The relationship between meteorological factors and the risk of bacillary dysentery in Hunan Province, China

Xuewen Li,1 Ning Wang,1,3 Guoyong Ding,2 Xiaomei Li2 and Xiaojia Xue2

1Department of Environment and Health, School of Public Health, Shandong University, Jinan, China
2Department of Epidemiology, School of Public Health, Taishan Medical University, Taian, China
3Department of Health Education, Shandong Provincial Health and Family Planning Publicity and Education Center, Jinan, China

Introduction

Diarrhoeal diseases are a serious global health problem, and their influence on disability-adjusted life expectancy renders them responsible for 4.1% of the global disease burden (WHO, 2004). Bacillary dysentery, caused by Shigella bacteria, is a common diarrhoeal disease worldwide, though it is most prevalent in developing countries. The morbidity and mortality rate of bacillary dysentery is the highest among diarrhoeal diseases (Kotloff et al., 2012). In China, the incidence rate of bacillary dysentery ranged from 46.37 cases per 100,000 people to 1018.93 per 100,000 people between 1950 and 1980. After this period, the rate of incidence decreased until 2008, when it reached 23.85 cases per 100,000 people. Since 2008, the incidence rate started to increase again, and it reached 29.83 cases per 100,000 people in 2012 (Chang et al., 2016). Between 2008 and 2012, morbidity due to bacillary dysentery was in the top four serious infectious diseases in China (Liu and Yuan, 2014). China has a higher bacillary dysentery morbidity than that of developed countries such as France (0.3 per 100,000 people) and Germany (2.7 per 100,000 people; Wang et al., 2006). Bacillary dysentery is therefore still a serious public health problem in China. The Hunan Province has been shown to have a more serious problem with bacillary dysentery epidemics than other regions in China, with 19 outbreaks from 2008 to 2011 (Chang et al., 2012).

Bacillary dysentery is a typical example of a disease which is transmitted via the faecal–oral route (Niyogi, 2005), and it can therefore spread via exposure to polluted water resources, food, and human contact. Thus, it is mainly influenced by local poverty levels, living conditions, water storage methods, and personal hygiene habits (Kunii et al., 2002; Kelly-Hope et al., 2008). The incidence of bacillary dysentery in Hunan Province has changed significantly, even though the social factors mentioned were stable for an extended period, indicating a connection between the disease and the seasonal variation (Zhang et al., 2008; Ma et al., 2013a). Meteorological factors have been shown to affect the spread of bacillary dysentery, causing changes in the reproductive rate of Shigella dysenteriae by reducing its incubation period (Patz et al., 1996). In addition, changes in meteorological conditions can exacerbate the spread of bacillary dysentery by precipitating changes in the dietary habits of humans (Zhang et al., 2008).

Studies on the effects of meteorological factors on the rate of spread of bacillary dysentery have produced inconsistent results that vary depending on the study area. In sub-Saharan Africa, an epidemiological study found that the shortage of rainfall in the dry season increased the prevalence of bacillary dysentery, and that an increase in maximum temperature raises dysenteric prevalence, while an increase in minimum monthly temperature lowers dysentery prevalence (Bandyopadhyay et al., 2012). However, one study from the Pacific Islands found positive correlations between the reported incidence of diarrhoea and temperature, and the reported incidence of diarrhoea and rainfall extremes (Singh et al., 2001). Some studies claimed that rainfall did not affect the transmission of enteric infections (D’Souza et al., 2004; Zhang et al., 2007; 2008). This phenomenon is probably due to the complicated relationship between bacillary dysentery morbidity and meteorological factors. Furthermore, the majority of those studies do not consider autocorrelation factors or seasonality effects, resulting in the overstatement or understatement of the role of meteorological factors.

The relationship between the morbidity of bacillary dysentery and meteorological factors is still unknown in Hunan Province, even though it has been identified as an area that is severely afflicted by bacillary dysentery. The area with the highest incidence of bacillary dysentery in Hunan Province was therefore selected for quantitative evaluation of the effects of meteorological factors on bacillary dysentery morbidity, in order to establish scientific constraints in the control and prevention of this disease.

Materials and methods

Study area

The Hunan Province is located at the junction of west and east China. It covers an area of 211,800 km² between 24°39’N and 30°08’N latitude, and 108°47’E and 114°15’E longitude (Figure 1), and it has a total population of 68.46 million. The province is generally characterised as subtropical monsoonal, with mild temperatures (15–18°C annual average) and plentiful rainfall (1200–1700 mm annual average). Xiangxi, the study area, is located in the northwest of the Hunan Province, with an area of 17,864 km² and a population of 2.6 million.

Data collection

Bacillary dysentery data were collected between 2005 and 2011 from the National Notifiable Disease Surveillance System (NDSS). The bacillary dysentery cases were defined based on the diagnostic criteria and principles of management for bacillary dysentery, issued by the Ministry of Health of the People’s Republic of China (GB 16002-1995; SAI Global). The information obtained included the number of bacillary dysentery cases by date (month and year) and district. The data collected for the chosen time period are considered to be reliable, based on the degree of compliance in disease notification exercised by the NDSS, which has a five-level network reporting system for infectious diseases from county level to national level, and a three-level network platform from the prefectoral-level city to
national level. Also, hospital physicians must report every case of bacillary dysentery to the database of national disease control and prevention via the Internet/VPN (Jin et al., 2006), and the local CDC conducts active surveillance regularly to reduce the rate of misreporting and underreporting.

Demographic data were obtained from the Center for Public Health Science Data in China (see http://www.phsciencedata.cn/). Monthly meteorological data were obtained from the China Meteorological Data Sharing Service System (see http://data.cma.cn/), with permission from the National Meteorological Information Center of China. The meteorological variables collected for this study were: average temperature, cumulative rainfall, average relative humidity, and average air pressure. The selection of these meteorological factors was based on the results of previous studies which indicate that there is a biologically plausible connection between these factors and the incidence of bacillary dysentery. For example, one study showed that variations in precipitation and temperature in particular influenced the prevalence of dysentery in children under the age of three in Africa (Bandyopadhyay et al., 2012). Other studies have shown that temperature, rainfall, relative humidity, hours of sunshine, and air pressure were significantly correlated with the incidence of dysentery (Zhang et al., 2007; 2008; Guan et al., 2008; Ma et al., 2013b).

**Study design and statistical analysis**

We started by calculating the annual average incidence rate of bacillary dysentery from 2005 to 2011. Spatial descriptive analysis was then performed to define the prefecture-level cities with the highest incidence of bacillary dysentery by comparing the cases in different areas in Hunan Province.

Spearman correlation analysis was used to examine the relationship between monthly bacillary dysentery cases and meteorological factors at the study site. The lagged effects for each meteorological factor were defined according to two aspects: (1) the maximum value of the correlation coefficient between meteorological factors and the incidence rate of bacillary dysentery; (2) the reproductive cycle and speed of spread of *Shigella dysenteriae* (the maximum lag effect was up to 2 months).

Time-series Poisson regression analysis was adopted to calculate the relationship between the meteorological factors and the monthly number of bacillary dysentery cases. Considering the autocorrelation and the trend of the seasonality effect on bacillary dysentery, the time factor *t* (month) and its sine function were added to the Poisson regression equation (the equations are shown in the supporting information Methods S1). According to the Akaike Information Criterion (AIC) value of the models and the multiple correlation coefficients (*r*) between the estimated and observed number of cases per month, the fitting effect of the model was evaluated to find the optimal model for the correlation between meteorological factors and bacillary dysentery. The model built with the data from 2005 to 2010 was used to predict the cases for 2011. Further evaluation was required based on the comparison between the model predictions and the observation data for 2011. A sensitivity analysis for the time-series Poisson regression model was tested by calculating the standardised regression coefficients (SRCs). The SRCs can themselves provide a very effective measure of the relative importance of the input variables. Of course, the SRCs can also be used as a measure of sensitivity with which to identify the certainty in the model’s output (Saltelli and Marivoet, 1990). All the statistical analyses were performed using Stata 12.0 (StataCorp LP, USA).

**Results**

**Temporal and spatial descriptive analysis for bacillary dysentery**

The incidence rates of bacillary dysentery in different prefecture-level cities from 2005 to 2010 are shown in Figure 2. The western, southern, and eastern parts of Hunan Province displayed higher annual incidence rates of bacillary dysentery than the central and northern parts. Annual morbidity fluctuation trends of bacillary dysentery displayed differences depending on the prefecture-level city under consideration. For instance, the trend in the morbidity of bacillary dysentery was stable in Zhuzhou from 2005 to 2010, while the trend in Yongzhou displayed an increase followed by a decrease. For the same period in Zhangjiajie, the incidence rate of bacillary dysentery showed a more complicated trend: a decrease, followed by an increase, followed by a final decrease. Serious morbidity of bacillary dysentery occurred mainly in Xiangxi, Yongzhou and Chenzhou, and Xiangxi had the highest incidence rate (44.07 per 100 000 people). Xiangxi was therefore selected as our study site for the investigation of the effects of meteorological factors on bacillary dysentery.

**Spearman correlation analysis**

Results of the correlation analysis for the monthly number of cases of bacillary dysentery and meteorological factors in Xiangxi are shown in Table 1. The monthly number of cases of bacillary dysentery was positively correlated with average temperature, cumulative rainfall, average relative humidity, and cumulative hours of sunshine (*P* < 0.05), and negatively correlated with average air pressure (*P* < 0.05). Analysis of lagged effects also resulted in a number of findings: first, cumulative rainfall had a 2-month lagged effect on bacillary dysentery; second, average air pressure and relative humidity both had a 1-month lagged effect; and, third, average temperature and cumulative hours of sunshine did not exhibit lagged effects.

**Time-series Poisson regression analysis**

After adjusting for the effects of autocorrelation and seasonality on bacillary dysentery, the data for the number of cases and the meteorological variables were put into the time-series Poisson model, in which...
The lagged effects of meteorological factors were taken into consideration. The results of the time-series Poisson model for the study site are presented in Table 2. The regression model showed that, at a monthly timescale, average temperature (with no lag effect), average relative humidity (with a 1-month lagged effect), cumulative hours of sunshine (with no lag effect), and cumulative rainfall (with a 2-month lagged effect) all have a significant statistical correlation with the number of cases of bacillary dysentery ($P < 0.05$).

The results of the regression modelling suggest the following: (1) a 1 °C rise in average temperature corresponds to a 2.68% (95% CI: 1.57–3.80%) increase in the number of cases of bacillary dysentery (i.e. the RR value of bacillary dysentery for average temperature was 1.0268); (2) a 1% rise in average relative humidity corresponds to a 0.73% (95% CI: 0.31–1.15%) increase in the number of cases of bacillary dysentery (i.e. the RR value of bacillary dysentery for average relative humidity was 1.0073); (3) a 1h increase in the cumulative number of hours of sunshine corresponds to a 0.13% (95% CI: 0.06–0.21%) increase in the number of cases of bacillary dysentery (i.e. the RR value of bacillary dysentery for the cumulative number of hours of sunshine was 1.0013); (4) cumulative rainfall was significantly correlated with the number of cases of bacillary dysentery ($RR = 1.0005$, 95% CI: 1.0002–1.0008). However, average air pressure did not correlate with the number of cases of bacillary dysentery in the regression model. Of the standardised regression coefficients of each meteorological variable, monthly average temperature exhibited the highest value, indicating that temperature was the meteorological factor with the strongest influence on the transmission of bacillary dysentery at the study site.

The results of the time-series Poisson model for observational data and model fit, from 2005 to 2010, are presented in Figure 3. The model diagnostics showed that there was an excellent goodness-of-fit for the number of observed and model fit cases of bacillary dysentery from the Poisson model ($r^2 = 0.86$). The monthly number of bacillary dysentery cases for 2011 was predicted using this model to further test its validity. The correlation between the number of predicted cases and the number of observed cases is presented in Figure 4 – it shows a goodness-of-fit value of 86%, with the number of predicted cases being slightly lower than the number of observed cases from January to March and slightly higher from July to September.

The use of SRCs was adopted for sensitivity analysis for the time-series Poisson regression analysis. The SRCs of temperature, humidity, hours of sunshine, rainfall and air pressure were 0.0024, 0.0006, 0.0005, 0.0008,
Meteorological factors and bacillary dysentery

Figure 4. Relationship between observed and predicted cases of bacillary dysentery in Xiangxi.

Discussion

Parts of the west, south, and east of Hunan Province were found in this study to display more serious bacillary dysentery incidence rates relative to the middle and northern parts. The western part of Hunan Province (Xiangxi) showed the highest incidence rate. The cases of bacillary dysentery in the Hunan Province seem to have been related to the presence of mountainous terrains, such as that found in Xiangxi; the western, southern, and eastern parts of the province all have mountainous terrain with higher elevations than the middle and northern parts of the province. This relationship could be a result of several factors. Firstly, water management issues may occur over steeper terrain, and limited water conservation facilities result in river water being used for irrigation and wells being used as a source of drinking water; a defective wastewater blowdown system can be easily polluted by pathogens under certain meteorological conditions, such as heavy rainfall. Secondly, meteorological factors themselves can be affected by the terrain. For instance, surface roughness affects aerodynamics and thermostability, and these factors can influence seasonal and interannual climate changes (Torres Silva dos Santos et al., 2013). Therefore, a region’s terrain can indirectly affect the transmission of bacillary dysentery through its influence on meteorological factors (which also indicates that meteorological factors may play an important role in the epidemic of bacillary dysentery).

This study shows that meteorological factors cause not only immediate effects but also lagged effects on the morbidity of bacillary dysentery within one or two months. This conclusion is supported by the research of Zhang et al. (2007) who found that maximum temperature, minimum temperature, rainfall, relative humidity, and air pressure were related to the morbidity of bacillary dysentery, with lagged effects varying from zero to two months in Jinan and Baolan in China (Zhang et al., 2007). Alexander et al. (2013) found that rainfall and minimum temperature affected the incidence of diarrhoea, with 1-month lagged effects, in Botswana. The lagged effects mainly include: the growth cycle of a pathogen under optimal living conditions; the period of its spread via food and water; and the time periods between morbidity, diagnosis, hospital treatment and a report being added to the database (Zhang et al., 2007). Therefore, in different areas with different natural and social conditions, the meteorological factors may cause different lagged effects in the morbidity of bacillary dysentery. This indicates that meteorological factors can be used as predictive factors in bacterial dysentery incidence, especially in cases of extreme climate events, such as heatwaves, droughts, and floods.

Multivariate analysis demonstrated that average temperature, relative humidity, rainfall, and hours of sunshine were significantly associated with dysentery transmission. Of these factors, temperature was shown to be the meteorological factor with the strongest influence on the number of cases of bacillary dysentery transmission. These findings are supported by other studies: Li et al. (2014) found that in Guangzhou, China a 1 degC rise in temperature was correlated with a 3.6% (95% CI: 3.03–4.18%) increase in the number of cases of bacillary dysentery; a study by Zhang et al. (2008) showed that there was a relationship between a maximum temperature rise and an increase of more than 10% in the number of cases of bacillary dysentery in Jinan, China; and research in Botswana by Alexander et al. (2013) showed that an increase in minimum temperature was the major causative factor in the increase in cases of diarrhoea between 1974 and 2003. These findings can be attributed to the fact that temperature affects the reproductive capacity of the pathogen responsible for bacillary dysentery. Suitable temperatures for the growth of *Shigella dysenteriae* range between 20 and 40°C, with optimal growth occurring at 37°C (Lake et al., 2009).
High temperatures can therefore improve the growth of *Shigella dysenteriae* and prolong its residence time in the environment, which increases the risk of food and water pollution. Particular temperature conditions can also strengthen the invasiveness of *Shigella dysenteriae*. Zhu et al. (2010) found that when the temperature rises to 37°C, the gene expression of virulence-related proteins such as IpaA, IpaB, IpaC and IpaD were stronger. In addition, high temperatures can also improve the reproduction and growth of various insect species, such as flies and cockroaches, which also increases the risk of food pollution.

Other meteorological factors, such as rainfall, humidity, and hours of sunshine, may also contribute to the transmission of bacillary dysentery. For instance, a positive relationship between rainfall and diarrhoea has been reported on the Pacific island of Fiji (Singh et al., 2001). Also, Huang et al. (2008) found that rainfall and relative humidity were positively correlated with the incidence of bacillary dysentery in Shenyang in China. Although our research is supported by these studies, the association between those meteorological factors and the incidence of bacillary dysentery is far from clear. For example, in Wuhan, China the morbidity of bacillary dysentery was negatively correlated with rainfall and humidity (Li et al., 2013). The growth of *Shigella dysenteriae* is inhibited when relative humidity is between 10% and 60%. However, when it is higher or lower than the boundaries of that range, the lifetime of *Shigella dysenteriae* is prolonged (Yang et al., 2008). Therefore, drought and high humidity conditions benefit the growth and reproduction of *Shigella dysenteriae*. Large amounts of rainfall can increase the frequency and extent of water pollution events (Curriero et al., 2001) because the pathogen is carried from faeces to the surface water and groundwater. Also, the overflow of drainage pipes leads to the spilling of wastewater into rivers and domestic water supply systems, resulting in severe cross pollution (Borchardt et al., 2003; Reynolds et al., 2008). Low amounts of rainfall can also adversely influence water pollution conditions, by decreasing the dilution ability of wastewater systems (Hashizume et al., 2007). Therefore, either too much or too little rain can cause an epidemic of bacillary dysentery. Xiangxi is an area with mild climate and plentiful rainfall, which are suitable conditions for the growth and reproduction of pathogens and insects, as was observed in our results, with rainfall and relative humidity showing positive correlations with the morbidity of bacillary dysentery in Xiangxi.

The time-series Poisson regression model suggests that the number of hours of sunshine is a factor that has affected the transmission of bacillary dysentery in Xiangxi. However, other studies argue that the number of hours of sunshine does not affect the transmission of enteric infections (Ding et al., 2013; Li et al., 2014). A possible explanation is that temperature is correlated with hours of sunshine and, therefore, an increase in the number of hours of sunshine is accompanied by an increase in temperature, which promotes the growth of pathogens. These changes also affect human activity; for example, people tend to participate in more outdoor activities on sunny days, which will increase their chance of exposure to pathogens (Zhang et al., 1999). Furthermore, a study by Zhang et al. (1999) showed that Th1 cells aid in the removal of *Shigella dysenteriae* in the body, but sunshine can inhibit the reaction of the Th1 cells. Long hours of sunlight may therefore indirectly increase the human susceptibility to infectious diseases (Norval, 2001).

The time-series Poisson regression model can control confounding factors, such as autocorrelation and seasonality, and therefore provide a more accurate analysis of the relationship between meteorological factors and the incidence of bacillary dysentery, as well as prediction models with excellent goodness-of-fit. Unfortunately, there are limitations to this study. First, when extreme climate events, such as droughts, floods and heatwaves, happen simultaneously, the model prediction might be inaccurate. Further study should address this limitation by combining extreme climate events with the meteorological factors in this study and also investigate the combined effect of extreme climate events in the predictive models. Second, due to a lack of data, this study does not account for economic factors, terrain, health habits, and social interventions, which also influence the morbidity of bacillary dysentery. Further data collection is required to investigate these factors, improve the models and better assess the relationship between meteorological variables and diseases.

Conclusions

Xiangxi was found to be the prefecture-level city with the highest incidence of bacillary dysentery in Hunan Province. Average temperature, rainfall, relative humidity, and hours of sunshine can significantly increase the risks of bacillary dysentery at the study site, with various lagged effects. Of the factors considered in this study, average temperature was found to be the most important meteorological factor influencing the bacillary dysentery risk. Public health actions should therefore be taken to reduce the future impacts of climate change, adjusted for local climatic conditions and population characteristics.

Acknowledgments

This study was supported by the National Basic Research Program of China (973 Program; Grant no. 2012CB955500-955502), the Natural Science Foundation of Shandong Province for the Joint Specific Program (Grant no. ZR2015HL100), the Medicine and Health Science Technology Development Program of Shandong Province (Grant no. 2016WS0605), the Science and Technology Development Plan of Taian City (Grant no. 2016NS1206), and the High-level Research Topic of Taishan Medical University for the Cultivated Program (Grant no. 2015GCC16 and 2016GCC05). We thank the Chinese Center for Disease Control and Prevention, the National Meteorological Information Center of China, and the Data Center for the Institute of Geographic Sciences and Natural Resources Research of China for sharing with us the data needed for this study.

References

Alexander KA, Carzolio M, Goodin D et al. 2013. Climate change is likely to worsen the public health threat of diarrheal disease in Botswana. Int. J. Environ. Res. Public Health 10: 1202–1230.

Bandyopadhyay S, Kanji S, Wang L. 2012. The impact of rainfall and temperature variation on diarrheal prevalence in Sub-Saharan Africa. Appl. Geogr. 33: 63–72.

Borchardt MA, Bertz PD, Spencer SK et al. 2003. Incidence of enteric viruses in groundwater from household wells in Wisconsin. Appl. Environ. Microbiol. 69: 1172–1180.

Chang Z, Zhang J, Zhang WD et al. 2012. Analysis of bacillary dysentery outbreaks in China, 2008–2011. Chin. J. Food Hyg. 24: 554–558 (in Chinese).

Chang Z, Zhang J, Ran L et al. 2016. The changing epidemiology of bacillary dysentery and characteristics of antimicrobial resistance of *Shigella* isolated in China from 2004–2014. BMC Infect. Dis. 16: 685.

Curriero FC, Patz JA, Rose JB et al. 2001. The association between extreme precipitation and waterborne disease outbreaks in the United States, 1948–1994. Am. J. Public Health 91: 1194–1199.

Ding G, Zhang Y, Gao L et al. 2013. Quantitative analysis of burden of infectious diarrhea associated with floods in northwest of Anhui province, China: a mixed method evaluation. PLoS One 8: e65112.

D’Souza RM, Becker NG, Hall G et al. 2004. Does ambient temperature affect foodborne disease? Epidemiology 15: 86–92.

Guan P, Huang D, Guo J et al. 2008. Bacillary dysentery and meteorological factors in northeastern China: a historical review based on classification and regression trees. Jpn. J. Infect. Dis. 61: 356–360.

Hashizume M, Armstrong B, Hajat S et al. 2007. Association between climate variability and hospital visits for non-diarrheal illnesses. Appl. Geogr. 27: 212–225.
cholera diarrhoea in Bangladesh: effects and vulnerable groups. Int. J. Epidemiol. 36: 1030–1037.

Huang D, Guan P, Guo J et al. 2008. Investigating the effects of climate variability on bacillary dysentery incidence in northeast China using ridge regression and hierarchical cluster analysis. BMC Infect. Dis. 8: 130.

Jin SG, Jiang T, Ma JQ. 2006. Brief introduction of Chinese infectious disease detection report information system. China Digital Med. 1: 20–22 (in Chinese).

Kelly-Hope LA, Alonso WJ, Thiem VD et al. 2008. Temporal trends and climatic factors associated with bacterial enteric diseases in developing countries: epidemiologic and clinical methods of the case/control study. Clin. Infect. Dis. 55(Suppl 4): S232–S245.

Li Z, Wang L, Sun W et al. 2009. The impact on health and risk factors of the diarrhoea epidemics in the 1998 Bangladesh floods. Public Health 116: 68–74.

Lake IR, Gillespie IA, Bentham G et al. 2009. A re-evaluation of the impact of temperature and climate change on foodborne illness. Epidemiol. Infect. 137: 1538–1547.

Li Z, Wang L, Sun W et al. 2013. Identifying high-risk areas of bacillary dysentery and associated meteorological factors in Wuhan, China. Sci. Rep. 3: 3239.

Li T, Yang Z, Wang M. 2014. Temperature and atmospheric pressure may be considered as predictors for the occurrence of bacillary dysentery in Guangzhou, Southern China. Rev. Soc. Bras. Med. Trop. 47: 382–384.

Liu TJ, Yuan J. 2014. An analysis of the spread pattern of contagious diseases emerging in China from 2008 to 2012. Health Res. 34: 484–486 (in Chinese).

Ma W, Sun X, Song Y et al. 2013a. Applied mixed generalized additive model to assess the effect of temperature on the incidence of bacillary dysentery and its forecast. PloS One 8: e62122.

Ma SL, Tang QL, Liu HW et al. 2013b. Correlation analysis for the attack of bacillary dysentery and meteorological factors based on the Chinese medicine theory of Yunqi and the medical-meteorological forecast model. Chin. J. Integr. Med. 19: 182–186.

Niyogi SK. 2005. Shigellosis. J. Microbiol. 43: 133–143.

Norval M. 2001. Effects of solar radiation on the human immune system. J. Photochem. Photobiol. B 63: 28–40.

Patz JA, Epstein PR, Burke TA et al. 1996. Global climate change and emerging infectious diseases. JAMA 275: 217–223.

Reynolds KA, Mena KD, Gerba CP. 2008. Risk of waterborne illness via drinking water in the United States. Rev. Environ. Contam. Toxicol. 192: 117–158.

Saltelli A, Marivoet J. 1999. Non-parametric statistics in sensitivity analysis for model output: A comparison of selected techniques. Reliab. Eng. Syst. Saf. 28: 229–253.

Singh RB, Hales S, de Wet N et al. 2001. The influence of climate variation and change on diarrheal disease in the Pacific Islands. Environ. Health Perspect. 109: 155–159.

Torres Silva dos Santos A, Moises Santos e Silva C. 2013. Seasonality, interannual variability, and linear tendency of wind speeds in the northeast Brazil from 1986 to 2011. Sci. World J. 2013: 490857.

Wang XY, Tao F, Xiao D et al. 2006. Trend and disease burden of bacillary dysentery in China (1991–2000). Bull. World Health Organ. 84: 561–566.

WHO. 2004. Changing History. World Health Report. Geneva, Switzerland: World Health Organization. http://www.who.int/whr/2004/en/report04_en.pdf (accessed 1 January 2016).

Yang L, Zhou GQ, Zhou CP. 2008. Analysis of grey correlation between the factors of meteorological phenomena and the occurrence of bacillary dysentery. J. Math. Med. 21: 707–708 (in Chinese).

Zhang Y, Bi P, Hiller JE et al. 2007. Climate variations and bacillary dysentery in northern and southern cities of China. J. Infect. 55: 194–200.

Zhang Y, Bi P, Hiller JE. 2008. Weather and the transmission of bacillary dysentery in Jinan, northern China: a time-series analysis. Public Health Rep. 123: 61–66.

Zhang Y, Gao J, Peng H. 1999. Regulative roles of T_H1 and T_H2 cells on mucosal immune responses of mice induced by the bivalent Shigella vaccine candidates. Chin. J. Microbiol. Immunol. 19: 1–6.

Zhu L, Zhao G, Stein R et al. 2010. The proteome of Shigella flexneri 2a 2457T grown at 30 and 37 degrees C. Mol. Cell. Proteomics 9: 1209–1220.

Supporting information

Methods S1. Poisson regression equations.

Correspondence to: G. Ding
dgy153@126.com

© 2018 The Authors Weather published by John Wiley & Sons Ltd on behalf of Royal Meteorological Society

This is an open access article under the terms of the Creative Commons Attribution License, which permits use, distribution and reproduction in any medium, provided the original work is properly cited.
doi:10.1002/wea.3085