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Assessment on the burden of bacillary dysentery associated with floods during 2005–2009 in Zhengzhou City, China, using a time-series analysis

Xiaowen Hu [a,1], Guoyong Ding [b,1], Ying Zhang [c], Qiyong Liu [d], Baofa Jiang [e,**], Wei Ni [e,f,*]

[a] Department of Acute Infectious Diseases, Municipal Centre of Disease Control and Prevention of Qingdao, Qingdao Institute of Prevention Medicine, Qingdao City, Shandong Province, PR China
[b] Department of Epidemiology, School of Public Health, Taishan Medical College, Taian City, Shandong Province, PR China
[c] School of Puxblic Health, China Studies Centre, The University of Sydney, New South Wales, Australia
[d] State Key Laboratory for Infectious Diseases Prevention and Control, National Institute for Communicable Disease Control and Prevention, China CDC, Beijing City, PR China
[e] Department of Epidemiology and Health Statistics, School of Public Health, Shandong University, Jinan City, Shandong Province, PR China
[f] Women and Children's Hospital, Qingdao University, Qingdao, Shandong Province, PR China

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ABSTRACT

Background: We aimed to quantify the impact of few times floods on bacillary dysentery in Zhengzhou during 2005–2009.
Methods: The Spearman correlation test was applied first to examine the lagged effects of floods on monthly morbidity of bacillary dysentery during 2005–2009 in Zhengzhou. We further quantified the effects of 7 flood events on the morbidity of bacillary dysentery using the time-series Poisson regression controlling for climatic factors, seasonality, gender and age groups. We estimated years lived with disability (YLDs) to estimate the burden of bacillary dysentery attributed to floods among different population groups.
Results: A total of 15,841 cases of bacillary dysentery were reported in the study region over the study period. The relative risks of floods on the morbidity of bacillary dysentery and attributable YLDs among the whole study population, males, females, below 14 years old group, 15–64 years old group, and over 65 years old group were 2.80, 3.13, 2.53, 2.75, 3.03, 2.48, and 1.206, 1.513, 0.913, 3.593, 0.638, 0.880, respectively.
Conclusions: Our findings contribute to developing local strategies to prevent and reduce health impact of floods.

Introduction

Climate change is a complex global environmental problem with the significant impacts on human health. Much of these impacts may be due to the perception that climate change is leading to an increase in the occurrence and magnitude of extreme flood events [1], and that problem is not going away [2]. Due to frequent heavy precipitation, Zhengzhou, as the capital city of Henan Province in China adjacent to Yellow River, has suffered from many times of floods since the 21st century [3].

The damages of floods include direct and indirect damages, which are acknowledged that playing an important role in evaluating flood impacts [4]. Some studies have examined the epidemics of water-borne diseases associated with flood events, such as cholera, gastro-enteritis, dysentery and typhoid [5–8]. The reason for increased morbidity could be due to drinking water or food contaminated by pathogens [9,10].

Bacillary dysentery is a bacterial infection of intestines caused by *Shigella* bacteria that results in severe diarrhea. Although the health burden due to bacillary dysentery has decreased considerably in

* Corresponding author at: Women and Children's Hospital, Qingdao University, No.6 Tongfu Road, 266000 Qingdao, Shandong Province, PR China.
** Corresponding author at: Department of Epidemiology and Health Statistics, School of Public Health, Shandong University, No.44 Wenhuaxi Road, 250012 Jinan City, Shandong Province, PR China.
E-mail addresses: bjiang@sdu.edu.cn (B. Jiang), 115438779@qq.com (W. Ni).
[1] These authors contributed equally to this work.

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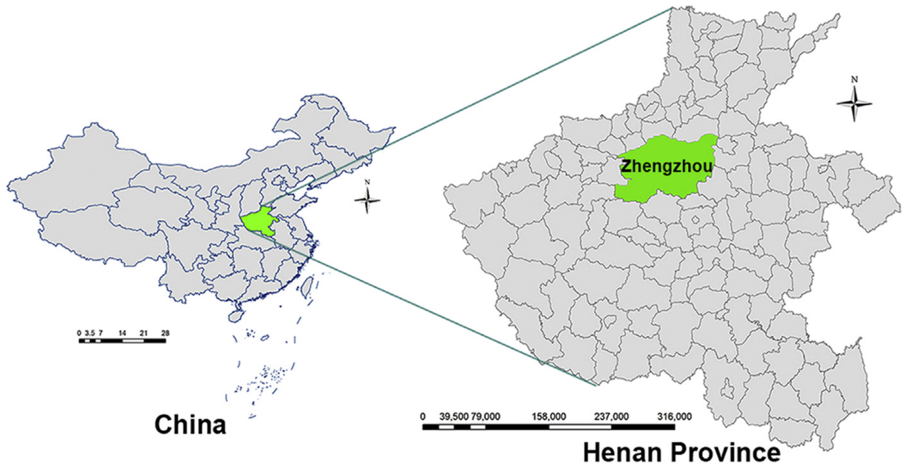

Fig. 1. Location of Zhengzhou in Henan Province, China.

China, it is still a public health problem in Zhengzhou. According to the National Report of Notifiable Diseases from Ministry of Health of China, there were 15,841 notified cases of bacillary dysentery during 2005–2009 in Zhengzhou, which was the third highest notified communicable disease, following Tuberculosis and Hepatitis B.

Years Lost with Disability (YLDs), as an indicator of burden of disease, is able to represent health outcomes appropriately, considering both mortality and morbidity. It can assist evidence-based allocation of limited health resources in public health disaster [11]. However, there has been little research to calculate the burden of bacillary dysentery under flooding scenarios, measured in terms of the comprehensive measurement-YLDs. To our knowledge, there have been four studies that attempted to quantify a wide range of health impacts resulting from flooding using YLDs [12–15]. However, these studies did not estimate the burden of diseases that can be attributed to more than one flood event in one region.

This study aimed to quantify the impact of a few flood events on bacillary dysentery in Zhengzhou during 2005–2009. Results are expected to provide scientific evidence for policy makers and public health practitioners to inform action to reduce future risks of bacillary dysentery infections associated with floods.

Materials and methods

Study area

As shown in Fig. 1, Zhengzhou City, the capital city of Henan Province, is located in the middle reaches of the Yellow River. Zhengzhou is located between latitude 34°16′–34°58′N and longitude 112°42′–114°14′E. It has a warm temperate continental monsoon climate with an annual average temperature from 13.7 °C to 14.2 °C and an average annual rainfall approximately 640.9 mm. The population of Zhengzhou was relatively stable during 2005–2009, ranging from 677 to 683 million.

Data collection and management

Disease surveillance data

Disease surveillance data on bacillary dysentery from 2005 January to 2009 December were obtained from the National Notifiable Disease Surveillance System (NDSS). The definition of bacillary dysentery from the NDSS is an infectious disease that is caused by *Shigellae*, which has fever, abdominal pain, tenesmus and bloody or mucus stool as the typical clinical presentation. In our study, all bacillary dysentery cases were defined based on the diagnostic criteria and principles of management for dysentery (GB 16002-1995) issued by Ministry of Health of the People's Republic of China [16]. Only the cases confirmed clinically and by laboratory tests, including microscopic examination and biochemical identification, were included in our study. Information of patients included age, gender, occupation, address, name of disease, cases classification, date of onset, and date of death. According to the National Communicable Disease Control Act, physicians in hospitals must report every case of dysentery to the local health authority. Then, the local health authority must report these cases to the next level of the organization within 24 h [17]. Therefore, it is believed that the degree of compliance in disease notification over the study period was consistent.

Data on floods

The Yearbooks of Meteorological Disasters in China recorded the occurrence, deaths, damage area and economic loss of floods in detail from 2005 to 2009 [18]. The definition of flooding in the Yearbook of Meteorological Disasters of China is a natural disaster resulting from the rivers overflowing due to short-term heavy precipitation, which leads to farmland and cities submerged, casualties and economic losses. According to the Yearbooks of Meteorological Disasters in China, there were 7 flood events occurred in Zhengzhou between 2005 and 2009, which took place in July 2005, July 2006, August 2006, August 2007, June 2008, July 2008 and June 2009, respectively.

Demographic and meteorological data

Demographic data were obtained from the Center for Public Health Science Data in China (http://www.phsciencedata.cn/). Monthly meteorological data were obtained from the China Meteorological Data Sharing Service System (http://cdc.cma.gov.cn/). The meteorological variables included monthly cumulative precipitation (MCP), monthly average temperature (MAT), monthly average relative humidity (MARH), monthly average wind velocity (MAWV), monthly average air pressure (MAAP) and monthly sunshine duration (MSD).

Statistical analysis

To quantifying the association between floods and morbidity of bacillary dysentery

Firstly, a descriptive analysis was performed to analyze the distribution of bacillary dysentery and climatic factors in flooded and non-flood months. Secondly, Spearman's correlation was used to examine the association between the monthly morbidity of dysentery, floods and climate factors at various lag values. The significant

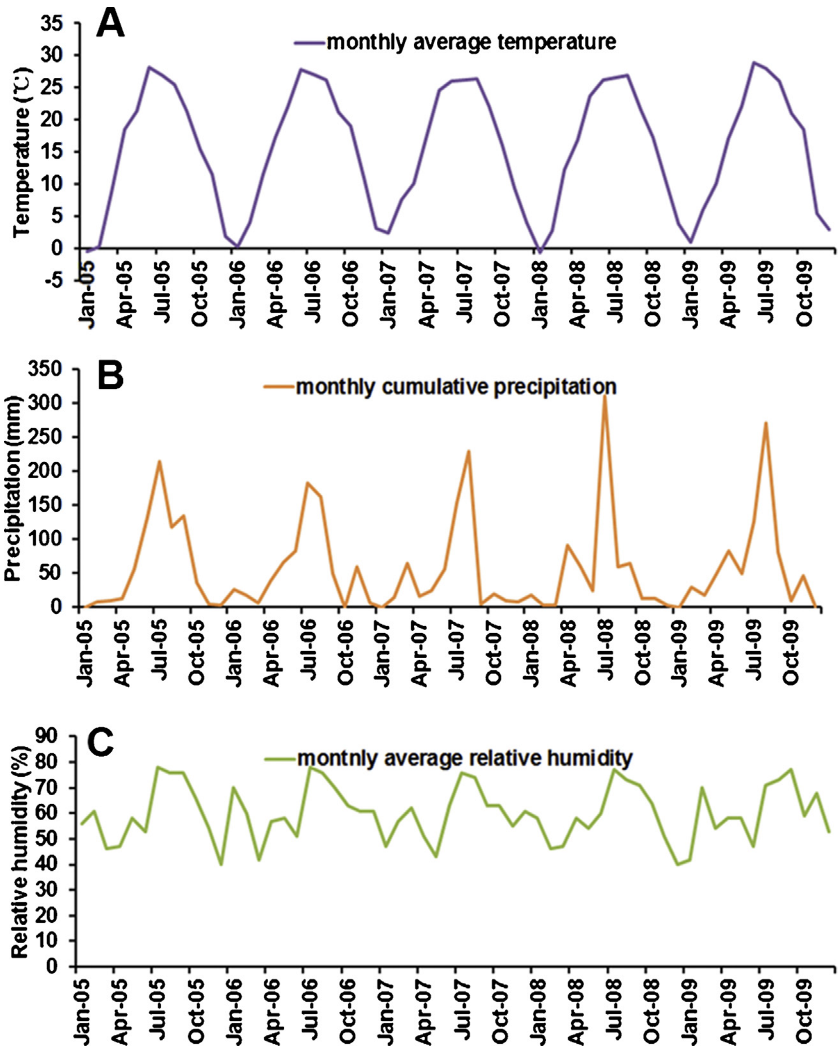

Fig. 2. Distribution of climate factors in Zhengzhou during the study period. (A) Distribution of monthly average temperature; (B) distribution of monthly cumulative precipitation; (C) distribution of monthly average relative humidity.

lag value with the maximum correlation coefficient for each climate variable was selected for inclusion in the subsequent analysis.

Then, a time-series Poisson regression model was used to analyze a categorical variable defined by non-flood and floods to estimate the risk of floods on morbidity of the bacillary dysentery. Our model was adjusted for the effects of monthly average temperature, monthly accumulative precipitation and monthly average relative humidity, which had significantly impacts on bacillary dysentery [19–22]. The regression model was described as follows:

$$\ln(Y_t) = \beta_o + \beta_1 t + \beta_2 \sin(2\pi t/12) + \beta_3 \mathit{flood} + \beta_4 \mathit{flood\ duration} + \beta_5 \mathit{temperature} + \beta_6 \mathit{precipitation} + \beta_7 \mathit{relative\ humidity}$$

where Y_t denoted the monthly morbidity of dysentery in specific months; the coefficients were individually represented by β_0 through β_7. *flood* was a categorical variable defined by non-flood and flood, endowed by 0 and 1, respectively. *flood duration*, *temperature*, *precipitation* and *relative humidity* represented the days of flood in a month, monthly average temperature, monthly accumulative precipitation and monthly average relative humidity in sequence. Considering the potential seasonality and long-term trends that may be associated with floods, our model included a triangular function, $\sin(2\pi t/12)$, to reveal the seasonal component in the time series. The Relative Risk (RR) and 95% confidence interval (CI) of floods for bacillary dysentery among different populations were estimated in this model. The descriptive analysis and Poisson regression model were performed using SPSS 16.0 (SPSS Inc., USA) and software R 2.3.1 (MathSoft Inc., USA), respectively.

To estimate the YLDs of bacillary dysentery attributable to floods

After quantifying the RRs, the YLDs were calculated to estimate the burden of disease due to bacillary dysentery during flood-month. The method of estimating YLDs, as recommended by the World Health Organization (WHO), was adopted [23]. Calculations of YLDs and YLD per 1000 were performed using the DisMod II (WHO, 2001) and the Microsoft Office Excel 2003 (Microsoft Corp, USA).

The potential impact fractions (PIFs) were estimated based on the environmental framework of comparative risk assessment (CRA) developed by the WHO. The burden of disease attributable to a specified change in level of a risk factor was estimated using the formula for the PIF [24]. The following formula for PIF was [25]:

$$PIF = \frac{(\sum P_i RR_i - 1)}{\sum P_i RR_i}$$

where P_i = proportion of the population in exposure category i. RR_i = relative risk at exposure category I compared to the reference level.

Table 1
Correlations between the explanatory variables among monthly data in the study area from 2005 to 2009.

	Lag period	Floods	MFD	MCP	MAT	MARH
All cases	Lag month 0	0.49*	0.49*	0.66*	0.84*	0.57*
	Lag month 1	0.44*	0.44*	0.68*	0.89*	0.35*
	Lag month 2	0.30*	0.29*	0.57*	0.67*	0.05
Female group	Lag month 0	0.49*	0.49*	0.64*	0.83*	0.53*
	Lag month 1	0.44*	0.42*	0.65*	0.87*	0.33*
	Lag month 2	0.30*	0.29*	0.56*	0.65*	0.04
Male group	Lag month 0	0.49*	0.49*	0.68*	0.86*	0.54*
	Lag month 1	0.44*	0.43*	0.69*	0.89*	0.31*
	Lag month 2	0.28*	0.28*	0.55*	0.64*	0.03
Below 14 age group	Lag month 0	0.50*	0.49*	0.68*	0.83*	0.53*
	Lag month 1	0.43*	0.43*	0.66*	0.84*	0.31*
	Lag month 2	0.26	0.26*	0.47*	0.59*	−0.03
15–64 age group	Lag month 0	0.49*	0.48*	0.65*	0.84*	0.54*
	Lag month 1	0.42*	0.41*	0.66*	0.89*	0.31*
	Lag month 2	0.30*	0.30*	0.59*	0.66*	0.05
Over 65 age group	Lag month 0	0.51*	0.51*	0.57*	0.67*	0.52*
	Lag month 1	0.44*	0.44*	0.61*	0.83*	0.34*
	Lag month 2	0.30*	0.29*	0.57*	0.72*	0.16

MFD, the monthly flood duration; MCP, monthly cumulative precipitation; MAT, monthly average temperature; MARH, monthly average relative humidity.
* $p < 0.05$.

Lastly, attributable YLDs were estimated for the percentage of disease burden due to bacillary dysentery caused by floods. The YLDs for the population were multiplied by PIF to calculate the fraction of bacillary dysentery attributable to floods for the study population [25], as shown in the following equation. *Attributable YLDs = PIF × YLDs*.

Results

Descriptive analysis for the disease and meteorological data

During 2005–2009, a total of 15,841 bacillary dysentery cases were reported in the study area with the monthly incidence rate ranging from $0.59/10^6$ to $15.41/10^6$. During the study period, the incidence of male ($0.75/10^6$–$18.91/10^6$) by month was significantly higher than that of female ($0.42/10^6$–$11.72/10^6$). Among the different age groups, monthly incidence of bacillary dysentery in below 14 years old group ($1.45/10^6$–$32.28/10^6$) was the highest among the study population, followed by 15–64 years old group ($1.15/10^6$–$16.05/10^6$) and over 65 years old group ($0.29/10^6$–$10.58/10^6$) in sequence. Fig. 2 shows the distribution of meteorological factors during the study period, including monthly average temperature, monthly cumulative precipitation and monthly average relative humidity.

Spearman's correlation analysis

Table 1 shows the results of Spearman's correlation between explanatory variables and monthly morbidity of bacillary dysentery. Results revealed the strongest lagged effect between floods and monthly morbidity of bacillary dysentery among all the populations was at 0 month, as well as the monthly flood duration and monthly average relative humidity. The strongest lagged effect between monthly average temperature and monthly morbidity of bacillary dysentery among all populations was at 1 month, as well as monthly cumulative precipitation except for below 14 years old group at 0 month.

Regression analysis

The parameters of the models and RRs of floods on dysentery among the different populations are presented in Table 2. Results showed that floods were significantly associated with morbidity of bacillary dysentery with adjustment for meteorological factors in the study area. Fig. 3 shows the morbidity and predictive value of the model among the different populations, which indicates that the dynamic of the monthly morbidity of bacillary dysentery corresponded well with this regression.

Table 2
Parameters coefficients from the generalized linear models for the bacillary dysentery among the populations.[a]

	Coefficients (95%CI)	p-Value	RR (95%CI)
Overall population			
Floods	1.03 (0.94, 1.13)	<0.01	2.80 (2.56, 3.10)
Flood duration	−0.22 (−0.26, −0.19)	<0.01	–
Male			
Floods	1.14 (1.05, 1.23)	<0.01	3.13 (2.86, 3.42)
Flood duration	−0.25 (−0.29, −0.22)	<0.01	–
Female			
Floods	0.93 (0.83, 1.04)	<0.01	2.53 (2.29, 2.83)
Flood duration	−0.20 (−0.24, −0.17)	<0.01	–
Below 14 years old			
Floods	1.01 (0.95, 1.08)	<0.01	2.75 (2.59, 2.94)
Flood duration	−0.24 (−0.26, −0.21)	<0.01	–
15–64 years old			
Floods	1.11 (0.99, 1.23)	<0.01	3.03 (2.69, 3.42)
Flood duration	−0.25 (−0.29, −0.21)	<0.01	–
Over 65 years old			
Floods	0.91 (0.82, 1.01)	<0.01	2.48 (2.27, 2.75)
Flood duration	−0.12 (−0.15, −0.09)	<0.01	–

[a] Adjusted R square of the model in overall population, males, females, below 14 years old group, 15–64 years old group, over 65 years old group were 0.82, 0.76, 0.80, 0.71, 0.73, 0.65, respectively.

During the flooding months, floods were significantly associated with an increased risk of bacillary dysentery in Zhengzhou with a RR of 2.80 (95%CI: 2.56–3.10) for the whole population. In different gender groups, the relative risk of female was 3.13 (95%CI: 2.86–3.42), followed by male with 2.53 (95%CI: 2.29–2.83). In the groups by age, the increased risk of 15–64 years old group was the highest among the age groups (RR = 3.03, 95%CI: 2.69–3.42), followed by younger than 14 years old and over 65 years old groups in sequence (RR = 2.75, 95%CI: 2.59–2.94; RR = 2.48, 95%CI: 2.27–2.75, respectively).

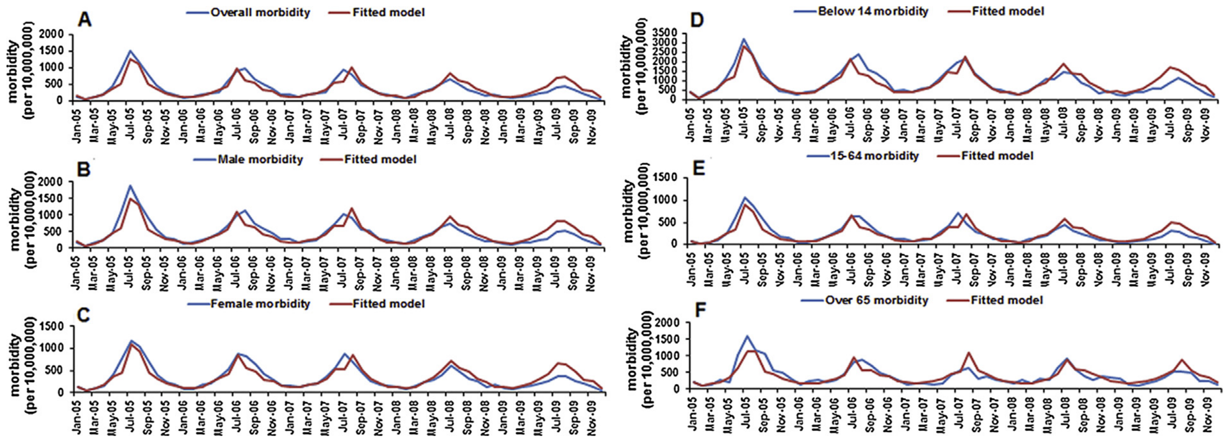

Fig. 3. Dynamics of dysentery in Zhengzhou with the analysis of Poisson regression from 2005 to 2009 (morbidity per 10,000,000 population). (A) Dynamics of bacillary dysentery in overall population; (B) dynamics of bacillary dysentery in males; (C) dynamics of bacillary dysentery in females; (D) dynamics of bacillary dysentery in below 14 years old group; (E) dynamics of bacillary dysentery in 15–64 years old group; (F) dynamics of bacillary dysentery in over 65 years old group.

Attributable YLDs estimation

Proportion of the study population exposed to floods was assumed at 100% (i.e. Pi = 1). Based on the estimates of RRs and the formula of PIF above, PIFs among overall population, males, females, below 14 years old group, 15–64 years old group, and over 65 years old group were 0.64, 0.68, 0.61, 0.64, and 0.60, respectively. The PIFs were considered in the further calculation of attributable YLDs. Fig. 4 shows YLD per 1000 and attributable YLD per 1000 of the overall population during 7 times of flood-month (1.87), and the attributable YLD among males (1.51) was higher than that among females (0.91). The highest attributable YLD per 1000 of bacillary dysentery was in aged below 14 years of age (3.60), followed by old people above 65 year of age (0.88) and the age of 15–64 years (0.64).

Discussion

This study has quantified the relationship between a few flood events and the morbidity of bacillary dysentery and estimated the burden of disease attributed to floods by YLDs, based on a longitudinal data from 2005 to 2009 in Zhengzhou City. Our study has confirmed that floods play an important role in the bacillary dysentery epidemics during the flooded months, leading to an increased risk of bacillary dysentery. Determining the effect of floods on dysentery would be beneficial for providing a basis for the policy making for dysentery control technologies.

Some studies believed that water-borne diseases outbreaks or epidemics have been associated with water sources for drinking and recreation due to floods after extreme precipitation [26–28]. Bacillary dysentery, as one of water-borne diseases with cholera, hepatitis A, typhoid fever, and other gastrointestinal diseases, were caused by ingestion of contaminated water containing *Shigella* [29]. Floods adversely affected water sources and supply systems, as well as sewerage and waste-disposal systems. The contamination can be washed into water source, causing the local water quality seriously deteriorated and increasing the transmission of enteric pathogens during the floods [30]. In China, the contaminated water may not be a direct risk factor for bacillary dysentery after floods due to the drinking boiled water traditionally. However, water is a significant component of many food and it can be added directly as an ingredient or be present as part of the raw materials, which means that the contaminated drinking water can be closely associated with food following floods. Consequently, food plays an important role in the transmission of pathogens, leading to an increase in the risk of bacillary dysentery infection. In addition, during the flood period, pathogens could be mobilized by the suitable climatic environment with mild temperature and humidity, and transported quickly into the aquatic environment. As a result, the drinking water, foods and other household items could be contaminated by bacteria easily, which increase the opportunity of bacillary dysentery infection to population. A study in Henan Province where Zhengzhou locates suggested that many people in Zhengzhou have the habit of eating raw fruits and cold food in summer, and more drinking water due to thirst could decrease the gastric acid concentration causing low immunity of digestive system to bacteria [31]. These risk conditions may be pathways of bacillary dysentery transmission and infection after floods in Zhengzhou.

The results from this study indicate that floods could significantly increase the risk of bacillary dysentery in Zhengzhou. Some studies reported an increased risk of infectious diarrhea following floods in both developing countries [6,32,33] and developed countries. For example in developed countries, flooded households significantly associated with a greater risk of diarrhea than non-flooded homes during the 2001 floods in Texas (OR: 10.8, $p < 0.01$) [34]. In the town of Lewes in Southern England, flooding of house were significantly associated with increased risk of gastroenteritis (RR: 1.7, $p < 0.05$) [8]. In addition, another study from the United States revealed that an increase in the incidence of diarrhea during the flood was observed (RR: 1.29, 95%CI: 1.06–1.58), and this effect was pronounced among persons with potential vulnerability to infectious diarrhea [35]. In Germany, a study also showed that the major risk factor for diarrhea was contact with floodwater (OR: 5.8, 95%CI: 1.3–25.1) [36]. As one of diarrheal diseases, similar findings have been reported in our study. Our study has identified that the risks of floods on bacillary dysentery vary among different population groups. During the flooded months, the risk of bacillary dysentery for males could be higher than females. It is not clear whether the difference in burden of bacillary dysentery between males and females is caused by different response behaviors between genders. A possible explanation is that in the flooding, males participated in more relief work and engaged more frequently than females, leading to a higher exposure for males. In this scenario, flooding may bring more health risks to men than women. In terms of the age-groups, it suggests that younger children are the most vulnerable groups to have bacillary dysentery associated with floods. The possible reasons may include the followings. Firstly, the lowered resistance and immunity of organism due to immature stage of physical development, increased the morbidity of bacillary after bacteria infected in children. Secondly, in

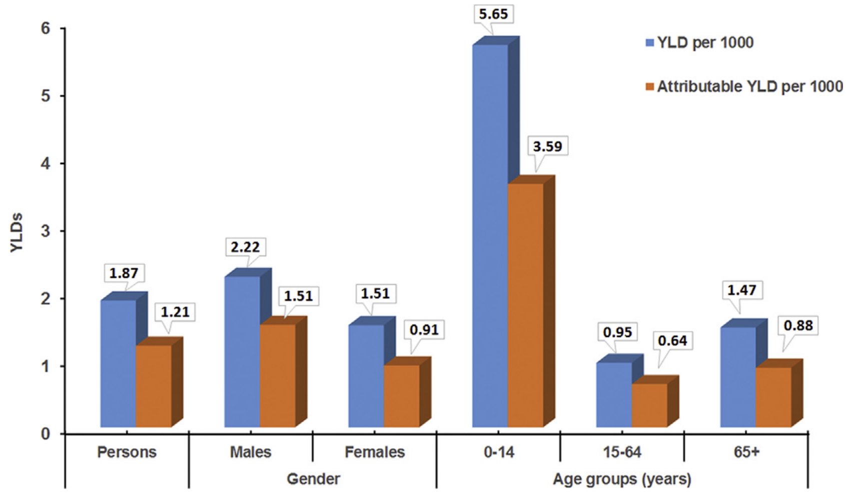

Fig. 4. YLD and attributable YLD per 1000 of the study population during 9 times of flood-month.

China, the quality of child health care in middle region where Zhengzhou locates was lower than that of east region [37]. It is noted that the consciousness of self-health care in children was poor in Zhengzhou, which meant that children eat frequently much cold drinking, milk, and other cold fruit and food stored in the fridge containing the pathogens during the flood period which occurred in summer. In addition, during the flood, children were more likely to be infected by the bacteria due to recreation in the contaminated floodwater.

The results of the multivariate models showed a negatively correlation between flood duration and the incidence of bacillary dysentery, which indicated that the risks on bacillary dysentery could be different because of the various floods. The risk of bacillary dysentery could be higher after a sudden and severe flooding than that after a prolonged and moderate flooding. During the sudden and severe flooding, heavy precipitation was strongly destructive for human and health infrastructure, which may cause serious floodwater contamination. In this case, more people would be contact with floodwater, resulting in a greater likelihood of being infected with bacillary dysentery. However, during a prolonged and moderate flooding, the transmission and infection of bacillary dysentery pathogens may be decreased due to lower destruction and contamination.

Figs. 2 and 3 suggested the potential relationship among floods, meteorological factors and bacillary dysentery morbidity. Results suggested that summer floods could increase the risk of bacillary dysentery with higher precipitation, temperature, and relative humidity. The floods in our study all occurred in summer months. During the summer months between June and August, precipitation, as a meteorological factor, was closely associated with floods, and the risk of floods could be increased by the higher precipitation and precipitation variability [38]. Although floods and meteorological factors could impact the bacillary dysentery under suitable condition, their effects were different to the disease. During non-flooded period, moderate precipitation, temperature and humidity could impact the bacillary dysentery after a longer process with a bit longer lagged effect. However, floods, as a kind of meteorological disasters, could impact the bacillary dysentery through a stronger and more rapid process with a shorter lagged effect.

It should be acknowledged that there are some limitations in our study. One of the limitations is that the effects of many factors, such as social and economic status, health services, and environmental hygiene, could not be analyzed in our study. Moreover, due to a lack of detailed laboratory information, we cannot identify the pathogens typing of bacillary dysentery in Zhengzhou. A study analyzing the epidemic and aetiological character of bacillary dysentery in Henan Province from 2005 to 2009 found that *Shigella flexneri* was the dominant strains in the province where Zhengzhou located, and *S. flexneri 2a*, *S. flexneri 4c* and *S. flexneri 1a* were the dominant sertypings [39]. These strains may be associated with floods in Zhengzhou during the study period. In addition, under reporting was inevitable in passive disease surveillance systems such as where we obtained our data for the current study and the notified cases were those with severe symptoms that chose to visit doctors in a hospital [40]. Some people with mild clinical symptoms and self-treated cases might not seek medical help. This could lead to an underestimation of the risk of bacillary dysentery due to floods. Further studies with detailed laboratory information of bacillary dysentery pathogens, socio-economic and other possible risk factors should be conducted to examine the association between the specific strains of bacillary dysentery and floods and have a better understanding of the health impact of floods.

Conclusion

In conclusion, floods can significantly increase the risks of bacillary dysentery in Zhengzhou. In addition, the burden of bacillary dysentery attributed to floods in males is higher than that of females. Younger people could be the most vulnerable groups affected by floods with the highest attributable burden of bacillary dysentery. Our findings contribute to developing local strategies to prevent and reduce health impact from bacillary dysentery in flooding areas.

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