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Effects of local climate variability on transmission dynamics of cholera in Matlab, Bangladesh

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Summary Cholera is considered as a model for climate-related infectious diseases. In Bangladesh, cholera epidemics occur during summer and winter seasons, but it is not known how climate variability influences the seasonality of cholera. Therefore, the variability pattern of cholera events was studied in relation to the variation in local climate variables in Matlab, Bangladesh. Classification and regression tree (CART) and principal component analysis (PCA) were used to study the dependency and variability pattern of monthly total cholera cases. An average temperature $<23.25\,^\circ C$ corresponded to the lowest average cholera occurrence (23 cases/month). At a temperature of $\geq 23.25\,^\circ C$ and sunshine <4.13 h/day, the cholera occurrence was 39 cases/month. With increased sunshine (≥ 4.13 h/day) and temperature (23.25—28.66 °C), the second highest cholera occurrence (44 cases/month) was observed. When the sunshine was ≥ 4.13 h/day and the temperature was $>28.66\,^\circ C$, the highest cholera occurrence (54 cases/month) was observed. These results demonstrate that in summer and winter seasons in Bangladesh, temperature and sunshine hours compensate each other for higher cholera incidence. The synergistic effect of temperature and sunshine hours provided the highest number of cholera cases.

1. Introduction

Cholera is still a major public health problem in developing countries of the world, including Bangladesh. The effects of climate change on cholera may be of significant public health concern since cholera causes 100 000—150 000 deaths annually worldwide.[1] The geographical distribution

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of water-borne diseases is often influenced by climatic variability and change. Cholera is one such disease that has a strong relationship with climatic events and is therefore considered as a model for climate-related infectious diseases.[2]

Salazar-Lindo et al.[3] observed that with an increase of >5 °C in temperature above the normal during winter, the number of daily admissions of diarrhoeal patients in a hospital in Lima, Peru, increased more than two-fold compared with the expected trend. Global average temperature is projected to increase by between 1.4 °C and 5.8 °C by the end of the century.[4] Such an increase in temperature will be accompanied by a change in the ecology of infectious diseases, particularly cholera and other water-borne diseases.[5,6] One ecological-based hypothesis for the link between climate variables and cholera involves the association of *Vibrio cholerae* with phytoplankton (algae), as phytoplankton is a long-term reservoir of *V. cholerae*. *Vibrio cholerae* enter the mucilaginous sheath of phytoplankton (*Anabaena variabilis*), remain viable but become non-culturable, multiply and maintain their progeny generations after generations and survive many years inside the phytoplankton.[7–9]

The occurrence of cholera in Bangladesh and in different parts of the world is thought to be influenced by El Niño Southern Oscillation-related anomalies.[10] El Niño may have effects on regional or local climate that sometimes affect various regions differently.[11] The El Niño-related changes in regional temperature, precipitation and other environmental variables may affect cholera incidence directly through dispersion of *V. cholerae*, the causative agent of cholera, or indirectly through affecting its reservoir. In Bangladesh, cholera epidemics occur twice every year during summer and winter seasons.[12–14] Cholera seasons in Bangladesh coincide with formation of the phytoplankton bloom in the aquatic environment.[15,16] However, it is not known how local climate variability influences the seasonality of cholera in Bangladesh by affecting this phytoplankton bloom formation. Bangladesh is a deltaic country and most areas are low lying. The aquatic environment of Bangladesh possesses enormous area of wetlands including rivers, streams, freshwater lakes, marshes, fish ponds, flooded cultivated fields and estuarine systems with extensive mangrove swamps. Many species of algae, mainly blue–green algae, grow abundantly in all kinds of aquatic habitats in Bangladesh in which *V. cholerae* take shelter, and thus the blue–green algae act as a reservoir of cholera.[8,9,17]

Although a relationship between El Niño-related anomalies and cholera occurrence in Bangladesh has been reported,[18] El Niño alone is not sufficient to clarify the seasonality and transmission dynamics of cholera. Thus, a study is required to find out how local climate variability influences the seasonality and reservoir of cholera and ultimately how it affects its transmission dynamics. The present study was therefore conducted to investigate the impact of local climate variability on seasonality and transmission dynamics of cholera.

2. Materials and methods

2.1. Hospital surveillance

Daily cholera case data from 1989–2005 were collected from the records of Matlab Hospital of the International Center for Diarrhoeal Disease Research, Bangladesh (ICDDR,B). Systematic cholera surveillance (Health and Demographic Surveillance System) has been ongoing in Matlab, Chandpur, Bangladesh, since 1963.[13] Monthly total cholera cases were calculated from the daily records and were used for analysis. Cholera cases are diagnosed by the conventional culture technique.

2.2. Meteorological data

Meteorological data were collected from the Bangladesh Meteorological Department from 1989 to 2005. Data were collected regarding daily temperature, humidity, sunshine

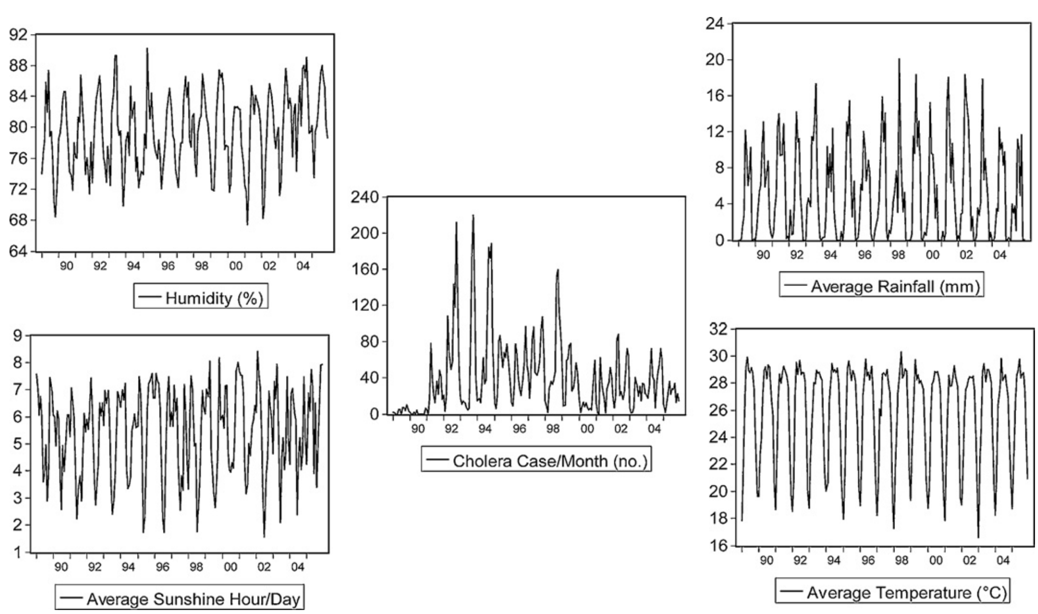

Figure 1 Monthly plot of climate variables and cholera cases from January 1989 to December 2005.

Table 1 Descriptive statistics of the climatic variables

Statistic	Humidity (%)	Rainfall (mm/day)	Sunshine (h/day)	Temperature (°C)
Minimum	67.45	0	1.58	16.58
1st quartile	76.03	0.45	4.13	23.25
Mean	79.54	5.39	5.44	25.89
Median	79.47	3.65	5.68	27.75
3rd quartile	83.29	9.48	6.82	28.66
Maximum	90.15	30.55	8.42	30.28

hours and rainfall from Chandpur meteorological station. Monthly means were calculated from the daily records.

2.3. Statistical analysis

The meteorological data had some missing observations that were estimated using autoregressive integrated moving average (ARIMA) models. Suitable ARIMA models were fitted for each variable and the missing observations were predicted using these models. Finally, the complete data set of five variables was obtained (Figure 1). A 3D surface plot was used in the first step to understand the variability patterns that exist in the cholera case data in relation to different climatic factors. Classification and regression tree (CART) was used to study the relationship among climatic variables and cholera incidence. To apply the 3D surface plot and CART, all climatic variables were categorised into three mutually exclusive groups as low (lowest observation up to first quartile), medium (first quartile to third quartile) and high (observations higher than the third quartile). For the 3D surface plot, the monthly cholera incidence was plotted over different categorical levels of two climatic variables. In CART, the monthly total cholera cases were classified based on categorised climatic variables and the descriptive statistics of each class were estimated. Exploratory data analysis failed to incorporate high dimensionality. Therefore, to understand the inter-relationship and variability patterns among climatic variables and cholera incidence, principal component analysis (PCA) was also used on the standardised data set.

3. Results

Figure 2 shows that medium and/or high levels of sunshine hours along with high temperature levels provided a suitable environment for a cholera outbreak. In the absence of high temperature, longer sunshine hours can contribute to a cholera outbreak.

The minimum, 1st quartile, median, 3rd quartile and maximum of each variable were estimated (Table 1). Using these statistics, monthly observations of the climatic variables were classified. Monthly total cholera cases were classified based on different categories of the climatic variables (Supplementary Figure 1). It was found that the overall mean of the study sample was 40 cases/month (node 0). CART algorithm identified four significant nodes that significantly improved the purity of the classified nodes. A low level of daily average temperature corresponded to the lowest average cholera occurrence (23 cases/month) (node 1). Medium or high-level temperature and a low level of sunshine hours corresponded to the comparatively higher monthly mean number of cholera cases (39 cases/month) (node 4) compared with node 1. The largest average number of cholera cases (54 cases/month) occurred at a high or medium level of sunshine hours and high level of temperature (node 6). The second largest average number of cholera cases (44 cases/month) occurred at a medium level of temperature and a high and/or medium level of sunshine hours (node 5). The CART growing method ranks each predictor variable according to its importance to the model. It was found that the importance of temperature to the model was highest, followed by sunshine hours. However, the categories of the other variables such as humidity and rainfall failed to contribute to the CART model.

PCA was used to verify the relationship among the climatic variables and monthly cholera incidence considering the climatic variables as continuous variables (Table 2). The loadings of the first principal component were all positive, except for sunshine hours. The negative sign corresponding

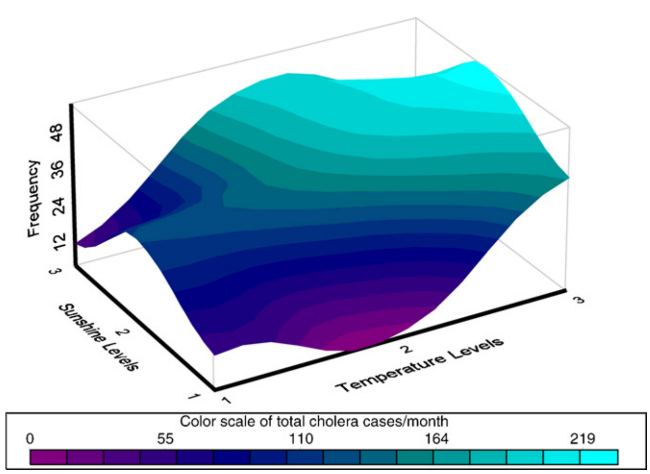

Figure 2 Three-dimensional surface plot of cholera cases/month for different levels of temperature (°C) and sunshine hours (h/day). Each colour indicates different levels of monthly total cholera cases. The colours are distributed over the surface of temperature and sunshine hour levels. The vertical axis displays the bivariate frequency of interpolated sunshine hours and temperature levels. Temperature level 1 = low (<23.25 °C), 2 = medium (23.25—28.66 °C) and 3 = high (>28.66 °C). Sunshine hours level 1 = low (<4.13 h/day), 2 = medium (4.13—6.82 h/day) and 3 = high (>6.82 h/day).

Table 2 Loadings and other statistics of the first three components

Variable	PC(1)	PC(2)	PC(3)
Humidity	0.480[a]	−0.15	−0.03
Rainfall	0.548[a]	−0.07	0.03
Sunshine hours	−0.493[a]	0.21[a]	−0.61[a]
Temperature	0.466[a]	0.27[a]	−0.71[a]
Total cholera cases (monthly)	0.093	0.93[a]	0.34[a]
Standard deviation	1.65	1.03	0.74
% of variance explained	54	21	11
Cumulative % of variance	54	75	86
λ_i (eigenvalue)	2.71	1.06	0.55

PC: principal component.
[a] Significant values.

to sunshine hours indicates that the variable contributed an opposite direction to the climatic variability explained by the first component. The first principal component is able to explain approximately 54% of the total variability of the climate.

In the second component, total cholera cases weighted most heavily, followed by sunshine hours and temperature. The second principal component explains 21% of the variability of the total climate and cholera system individually and 75% jointly with the first principal component. The second principal component can be identified as the cholera dynamics subsystem in the regional climate condition. The third principal component explains 11% of the remaining variability and 86% jointly with the first and second principal components. Loadings corresponding to sunshine hours and temperature are high and negative in the third principal component. The loading of the monthly total cholera cases is positive and significant. It is also found that the eigenvalue (λ_i) corresponding to the third principal component is <1 (0.55), which implies that the third principal component has low power to explain the variability and can be merged with the second principal component. Since the second principal component included positive effects and the third principal component included negative effects of sunshine hours and temperature, this explains that there might exist at least one non-linear relationship within the variables of the system. Such types of relationship most likely exist within temperature, sunshine hours and monthly total cholera cases.

The scatter plot presented in Supplementary Figure 2 shows the relationship among the scores of the principal components and all standardised variables. The horseshoe effect of temperature in the first principal component indicates that a non-linear relationship exists between temperature and some other variables included in the first principal component. The scatter plot also shows that a non-linear relationship exists between sunshine hours and temperature as well as temperature and humidity.

4. Discussion

In the present study, the effect of local climatic variables (temperature, humidity, rainfall and sunshine hours) on the variability of cholera occurrence in Matlab, Chandpur, Bangladesh, was studied. Considering the climatic variables along with the monthly total cholera cases as a system, three uncorrelated subsystems have been identified that explain 86% of the variability (cumulative proportion) of the total system (Table 2). The first component identifies the characteristic of local climate variability and includes humidity, rainfall, sunshine hours and temperature of Chandpur. It was observed that all the climate variables have almost the same contribution to the local climate system. The second component explains the cholera outbreak system. In this component, the monthly total cholera cases had the largest contribution to the component. The results suggest that an increase in temperature and sunshine hours positively affects the variability of the monthly cholera occurrence. It was also observed that higher temperature and medium sunshine hours provided favourable conditions for cholera outbreaks. However, cholera outbreaks can also occur when a lower temperature (level 2) is compensated with longer (level 3) sunshine hours (Figure 2). Similar results were also obtained by CART analysis. It was observed that when the sunshine hours are high or medium and the average temperature is high, the average monthly cholera incidence was the highest (≈54/month). High temperature and relatively shorter sunshine hours than winter are the climatic phenomena of summer in Bangladesh. In summer, the sunshine hours are shorter owing to cloud cover.[16] During winter, although the temperature is comparatively low, longer sunshine hours compensate the low temperature to maximise cholera incidence. Therefore, the climate factors such as sunshine hours and temperature act synergistically during cholera seasons to create a favourable environment for multiplication of the reservoir (phytoplankton) of cholera along with *V. cholerae*. Longer sunshine hours and high temperature create favourable conditions for phytoplankton bloom formation.[19] Phytoplankton bloom provides suitable conditions for *V. cholerae* multiplication in the aquatic environment.[3,20] *Vibrio cholerae* can survive in a dormant stage in association with phytoplankton.[7,9,20–23] When the water temperature rises, phytoplankton blooms and the population of *V. cholerae* increases.[3] The surface water systems such as ponds, lakes, rivers etc. then become more contaminated with *V. cholerae*. People contract cholera from the aquatic environment as they interact very closely with the surface water systems. Once an index case occurs in the community owing to lack of knowledge about personal, domestic and environmental hygiene, secondary transmission occurs an causing epidemic. Therefore, sunshine and temperature play an important role in the transmission dynamics of cholera.

Global temperature-induced climate change has a great impact on agriculture, forestry as well as environment-driven infectious disease prevalence. Regional climate variability also has effects on outbreaks and transmission of infectious disease.[6] Epidemiological evidence has demonstrated a widespread environmental cause for recent outbreaks of cholera in East Africa (1997—1998).[24]

In this study, the synergistic effect of sunshine hours and temperature has been demonstrated in cholera outbreaks using time series data for cholera in Matlab, Bangladesh. These findings suggest that cholera would be an increasing problem if the global climate continues to warm. The Intergovernmental Panel on Climate Change (IPCC) has already predicted that the global climate is going to be warmer.[25] Therefore, to substantiate this retrospective study, a prospective study is required to investigate the impact of climate change on transmission dynamics of cholera considering the possible changes in the aquatic ecosystems in Bangladesh.

Authors' contributions: MSI, IR, CPL, SPL and HPE participated in the conception and design of the study protocol; MAYS, SR, SH, ZHM and MSI collected the data; MAYS, AMKU and SPL analysed the data; MAYS, MY, MSO, RE, IR, SPL, HPE and AC interpreted the data; MSI, MAYS and MSI drafted the manuscript. All authors revised the article for intellectual content and read and approved the final version. MSI is guarantor of the paper.

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Conflicts of interest: None declared.

Ethical approval: Not required.

Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at doi:10.1016/j.trstmh.2009.04.016.

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