in the multivariable model. Akaike information criterion (AIC) was used to compare model fit, with lower AIC values indicating improved ft (Neter et al., 1996). The final model included temperature, heatwave, heatwave in a 2-day lag and heatwave in a 4-day lag as the explanatory variables. We did not include rainfall and rainfall lag variables in the final model because preliminary model results did not identify a significant association between these variables and cholera risk (Table S1).

We further stratified models by rainfall, sex, age, and tree cover. We classified the days as dry (no rainfall) and wet (rainfall) based on the rainfall data. We also created a rainfall variable, the number of wet days in 2 days prior to hospital admittance (including the same day of hospital admittance, one day before hospital admittance and two days before hospital admittance), to examine effect modification by rainfall on the association between cholera and heatwave. We chose the number of wet days in the prior 2 days because the incubation period of cholera usually takes 2-3 days. Age was categorized into three groups: children (age <18 years), adult (age=18-64 years), and elder (age>64 years). In terms of tree cover, we were interested in medium and dense tree cover. Since dense tree cover accounted for a small percentage, we combined it with the medium tree cover. We divided the households based on the quantile classification of medium-dense tree cover. For the tree cover analysis, we selected the lowest quantile classification of the medium-dense tree cover (Q1) and the highest quantile classification of the medium-dense tree cover (Q4). Odds ratios (OR) and 95% confidence intervals (CI) were calculated to indicate the magnitude of association between risk of cholera and the climatic variables. Similarly, we also divided the households into four categories based on quantile classification of sparse tree cover to examine the effect of heatwaves on cholera. We did not examine the effect of no tree cover because it is mainly water, which are not expected to mitigate heatwaves. We set the significance level at 0.05 ($p<0.05$). If the OR was significantly above 1.00, a positive association was assumed, while a negative or inverse association was assumed if the OR was significantly below 1.00. All statistical analyses were carried out using SAS 9.3 (SAS Institute, Inc., Cary, NC).

3. Results

3.1. Description of cholera data and exploratory variables

In total 9,519 hospital-identified cholera cases were observed from January 1983 to April 2009. 50% (4748/9517) of the cases were male. The highest number of cases were observed in 1993 (n = 1142), followed by 1983 (n = 822) and in 1986 (n = 785) (Figure S3). The months with the highest number of cases were October 1983 (n = 253), March 1983 (n = 207), and May 1986 (n = 193) (Figure 2).

During the study period, 348 heatwave days were observed. Annual heatwave days ranged from 0 to 32 days. Years with the highest number of heatwave days were 1988 (n = 32) and 2004 (n = 23) (Figure S3). Heatwave days were not observed in 1985, and only 2 heatwave days were observed in 1984, 2001, and 2002. Months with the highest number of heatwave days were April, May, and June, with an average of 2.2, 5.2, and 3.6 heatwave days, respectively (Figure 2). The average temperature during the study period was 25.8 °C. The highest average monthly temperatures were observed in August (28.8 °C), May (28.7 °C), and June (28.7 °C). The average daily rainfall was 5.81 mm. Months with the highest average daily rainfall observed in June (13.42 mm), July (12.31 mm), and August (10.71 mm) (Figure S4). The majority of tree cover around households were classified as sparse tree cover (74.4% on average) (Table 1).

3.2 Association between heatwave and cholera

The bivariate logistic regression results did not show any significant association between risk of cholera and climate factors (Table S2). Results from the stratified multivariable logistic regression models (Table 2) show a significant positive association between the risk of cholera and heatwave after a 2-day lag (OR=l .53, 95% CI: 1.07 – 2.19) in wet days (rainfall>0 mm). No significant associations were observed between the risk of cholera and climate variables in dry days. The risk of cholera was negatively associated with heatwave after a 4-day lag in the male stratified model (OR=0.75, 95% CI: 0.60 – 0.95). Age stratified models identified a significant negative association between risk of cholera and heatwave after a 4-day lag (OR=0.79, 95% CI: 0.64 – 0.99) among children (age< 18years). Significant associations were not observed in the adult (18<age<65 years) or elder (age>64 years) in the age stratified models (Table 2).

3.3 Co-effects of rainfall and tree cover

Tree cover modified the associations between heatwave and the risk of cholera (Figure 3). Heatwaves after a 2-day lag were positively associated (OR=1.80, 95% CI: 1.01 – 3.22) with the risk of cholera in wet days among households with a lower percentage (Ql) of medium-dense tree cover, but was not significant for households with a high percentage (Q4) of medium-dense tree cover. Significant associations were not observed during dry days regardless of the distribution of medium-dense free cover (Figure 3). Consistent results were observed when the models were stratified by the number of wet days and medium-dense tree cover (Table S3). For households with the intermediate level of medium-dense tree cover (Q2 and Q3), the associations between the risk of cholera and heatwave variables were not significant in wet days as well as in dry days (Table S4).

When the models were stratified by rainfall and sparse tree cover, the risk of cholera had a positive association with heatwaves after a 2-day lag for households with either a high percentage or a low percentage of sparse tree cover in wet days. In dry days, the risk of cholera had no significant associations with heatwaves for households with a high percentage of sparse tree cover. The risk of cholera also had no significant positive associations with heatwaves but had a negative association with heatwaves after a 4-day lag for households with a low percentage of sparse tree cover (Figure 4).

4. Discussion

By analyzing the cholera data over a 27-year period, we found that heatwaves after a 2-day lag had a significant positive association with the occurrence of cholera in wet days. The significant positive association held for households with a lower percentage of medium-dense tree cover canopy nearby but not for households with a large percentage of medium-dense tree cover canopy around. Our results suggest that rainfall and tree cover play contrasting roles in the relationship between heatwave and cholera. In our study, rainfall promoted the effect of heatwaves on the risk of cholera, while medium-dense tree cover mitigated the effect of heatwave on the risk of cholera. Since heatwave is a major consequence of climate change (IPCC 2014), the findings of our study provide useful information for understanding the potential impact of climate change on cholera outbreaks. Our study also provides evidence that the neighborhood tree cover canopy can effectively mitigate heat-related health effects although the mechanisms behind this pattern need to be investigated.

Our case-crossover study results indicate that the risk of cholera increased (OR=1.53, 95% CI: 1.07 – 2.19) during a heatwave on wet days and was even higher in households with less medium-dense tree cover. This suggests that rainfall may exacerbate the effect of heatwaves on cholera occurrence. There are potential mechanisms that underlie this pattern. Under higher temperatures, the growth and multiplication of *V. cholerae* might be promoted (Hashizume et al., 2010), potentially increasing food and water contamination. Rainfall can also spread pathogens and affect sanitary conditions, increasing human exposure to cholera (Hashizume et al., 2008). In addition, low rainfall might change water supply and affect personal hygiene behaviors, thus influencing the occurrence of cholera (Hashizume et al., 2008). We also observed that the effect of a heatwave event after a 2-day lag was significant when there was rainfall, but other lag periods were not significant. This is reasonable because cholera is an acute disease and symptoms are more likely to appear within 2 days of exposure. Another possible contributing factor for increased cholera during heatwaves is that they might induce immune disorders (Dittmar et al., 2014). We did not observe that cholera had significant associations directly with rainfall and its lag variables, which was roughly consistent with a previous study in the same area (Ali et al., 2013). However, our result from the stratified analysis clearly showed that rainfall was an effect modifier in cholera-heatwave associations.

Interestingly, the positive association between heatwaves and risk of cholera during wet days was significant for households with less medium-dense tree cover but not for households with more medium-dense tree cover, suggesting that tree cover canopy can buffer the effects of heatwaves. It is known that trees can lower surface and air temperatures by providing shade and through evapotranspiration (McPherson et al., 2005). Evidence also shows that trees and other vegetation can cool cities and reduce heat island effects, providing human health benefits (Bowler et al., 2010). Neighborhood tree cover is also shown to significantly reduce heat-related ambulance calls during extreme heat events (Graham et al., 2016). Our study results suggest that increasing neighborhood tree cover could potentially mitigate climate-related cholera outbreaks. Besides reducing surface and air temperature, trees also reduce water runoff, and improve water quality by absorbing and filtering rainwater. However, we do not rule out the possibility that households with more medium-dense tree cover may have better socioeconomic status (SES), which is inversely associated with cholera incidence in that area because households with better SES may have access to safer drinking water and better sanitary facilities (Emch et al., 2010). Therefore, whether the observed beneficial effect of tree cover is a confounding effect of SES on the cholera risk needs further investigation. We also examined the associations between cholera and heatwaves by gender and age groups. No significant positive associations were observed in different sub-groups. However, significant negative associations between cholera and heatwave in a 4-day lag were observed in the female group and the group at the age <18. These results look odd, which might be a feature called short-term displacement commonly in models with lag variables, a phenomenon showing a raised risk at short-term lags followed by a reduced risk at longer lags (Bhaskaran et al., 2013).

A strength of our study is the use of a long-term cholera dataset allowing us to examine the effects of heatwaves, which are abnormal weather conditions. Second, our use of individual level data makes it possible to detect complex exposure-outcome relationships and avoid ecological bias. Furthermore, the case-crossover study design can control for some confounding factors that likely do not change over short time periods, such as socioeconomic status and hygienic practices.

A limitation of our study is that our definition of heatwave is arbitrary due to the nonexistence of a universally accepted definition. Changes in definition may change heatwave frequency, leading to uncertainty in understanding health-related effects (Wu et al., 2014). To test the influence of heatwave definition on model results, we used an alternative definition, which defined a heatwave as two or more consecutive days with temperatures above 90% of the distribution of the 30-year daily mean temperature data, and examined the association between cholera risk and heatwaves. The results obtained based on two heatwave definition are consistent (Figure S5). Our rainfall data were collected from two sources, which might have discrepancies as the correlation coefficient was not very high. We divided the datasets into two time periods (1983–2001 vs. 2002– 2009) based on rainfall data sources and examined the associations between heatwaves and cholera (Table S5 and S6). The positive association between heatwave in a 2-day lag and cholera risk still remained during 1983-2001(Table S5). Our use of 250 m circular buffer for capturing household tree coverage may not reflect accurate exposure. Further studies on the exposure to tree cover are needed. Another limitation of our study is that tree cover datasets prior to 2000 were unavailable and it is likely that the land cover changed during the 1980s and 1990s. However, we compared the tree cover surrounding households in 2000, 2005 and 2010, and found that tree cover changed slightly and the percentage of each tree cover type was highly correlated across the three periods. For example, the percentage of medium-dense tree cover surrounding each household in 2000 was significantly correlated with those in 2005 and 2010, respectively (Table S7 and S8). Therefore, tree cover change is unlikely to influence our results significantly.

5. Conclusion

We found that heatwaves were positively associated with the occurrence of cholera in the rural endemic area of Bangladesh, and rainfall and tree cover modified this relationship. Major mechanisms underlying the positive association between heatwaves and cholera as well as the beneficial effects of tree cover need to be farther investigated.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

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Highlights

- Relationship between heatwave and cholera was examined at the individual level
- Heatwave after a 2-day lag was positively associated with cholera risk in wet days
- Tree cover could mitigate the adverse effect of heatwave on cholera
- Further studies are needed to explore mechanisms of the effect of heatwaves

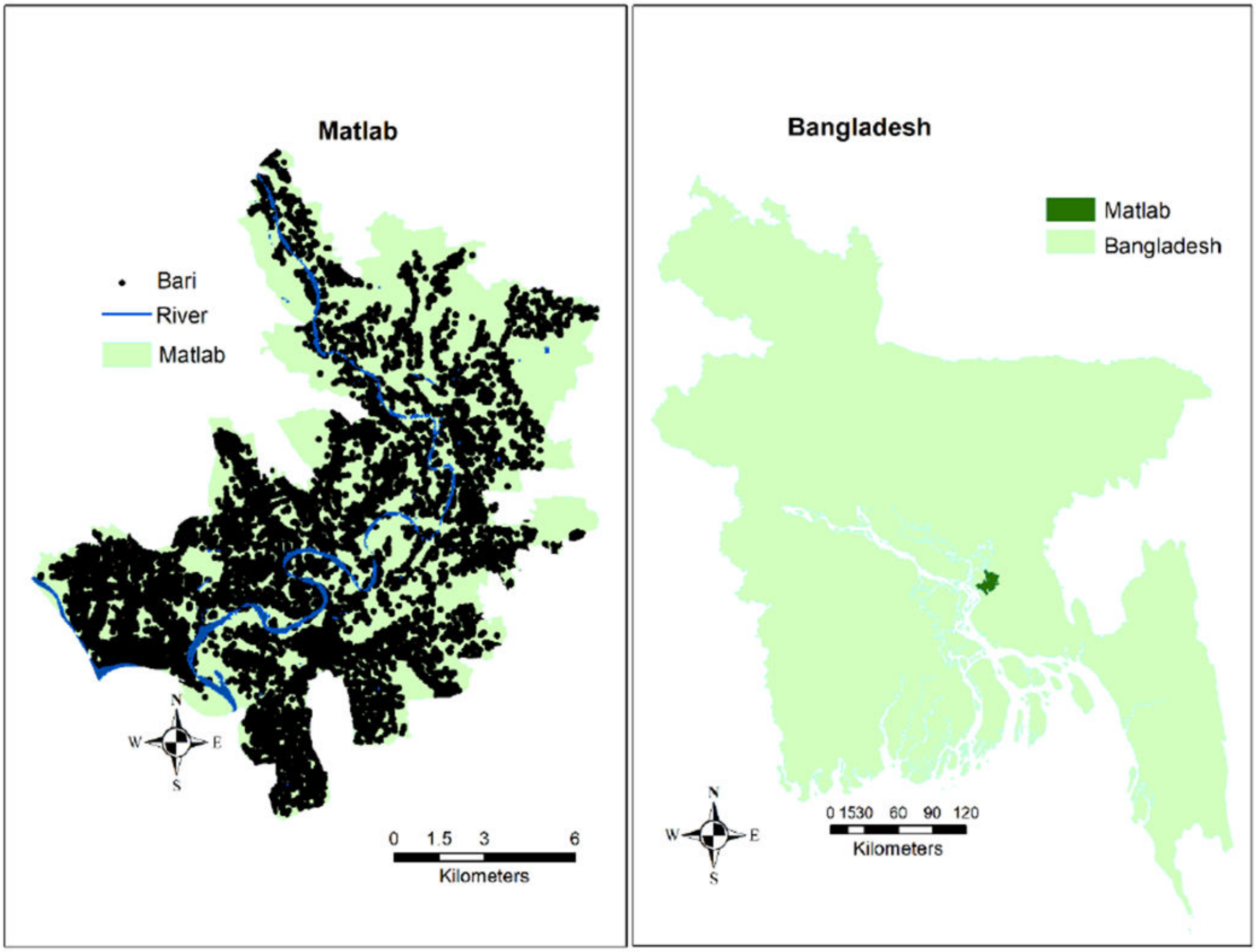


Figure 1.

The study area of Matlab, Bangladesh

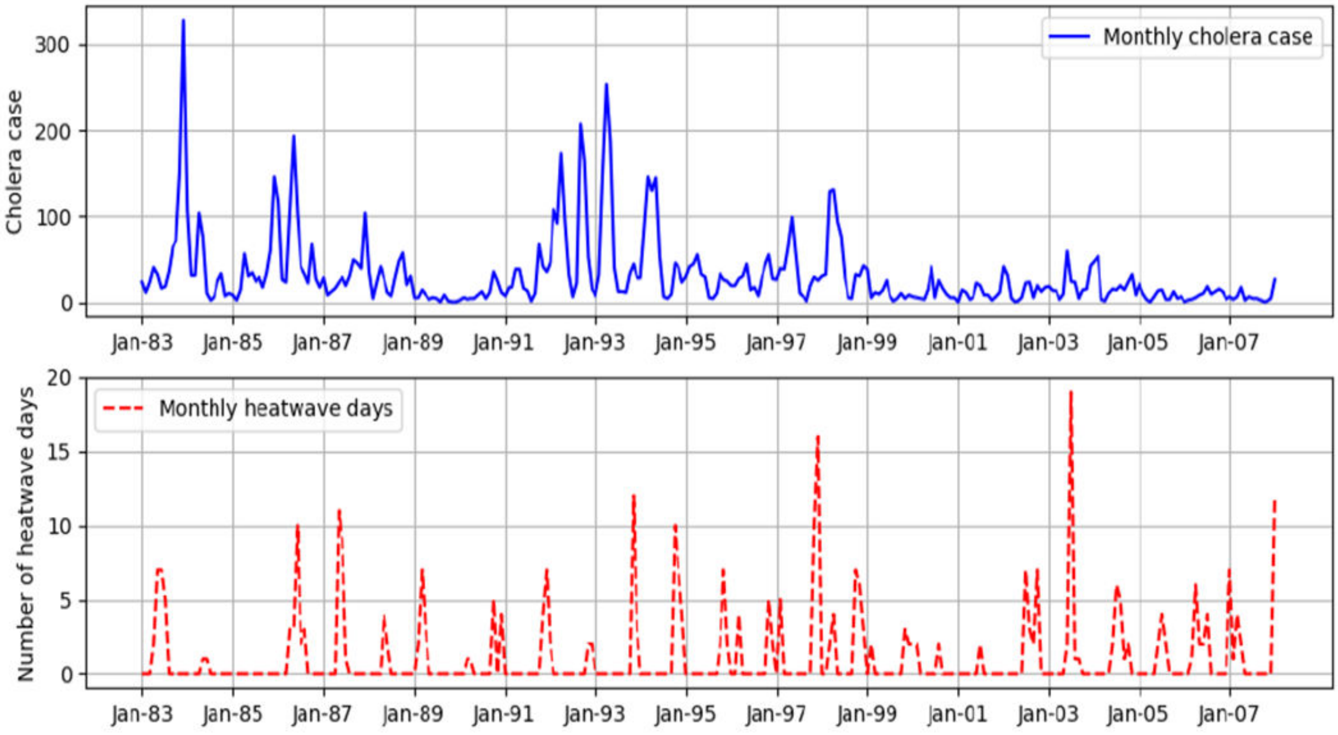
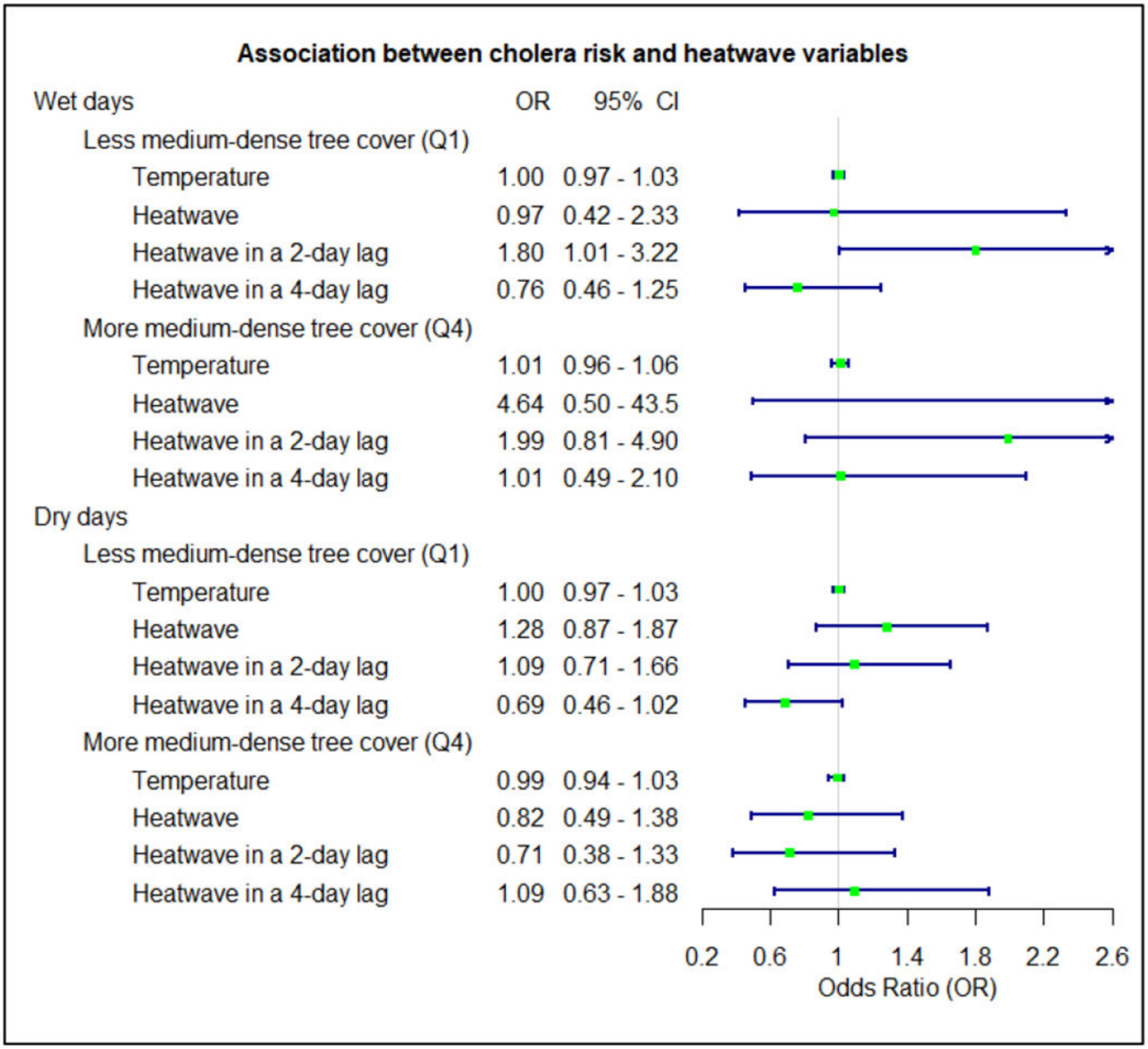


Figure 2.

Time series data of cholera cases and heatwave days from January 1983 to April 2009.

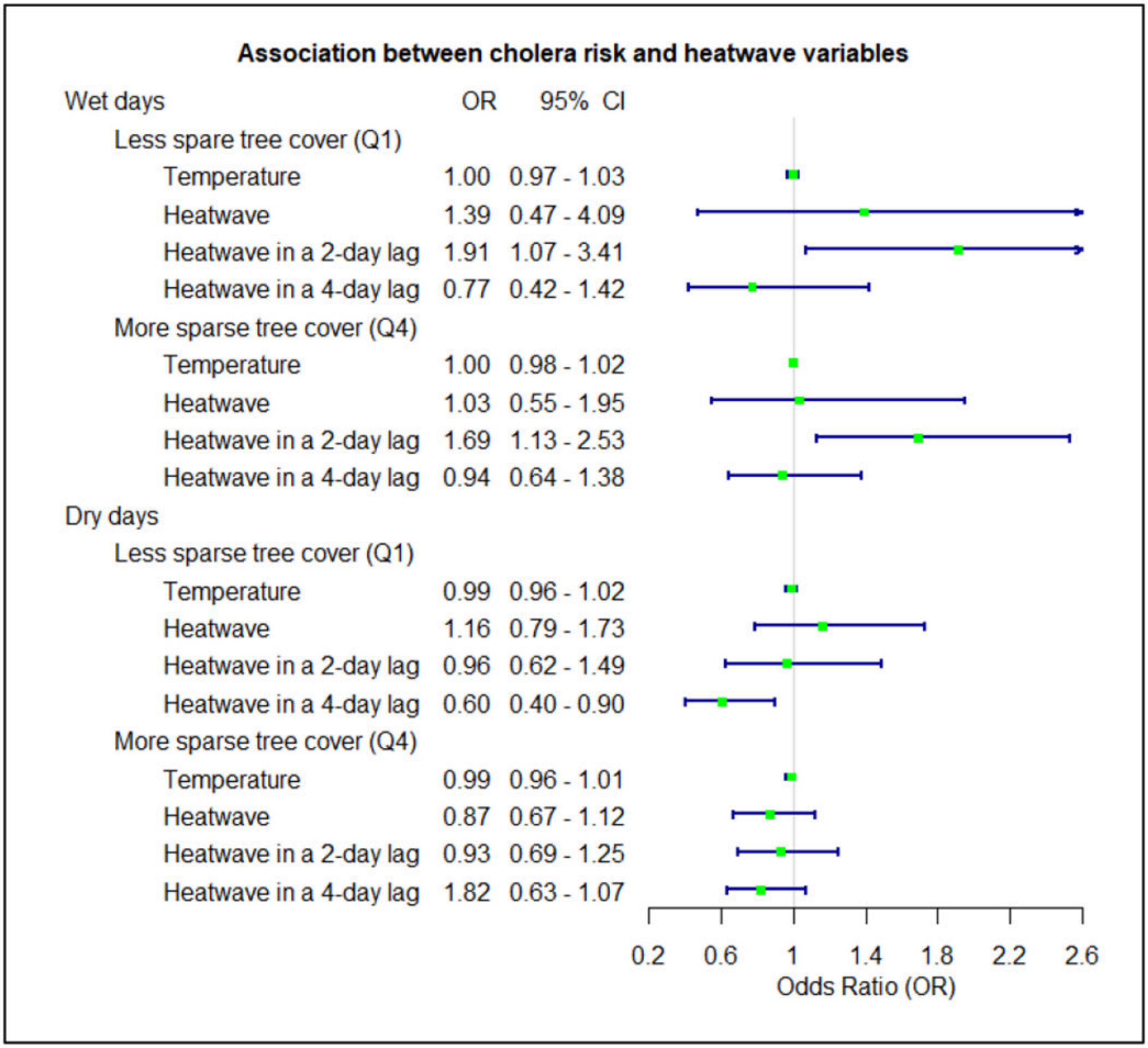


Association between cholera risk and heatwave variables

Wet days	OR	95% CI
Less medium-dense tree cover (Q1)		
Temperature	1.00	0.97 - 1.03
Heatwave	0.97	0.42 - 2.33
Heatwave in a 2-day lag	1.80	1.01 - 3.22
Heatwave in a 4-day lag	0.76	0.46 - 1.25
More medium-dense tree cover (Q4)		
Temperature	1.01	0.96 - 1.06
Heatwave	4.64	0.50 - 43.5
Heatwave in a 2-day lag	1.99	0.81 - 4.90
Heatwave in a 4-day lag	1.01	0.49 - 2.10
Dry days		
Less medium-dense tree cover (Q1)		
Temperature	1.00	0.97 - 1.03
Heatwave	1.28	0.87 - 1.87
Heatwave in a 2-day lag	1.09	0.71 - 1.66
Heatwave in a 4-day lag	0.69	0.46 - 1.02
More medium-dense tree cover (Q4)		
Temperature	0.99	0.94 - 1.03
Heatwave	0.82	0.49 - 1.38
Heatwave in a 2-day lag	0.71	0.38 - 1.33
Heatwave in a 4-day lag	1.09	0.63 - 1.88

Figure 3.

The association between the risk of cholera and heatwave stratified by rainfall and medium-dense tree cover examined using multivariable logistic regression models. Each model has four exploratory variables: temperature, heatwave, heatwave in a 2-day lag and heatwave in a 4-day lag.



Wet days	OR	95% CI
Less spare tree cover (Q1)		
Temperature	1.00	0.97 - 1.03
Heatwave	1.39	0.47 - 4.09
Heatwave in a 2-day lag	1.91	1.07 - 3.41
Heatwave in a 4-day lag	0.77	0.42 - 1.42
More sparse tree cover (Q4)		
Temperature	1.00	0.98 - 1.02
Heatwave	1.03	0.55 - 1.95
Heatwave in a 2-day lag	1.69	1.13 - 2.53
Heatwave in a 4-day lag	0.94	0.64 - 1.38
Dry days		
Less sparse tree cover (Q1)		
Temperature	0.99	0.96 - 1.02
Heatwave	1.16	0.79 - 1.73
Heatwave in a 2-day lag	0.96	0.62 - 1.49
Heatwave in a 4-day lag	0.60	0.40 - 0.90
More sparse tree cover (Q4)		
Temperature	0.99	0.96 - 1.01
Heatwave	0.87	0.67 - 1.12
Heatwave in a 2-day lag	0.93	0.69 - 1.25
Heatwave in a 4-day lag	1.82	0.63 - 1.07

Figure 4.

The association between the risk of cholera and heatwave stratified by rainfall and sparse tree cover examined using multivariable logistic regression models. Each model has four exploratory variables: temperature, heatwave, heatwave in a 2-day lag and heatwave in a 4-day lag.

Table 1.

Percentage of tree cover around 250 m in each household in Matlab, Bangladesh

Tree cover	Mean	Standard Deviation	Minimum	Maximum	Lower Quartile	Upper Quartile
No	6.10	12.35	0.00	87.46	0.00	4.28
Sparse	74.40	15.01	12.08	100.00	64.97	86.40
Medium	17.55	10.33	0.00	66.41	9.41	23.80
Dense	1.95	2.87	0.00	26.21	0.11	2.73

Table 2.

The association between the risk of cholera and heatwave stratified by rainfall, sex and age examined using multivariable logistic regression models. Each model has four exploratory variables: temperature, heatwave, heatwave in a 2-day lag and heatwave in a 4-day lag.

Stratification	Exploratory variables	OR	95% CI	p – value
No	Temperature	0.99	0.98 – 1.01	0.286
	Heatwave	1.03	0.87 – 1.22	0.768
	Heatwave in a 2-day lag	1.06	0.90 – 1.26	0.478
	Heatwave in a 4-day lag	0.88	0.75 – 1.04	0.128
Day type				
Dry (Rainfall=0)	Temperature	0.98	0.97 – 1.00	0.082
	Heatwave	0.99	0.79 – 1.25	0.938
	Heatwave in a 2-day lag	0.95	0.73 – 1.24	0.710
	Heatwave in a 4-day lag	0.80	0.63 – 1.01	0.065
Wet (Rainfall>0)	Temperature	1.00	0.98 – 1.02	1.000
	Heatwave	1.19	0.69 – 2.06	0.524
	Heatwave in a 2-day lag	**1.53**	**1.07 – 2.19**	**0.019**
	Heatwave in a 4-day lag	0.85	0.62 – 1.17	0.307
Sex				
Male	Temperature	0.99	0.98 – 1.01	0.257
	Heatwave	0.94	0.73 – 1.20	0.596
	Heatwave in a 2-day lag	1.16	0.91 – 1.48	0.221
	Heatwave in a 4-day lag	**0.75**	**0.60 – 0.95**	**0.017**
Female	Temperature	1.00	0.98 – 1.01	0.702
	Heatwave	1.12	0.89 – 1.41	0.346
	Heatwave in a 2-day lag	0.96	0.76 – 1.23	0.770
	Heatwave in a 4-day lag	1.03	0.82 – 1.29	0.801
Age				
<18 years	Temperature	0.99	0.97 – 1.00	0.094
	Heatwave	0.92	0.74 – 1.16	0.498
	Heatwave in a 2-day lag	1.11	0.88 – 1.40	0.387
	Heatwave in a 4-day lag	**0.79**	**0.64 – 0.99**	**0.036**
18 – 64 years	Temperature	1.00	0.98 – 1.01	0.657
	Heatwave	1.20	0.92 – 1.57	0.169
	Heatwave in a 2-day lag	0.94	0.72 – 1.24	0.675
	Heatwave in a 4-day lag	1.04	0.81 – 1.33	0.762
65 years and older	Temperature	1.05	1.00 – 1.11	0.059
	Heatwave	0.97	0.39 – 2.44	0.952
	Heatwave in a 2-day lag	1.73	0.79 – 3.81	0.171
	Heatwave in a 4-day lag	0.81	0.33 – 1.97	0.640