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Quantitative analysis of burden of bacillary dysentery associated with floods in Hunan, China

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HIGHLIGHTS

- Floods have significantly increased the risks of bacillary dysentery.
- To quantify the impact of floods on the burden of bacillary dysentery.
- The lagging effect of floods on bacillary dysentery was observed.
- Different levels of floods may have different impacts on bacillary dysentery.

GRAPHICAL ABSTRACT

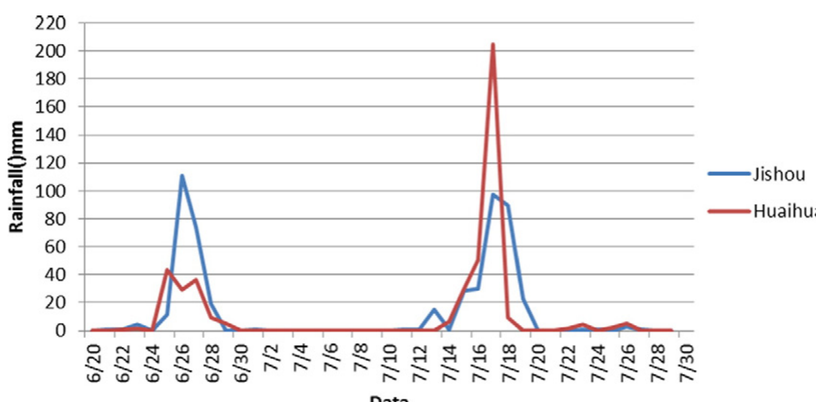

Figure 1.Daily rainfalls in Jishou and Huaihua during the meiyu-flood-season,2012

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ABSTRACT

Background: Jishou and Huaihua, two cities in the west of Hunan Province, had suffered from severe floods because of long-lasting and heavy rainfall during the end of June and July 2012. However, the Disability Adjusted of Life Years (DALYs) of bacillary dysentery caused by the floods have not been examined before. The study aimed to quantify the impact of the floods on the burden of bacillary dysentery in Hunan, China.
Methods: A unidirectional case-crossover study was firstly conducted to determine the relationship between daily cases of bacillary dysentery and the floods in Jishou and Huaihua of Hunan Province in 2012. Odds ratios (ORs) estimated by conditional logistic regression were used to quantify the risk of the floods on the disease. The years lived with disability (YLDs) of bacillary dysentery attributable to floods were then estimated based on the WHO framework to calculate potential impact fraction in the Burden of Disease study.
Results: Multivariable analysis showed that floods were significantly associated with an increased risk of the number of cases of bacillary dysentery (OR = 3.270, 95% CI: 1.299–8.228 in Jishou; OR = 2.212, 95% CI: 1.052–4.650 in Huaihua). The strongest effect was shown with a 1-day lag in Jishou and a 4-day lag in Huaihua. Attributable YLD per 1000 of bacillary dysentery due to the floods was 0.0296 in Jishou and 0.0157 in Huaihua.
Conclusions: Our study confirms that floods have significantly increased the risks of bacillary dysentery in the study areas. In addition, a sudden and severe flooding with a shorter duration may cause more burdens of

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bacillary dysentery than a persistent and moderate flooding. Public health preparation and intervention programs should be taken to reduce and prevent a potential risk of bacillary dysentery epidemics after floods.

1. Introduction

A changing climate leads to changes in the frequency, intensity, spatial extent and duration of extreme weather and climatic events (Wang et al., 2015). Increasing evidence shows that such changes in the global-scale climate system may already pose a threat to humans through increased morbidity and mortality caused by heat, cold, drought or rainfalls, changes in air and water quality, and the ecology of infectious diseases (Chou et al., 2010; Semenza and Menne, 2009; Gregory et al., 2009). Flood is one of the most common and most severe forms of natural disasters, accounting for up to one half of all natural disasters in the world (Feng et al., 2007; Alderman et al., 2012; Wakuma Abaya et al., 2009). Flooding events are expected to increase in frequency and intensity due to rising sea levels and more frequent and extreme precipitation events (Ramin and McMichael, 2009; Cao et al., 2013). As China is a country prone to a variety of natural disasters, flooding is the major meteorological disasters affecting many regions (Xu et al., 2014; Agtini et al., 2005). A study suggested that the population exposed to floods shows a significantly increasing trend in all Provinces in China (Wang et al., 2015).

Bacillary dysentery, caused by *Shigella* species, remains a major public health problem around the world, especially in some developing countries (Kosek et al., 2003). The annual number of *Shigella* episodes throughout the world was estimated to be 164.7 million, of which 163.2 million were in developing countries (with 1.1 million deaths) and 1.5 million in industrialized countries (Wang et al., 2006). In China, despite the improvement of public health management for diseases control and prevention, dysentery disease still has a higher relapse rate, which seriously endangers public health (Ma et al., 2013).

Many studies suggest that floods attributed to heavy precipitation may affect the morbidity and mortality of dysentery (Alderman et al., 2012; Du et al., 2010; Mike Ahern et al., 2005). After floods, the morbidity of dysentery may be increased by the transmission and infection of the pathogens (Kondo et al., 2002). However, findings are not always consistent. For example, after fully controlling for pre-flood rate differences and seasonality, research conducted in rural Bangladesh found that there was no clear evidence of increased risk of diarrhea during or after floods (Milojevic et al., 2012).

Severe floods that struck China's Hunan Province during the end of June and July 2012 left hundreds of thousands of residents homeless. Many infrastructural and agricultural projects were damaged. However, evidence on the association between floods and bacillary dysentery is far from clear. In addition, the IPCC fourth Assessment Report (IPCC AR4) has shown that studies on floods and human health in China are very limited.

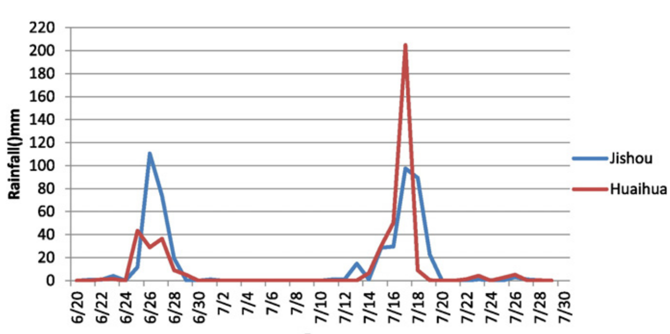

Fig. 1. Daily rainfalls in Jishou and Huaihua from the end of June to July, 2012.

In view of the background summarized above, this study aimed to explore the impact of the floods in 2012 on bacillary dysentery in Hunan, one of the most affected regions in China. Results will contribute to have a better understanding of the health effects of floods and assist in developing national strategies to prevent and reduce the burden of bacillary dysentery associated with floods.

2. Materials and methods

2.1. Study areas and the floods

Our study areas covered Jishou and Huaihua, two of the worst hit areas by the floods in 2012, which both located in the west of Hunan Province. Fig. 1 shows distribution of daily rainfall in Jishou and Huaihua during the end of June and July 2012. The total precipitation in Jishou was 196.0 mm from 25 June to 27 June and 216.6 mm from 16 July to 18 July; Huaihua had received 306.5 mm from 14 July to 23 July. According to the flood classification defined by the Comprehensive Study Group of Major Natural Disasters of the State Science and Technology Commission in China, a moderate flood is defined as a natural disaster that cumulative rainfall of more than 80 mm for three consecutive days or 250 mm for ten consecutive days; cumulative rainfall of more than 150 mm for three consecutive days or 350 mm for ten consecutive days is a severe flood. By the definition above, Jishou had suffered two severe flooding and Huaihua had suffered one moderate flooding.

The study areas both lie in the west of Hunan province. The similar geographic location determines the cities with characteristics of the subtropical humid monsoon climate. Population in the two study areas was 295,700 in Jishou and 4,775,000 in Huaihua in 2012, accounting for 7.64% of whole population in Hunan Province.

2.2. Data collection and management

2.2.1. Disease surveillance data

Daily disease surveillance data on bacillary dysentery from May to September 2012 were extracted and verified from the National Notifiable Disease Surveillance System (NDSS). The definition of bacillary dysentery from the NDSS is a group of the human diseases that are caused by Shigellae, which have fever, abdominal pain, tenesmus and bloody or mucus stool as the typical clinical presentation. 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 China. In China, bacillary dysentery is a statutory notifiable category B infectious disease. 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 (WOHC, 2006). So it is believed that the degree of compliance in disease notification over our study period was consistent. Information of cases included age, gender, residential address, type of disease, date of onset, and date of death. Demographic data were obtained from the Center for Public Health Science Data in China (http://www.phsciencedata.cn/).

2.2.2. Meteorological data

Daily meteorological data from May to September in 2012 were collected from the China Meteorological Data Sharing Service System (http://cdc.cma.gov.cn/). The meteorological variables included daily average temperature (AT), daily average relative humidity (ARH), daily average air pressure (AAP), daily average wind velocity (AWV),

Table 1
Distribution of daily cases of bacillary dysentery and meteorological variables in Jishou.

	Period	Mean ± SD	Min	P_{25}	Median	P_{75}	Max
Cases of diarrhea*	Exposure	8.00 ± 2.00	5.00	6.50	8.00	10.00	10.00
	Control	3.00 ± 1.26	1.00	2.50	3.00	5.00	8.00
AT (°C)	Exposure	25.05 ± 0.52	24.30	24.45	25.25	25.45	25.60
	Control	26.40 ± 2.89	20.00	25.30	26.40	28.90	29.50
ARH (%)	Exposure	88.67 ± 3.14	83.00	86.75	89.00	91.25	92.00
	Control	72.80 ± 8.88	63.00	66.00	69.00	79.00	90.00
AAP (hPa)*	Exposure	977.62 ± 3.25	973.30	974.73	977.80	980.35	981.70
	Control	978.50 ± 2.04	976.00	976.80	978.00	979.60	983.40
AWV (m/s)	Exposure	1.18 ± 0.37	0.90	0.90	1.00	1.63	1.70
	Control	1.27 ± 0.44	0.60	1.00	1.20	1.70	2.00
RF (mm)	Exposure	68.77 ± 39.52	11.70	25.20	81.55	100.78	110.60
	Control	1.45 ± 3.91	0.00	0.00	0.00	1.10	15.20
AVP (hPa)*	Exposure	28.07 ± 0.92	26.60	27.28	28.20	28.83	29.20
	Control	24.43 ± 2.82	20.40	21.90	25.20	26.20	29.60
SD (h)*	Exposure	0.00 ± 0.00	0.00	0.00	0.00	0.00	0.00
	Control	4.41 ± 3.59	0.00	0.00	4.70	7.80	9.50

SD: standard deviation; Min, minimum; P_{25}, the 25th percentile; P_{75}, the 75th percentile; Max, maximum. AT, average temperature; ARH, average relative humidity; AAP, average air pressure; AWV, average wind velocity; RF, rainfall; AVP, average vapor pressure; SD, sunshine duration.
* $p < 0.05$ vs. Control.

daily rainfall (RF), daily average vapor pressure (AVP), and daily sunshine duration (SD).

2.3. Statistical analysis

Firstly, a unidirectional case-crossover study was performed to determine the exposure and control periods. The exposure periods were flooding periods in the two areas, i.e. two floods (25 June to 27 June and 16 July to 18 July) in Jishou, and one flood (14 July to 23 July) in Huaihua. Then a 1:3 unidirectional design was applied for selecting the control days, matching on day of the week with 3 weeks prior to the case occurred because some studies suggested that the effects of flooding on diarrhea incidence have a lag effect (Ding et al., 2013; Hashizume et al., 2008). If one exposure day was included in a control period, then it was excluded from control days. Therefore, one exposure day was matched with two or three control days. Jishou had 6 exposure days and 15 control days, and Huaihua had 10 exposure days and 24 control days.

Then the Wilcoxon Two-Sample test was applied to examine the difference in the number of daily cases of bacillary dysentery and meteorological variables between the exposure and control periods. With the consideration of potential lagged effects on bacillary dysentery of the floods, lagged effects (up to seven days) were calculated by conditional logistic regression analysis. Odds ratios (ORs) and 95% confidence intervals (CI) of the floods on the number of incident cases of bacillary dysentery were estimated in each model. After fitting the lags, we adjusted for temperature, humidity, air pressure, wind velocity, vapor pressure and sunshine duration in the multivariate conditional logistic regression models. ORs and 95% CI of bacillary dysentery attributable to the exposure of the floods were estimated. All statistical analyses were performed using SAS 9.1.3 (SAS Institute Inc., USA).

Secondly, the potential impact fraction (PIF), which based on the environmental framework of comparative risk assessment (CRA) developed, by the WHO was calculated. This formula can be used to estimate the fraction of the disease burden attributable to the risk factor, as compared to some "alternative" or counterfactual level, which might be the minimum that can be feasibly achieved in a given time frame (WHO, 2004).

$$\mathrm{PIF} = \frac{\sum \mathrm{P_i RR_i} - \sum \mathrm{P_i' RR_i}}{\sum \mathrm{P_i RR}_i}$$

where: PIF = potential impact fraction; P_i = the proportion of the population at exposure category "i"; P_i' = the proportion of the population in exposure category "i" after an intervention or other change; RR_i = the relative risk at exposure category "i" compared to the reference level.

Table 2
Distribution of daily cases of bacillary dysentery and meteorological variables in Huaihua.

	Period	Mean ± SD	Min	P_{25}	Median	P_{75}	Max
Cases of diarrheah6	Exposure	8.7 ± 3.47	5.00	5.70	8.00	13.00	14.00
	Control	3.0 + 1.38	1.00	2.00	3.00	3.40	6.00
AT (°C)	Exposure	27.04 ± 2.16	24.60	24.90	26.95	29.58	30.30
	Control	29.81 ± 1.20	26.80	29.00	30.20	30.78	31.20
ARH (%)	Exposure	81.30 ± 9.27	66.00	71.00	81.50	89.50	92.00
	Control	62.75 ± 7.83	54.00	56.25	60.00	67.75	81.00
AAP (hPa)	Exposure	973.38 ± 1.74	970.90	971.68	973.45	975.10	976.10
	Control	972.70 ± 1.48	970.20	971.70	972.45	973.20	975.80
AWV (m/s)*	Exposure	1.34 ± 0.40	0.50	1.08	1.40	1.70	1.80
	Control	2.31 ± 0.81	0.70	1.83	2.30	2.90	4.00
RF (mm)*	Exposure	30.65 ± 63.38	1.40	2.25	15.40	35.05	204.90
	Control	0.65 ± 2.05	0.00	0.00	0.00	0.00	9.00
AVP (hPa)*	Exposure	28.52 ± 0.26	28.10	28.28	28.60	28.63	29.00
	Control	25.77 ± 2.16	23.80	24.10	24.95	26.60	30.70
SD (h)	Exposure	4.27 ± 4.82	0.00	0.00	2.95	9.00	12.20
	Control	9.54 ± 3.00	0.60	8.23	10.55	11.73	12.60

SD: standard deviation; Min, minimum; P_{25}, the 25th percentile; P_{75}, the 75th percentile; Max, maximum.AT, average temperature; ARH, average relative humidity; AAP, average air pressure; AWV, average wind velocity; RF, rainfall; AVP, average vapor pressure; SD, sunshine duration.
* $p < 0.05$ vs. Control.

Table 3
Age–sex specific incidence rates of bacillary dysentery in the flood-period ($1/10^5$).

Age group (years)	Jishou			Huaihua		
	Male	Female	Total	Male	Female	Total
0–4	23.365	10.950	17.648	10.051	6.533	8.430
5–14	0.481	0.000	0.250	1.089	0.777	0.938
15–29	0.834	1.286	1.049	0.985	1.443	1.203
30–44	1.123	1.694	1.086	1.776	1.918	1.844
45–59	1.295	0.847	1.081	2.556	1.111	1.863
60–69	2.974	3.217	3.091	3.633	2.601	3.135
70–79	6.449	4.837	5.617	5.099	2.302	3.629
80+	5.504	0.000	2.150	0.000	0.000	0.000
Total	2.483	1.657	2.301	2.349	1.933	2.158

If exposed populations were to be compared with unexposed populations, the reduction of burden of disease can be calculated from a simplified form of the below formula (Ding et al., 2013):

$$\mathrm{PIF} = \frac{\left(\sum \mathrm{P_i RR_i} - 1\right)}{\sum \mathrm{P_i RR_i}}.$$

The relative risk (RR) can be best estimated using a population sample. If the rare disease assumption holds, OR is a good approximation to RR (Viera, 2008). Therefore, the following calculation applied.

$$\mathrm{PIF} = \frac{\left(\sum \mathrm{P_i OR_i} - 1\right)}{\sum \mathrm{P_i OR_i}}$$

We then calculated PIF of bacillary dysentery due to the floods based on the estimates of ORs above.

Thirdly, years lived with disability (YLDs) and attributable YLDs were calculated to estimate the burden of bacillary dysentery due to the floods. Since there was no death of bacillary dysentery notified during the study period, we adopted the YLDs to assess the burden of bacillary dysentery. The method to estimate the disease burden of bacillary dysentery (YLDs) was recommended by the WHO (Mathers et al., 2011). Calculations of YLDs and YLD per 1000 were made using DISMOD II and Microsoft Office Excel 2003. To calculate the fraction of bacillary dysentery attributable to the floods for the study population, the YLDs for the population were multiplied by PIF. The equation used (Waring et al., 2002):

$$\text{Attributable YLDs} = \text{PIF} \times \text{YLDs}.$$

3. Results

3.1. Descriptive analysis for the disease and meteorological

A total of 184 bacillary dysentery cases were notified in the two study areas over the exposure and control periods. Tables 1 and 2 display a summary of the distribution of daily data of bacillary dysentery cases and meteorological variables in the study areas. The distribution of the number of daily cases of bacillary dysentery, AAP, AVP and SD were significantly different between the exposure and control periods in Jishou ($p < 0.05$). The daily number of cases of bacillary dysentery, AWV and AVP in the exposure period were significantly different to those in the control period in Huaihua ($p < 0.05$).

A total of 98 cases of bacillary dysentery were identified by the local relevant laboratories during the flood-period. As shown in Table 3, the incidence rates of bacillary dysentery in Jishou and Huaihua were $2.301/10^5$ and $2.158/10^5$, respectively. The incidence rates of male in the study areas were significantly higher than those of female ($2.483/10^5$ vs. $1.657/10^5$ in Jishou, and $2.349/10^5$ vs. $1.933/10^5$ in Huaihua). The incidence rates of bacillary dysentery were highest in children under 4 years of age ($10.950/10^5$in Jishou, $6.533/10^5$ in Huaihua).

3.2. Analysis for lagged effects (Figs. 2–3)

Figs. 2–3 show the estimated ORs of the floods on the risk of bacillary dysentery on various lagged days. Floods significantly increased the number of cases in Jishou (ORs > 1 from lag 0 to lag 4) and Huaihua (all ORs > 1 on different lagged days). The strongest effect was observed at lag 1 days in Jishou (OR = 3.537, 95% CI: 1.793–6.974), and lag 4 days in Huaihua (OR = 2.217, 95% CI: 1.480–3.321), respectively. These lagged effects were incorporated in the next multifactorial regression analysis.

3.3. Conditional logistic regression analysis (Table 4)

The results of multifactorial conditional logistic models in the two areas are presented in Table 4. Multivariable analysis showed that the floods were significantly associated with an increased risk of bacillary dysentery after adjusting for other meteorological factors (OR = 3.270, 95% CI: 1.299–8.228 in Jishou; OR = 2.212, 95% CI: 1.052–4.650 in Huaihua).

3.4. Analysis for YLDs and attributable YLDs of bacillary dysentery (Table 5)

YLD per 1000 of bacillary dysentery among age-sex groups in the flood-period is presented in Table 5. The total YLD per 1000 in Jishou was significantly higher than that in Huaihua (0.0369 vs. 0.0194). The YLD per 1000 of male in Jishou was higher than that of female (0.0226 vs. 0.0143), while the same was the case in Huaihua (0.0114 vs. 0.0080). The YLD per 1000 of bacillary dysentery in Huaihua was highest between the ages of 60 and 69 years (0.0310), following by the age of 70–79 (0.0306). While the highest YLD per 1000 in Jishou was in children less than 4 years of age (0.0645), the second was in people aged 70–79 (0.0522).

The attributable YLDs and YLD per 1000 in Jishou (22.6438, 0.0296) were significantly higher than those in Huaihua (11.8790, 0.0157).

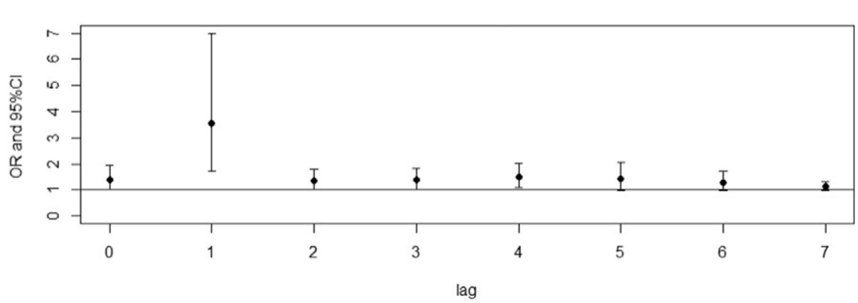

Fig. 2. OR estimates of the floods on the risk of bacillary dysentery in different lagged days in Jishou.

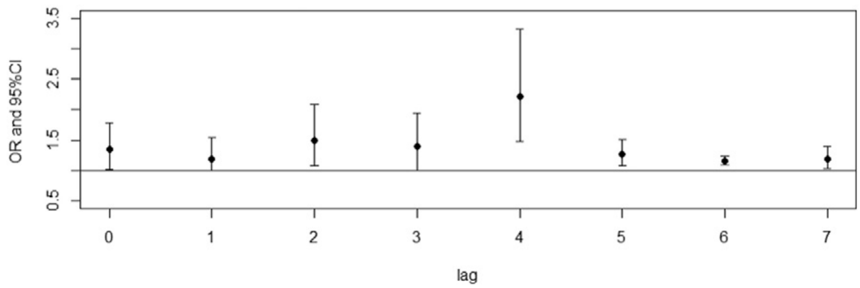

Fig. 3. OR estimates of the floods on the risk of bacillary dysentery in different lagged days in Huaihua.

4. Discussion

This study has, for the first time, quantified the association between floods and bacillary dysentery in Hunan, China. The results indicate that floods play an important role in the bacillary dysentery epidemics during the flood periods. It confirms that flood periods would bring more morbidity of bacillary dysentery than non-hazard periods in the study areas, which has been reported in both developing countries and developed countries. For example, a survey of households affected by Tropical Storm Alison found that diarrhea was significantly associated with residing in a flooded home (OR = 6.2, 95% CI: 1.4–28.0) (Waring et al., 2002). In the United States, a study revealed that an increase in the incidence of diarrhea during the flood was observed (incidence RR = 1.29, 95% CI: 1.06–1.58) (Wade, 2004). Another study during the 2001 floods in Texas, a developed countries, flooded households were associated with a greater risk of diarrhea than non-flooded homes (OR = 10.8, $p < 0.01$ (Waring et al., 2005). In the town of Lewes in Southern England, flooding of houses was significantly associated with increased risk of gastroenteritis (RR: 1.7, $p < 0.05$) (Reacher et al., 2004). Although limited studies have been conducted in China examining impacts of floods on bacillary dysentery. Our results are consistent with previous studies conducted in other regions of China, indicating that floods could lead to increased risks of bacillary dysentery in China (Ni et al., 2014a, 2014b, Liu et al., 2015).

Analysis from our study indicates that the morbidity of bacillary dysentery during the flooded could be higher than the non-flooded periods. Heavy rainfall may cause flooding and changes in living environment. Floodwaters are able to foster the growth of many pathogens and lead to a lack of clean water and food supply. There are three ways in which increased or extreme precipitation can affect water contamination and hence the risk of getting bacillary dysentery. Firstly, increased extreme precipitation increases the risk of sewer overflows, which might lead to water supply contamination (Huey-Jen et al., 2011; Hofstra, 2011; Gibson et al., 1998). Secondly, runoff of manure and animal excreta on soil and (sub) surface will increase, leading to higher concentrations of pathogens in surface waters (Poulton et al., 1991; Atherholt et al., 1998; Wilby et al., 2005). Thirdly, increased precipitation and more extreme precipitation events increase turbulences and lead to sediment resuspension, which disperse accumulated pathogens (Moors et al., 2013; Garzio-Hadzick et al., 2010; Muirhead et al., 2004; Wu et al., 2009).

Our study also shows that the risk for the morbidity of bacillary dysentery following prolonged moderate floods was lower than that following severe floods with shorter duration. It provides evidence that different degrees of floods can be relevant to the occurrence of bacillary dysentery. During the beginning of the flood period after heavy precipitation, the pathogens could grow fast and reproduce rapidly under a suitable environment, and then may spread through the contaminated water or food (Alderman et al., 2012). It is also argued that the effects of increased or extreme precipitation might only be short lived. With continued rainfall a dilution and flushing effect might subsequently decrease pathogen loads in water (Moors et al., 2013). A study also showed that 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 dysentery. However, during a prolonged and moderate flooding, the transmission and infection of dysentery pathogens may be decreased due to lower destruction and contamination (Ni et al., 2014a, 2014b).

Although this study has identified a lower effect of floods on bacillary dysentery in Huaihua, a longer lagged effect has been observed. The factors that may affect the lagged effect include the growth of pathogens under suitable environmental conditions that cause diarrhea, spread through contaminated food or water and other health infrastructures (Zhang et al., 2007). The longer duration of the flood in Huaihua has led to more chances for individuals to contact with floodwater than Jishou.

To estimate the burden of bacillary dysentery, we have adopted the comprehensive measurement-YLDs, which have been widely adopted by national and global burden of disease studies for both chronic and infectious diseases. However, weaknesses and limitations exist (WHO, 2004). The WHO estimated that 1,459,000 DALYs of diarrhea were attributable to climate change in 2000 ((WHO, 2004). It is important to estimate morbidity (YLDs) in burden of infectious disease studies, particularly for those infectious diseases that have few deaths and high incidence or prevalence, such as diarrhea (Zhang et al., 2012). Our finding suggests that male may suffer more burden of disease than female

Table 4
Parameters of the variables that were significantly included in the multifactorial conditional logistic models in the two areas.

Area	Variable	Estimate	SE	Wald χ^2	p-Value	OR	95% CI
Jishou[a]	Flood	1.185	0.471	6.331	0.012	3.270	1.299–8.228
	AT	−0.041	0.001	971.106	0.000	0.960	0.957–0.962
	AWV	−0.095	0.030	10.054	0.002	0.909	0.857–0.964
	AAP	−0.466	0.169	7.572	0.006	0.628	0.450–0.875
Huaihua[b]	Flood	0.998	0.379	4.385	0.036	2.212	1.052–4.650
	AWV	−0.192	0.017	128.131	0.000	0.825	0.798–0.853
	AAP	−0.491	0.172	6.961	0.017	0.724	0.613–0.899

[a] Lag time = 1 day.
[b] Lag time = 4 days.

Table 5
YLD per 1000 of bacillary dysentery among age-sex groups in the flood-period.

Age group (years)	Jishou			Huaihua		
	Male	Female	Total	Male	Female	Total
0–4	0.0427	0.0218	0.0645	0.0153	0.0093	0.0246
5–14	0.0032	0.0000	0.0032	0.0083	0.0054	0.0137
15–29	0.0069	0.0056	0.0125	0.0072	0.0061	0.0133
30–44	0.0074	0.0061	0.0135	0.0069	0.0071	0.0140
45–59	0.0094	0.0082	0.0176	0.0113	0.0098	0.0211
60–69	0.0125	0.0202	0.0327	0.0186	0.0124	0.0310
70–79	0.0518	0.0204	0.0522	0.0207	0.0099	0.0306
80+	0.0413	0.000	0.0213	0.0000	0.0000	0.0000
Total	0.0226	0.0143	0.0369	0.0114	0.0080	0.0194

during the exposure period. It is not clear whether the difference in burden of disease between male and female is caused by different response behaviors. A possible explanation is that in the flooding periods, all people participated in relief work, and females and males had similar exposures to adverse environment. In this scenario, flooding may bring more health risks to women than men (Ding et al., 2013). In terms of the age-group distribution of burden of disease, our study has found that there is a considerable burden of bacillary dysentery in all age groups, especially among the youngest and the oldest population groups. This arrives at the same conclusion as many previous observations. For example, a study conducted in North Jakarta suggested that Shigellosis was most common among children and the elderly (Agtini et al., 2005). Another study showed that bacillary dysentery is still a public health problem in China, particularly among children and elderly with low economic status (Zhang et al., 2007).The Special Report on Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation (SREX) released by the Intergovernmental Panel on Climate Change (IPCC) notes that if the exposure to extremes is the same, the severity and impacts of climate extremes depend strongly on vulnerability (IPCC, 2014). The reason why children and elderly are more likely to be killed or injured during natural disasters may be due to their underdeveloped or compromised immune systems.

Some limitations of this study should be acknowledged. Firstly, the main limitations is that many factors, e.g. socioeconomic status, availability of health services, environmental hygiene, which may affect the transmission of bacillary dysentery could not be included in this analysis. Secondly, the study was based on the assumption that all the population in the study areas exposed equally to the floods. In addition, no control group was selected for comparison. Thirdly, only two study areas of Hunan Province are selected in the study. In order to have a better understanding of the health impact of floods, more regions that are affected by floods in China should be analyzed.

5. Conclusion

Few studies provide data on the burden of bacillary dysentery associated with floods in China. Our study has quantified the effects of floods on bacillary dysentery in two regions of Hunan, China. Flooding can significantly increase the risks of bacillary dysentery in the study areas with various lagged effects. In addition, a sudden and severe flooding may bring more burdens of bacillary dysentery than a prolonged and moderate flooding. Our findings have significant implications for developing strategies to prevent and reduce health impact of floods.

References

Agtini, M.D., Soeharno, R., Lesmana, M., Punjabi, N.H., Simanjuntak, C., Wangsasaputra, F., Nurdin, D., Pulungsih, S.P., Rofiq, A., Santoso, H., Pujarwoto, H., Sjahrurachman, A., Sudarmono, P., Seidlein, L.v., Deen, J.L., Ali, M., Lee, H., Kim, D.R., Han, O., Park, J.K., Suwandono, A., Ingerani, Oyofo, B.A., Campbell, J.R., Beecham, H.J., Corwin, A.L., Clemens, J.D., 2005. The burden of diarrhoea, shigellosis, and cholera in North Jakarta, Indonesia: findings from 24 months surveillance. BMC Infect. Dis. 5, 89.

Alderman, K., Turne, L.R., Tong, S., 2012. Floods and human health: a systematic review. Environ. Int. 47, 37–47.

Atherholt, T.B., LeChevallier, M.W., Norton, W.D., Rosen, J.S., 1998. Effect of rainfall on *Giardia* and *Crypto*. J. Am. Water Works Assoc. 90, 66–80.

Cao, L., Zhong, J., Su, B., Zhai, J., Gemmer, M., 2013. Probability distribution and projected trends of daily precipitation in China. Adv. Clim. Chang. Res. 4 (3), 153–159.

Chou, W., Wu, J., Wang, Y., Huang, H., Sung, F.-C., Chuang, C., 2010. Modeling the impact of climate variability on diarrhea-associated diseases in Taiwan (1996–2007). Sci. Total Environ. 409, 43–51.

Ding, G., Zhang, Y., Gao, L., Ma, W., Li, X., Liu, J., Liu, Q., Jiang, B., 2013. Quantitative analysis of burden of infectious diarrhea associated with floods in Northwest of Anhui Province, China: a mixed method evaluation. PLoS One 8 (6), e65112.

Du, W., FitzGerald, G.J., Clark, M., Hou, X., 2010. Health impacts of floods. Prehosp. Disaster Med. 25 (3), 265–272.

Feng, S., Tan, H., Benjamin, A., Wen, S., Liu, A., Zhou, J., Li, S., Yang, T., Zhang, Y., Li, X., Li, G., 2007. Social support and posttraumatic stress disorder among flood victims in Hunan, China. Ann. Epidemiol. 17, 827–833.

Garzio-Hadzick, A., Shelton, D.R., Hill, R.L., Pachepsky, Y.A., Guber, A.K., Rowland, R., 2010. Survival of manure-borne *E. coli* in streambed sediment: effects of temperature and sediment properties. Water Res. 44, 2753–2762.

Gibson, C.J., Stadterman, K.L., States, S., Sykora, J., 1998. Combined sewer overflows: a source of *Cryptosporidium* and *Giardia*? Water Sci. Technol. 38, 67–72.

Gregory, P.J., Johnson, S.N., Newton, A.C., Ingram, J.S.I., 2009. Integrating pests and pathogens into the climate change/food security debate. J. Exp. Bot. 60, 2827–2838.

Hashizume, M., Wagatsuma, Y., Faruque, A.S., Hayashi, T., Hunter, P.R., Armstrong, B., Sack, D.A., 2008. Factors determining vulnerability to diarrhoea during and after severe floods in Bangladesh. J. Water Health 6 (3), 323–332.

Hofstra, N., 2011. Quantifying the impact of climate change on enteric waterborne pathogen concentrations in surface water. Curr. Opin. Environ. Sustain. 3, 471–479.

Huey-Jen, S., Chen, M.-J., Wang, J.-T., 2011. Developing a water literacy. Curr. Opin. Environ. Sustain. 3, 517–519.

IPCC, 2014. Climate Change 2014: Impacts, Adaptation and Vulnerability. Cambridge University Press, Cambridge.

Kondo, H., Seo, N., Yasuda, T., Hasizume, M., Koido, Y., Ninomiya, N., Yamamoto, Y., 2002. Post-flood—infectious diseases in Mozambique. Prehosp. Disaster Med. 17 (3), 126–133.

Kosek, M., Bern, C., Guerrant, R.L., 2003. The global burden of diarrhoeal disease, as estimated from studies published between 1992 and 2000. Bull. World Health Organ. 81, 197–204.

Liu, Z., Ding, G., Zhang, Y., Xu, X., Liu, Q., Jiang, B., 2015. Analysis of risk and burden of dysentery associated with floods from 2004 to 2010 in Nanning. China. Am. J. Trop. Med 93 (5), 925–930.

Ma, S., Tang, Q., Liu, H., He, J., Gao, S., 2013. 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. 3, 182–186.

Mathers CD, Vos T, Lopez AD, Salomon J, Ezzati M (Ed.) National Burden of Disease Studies: A Practical Guide. Edition 2.0. Global Program on Evidence for Health Policy. Geneva: World Health Organization. Available: http://www.who.int/entity/healthinfo/nationalburdenofdiseasemanual.pdf. Accessed 23 October 2011.

Mike Ahern, R., Kovats, S., Wilkinson, P., Few, R., Matthies, F., 2005. Global health impacts of floods: epidemiologic evidence. Epidemiol. Rev. 27, 36–46.

Milojevic, A., Armstrong, B., Hashizume, M., McAllister, K., Faruque, A., Yunus, M., Kim Streatfield, P., Moji, K., Wilkinson, P., 2012. Health effects of flooding in rural Bangladesh. Epidemiology 23 (1), 107–115.

Ministry of Health of the People's Republic of China (WOHC), 2006. Emergency events and regulation of the notifiable disease surveillance system [in Chinese]. Available: http://www.gov.cn/zwgk/2006-09/08/content_382018.htm. Accessed 6 January 2013.

Moors, E., Singh, T., Siderius, C., Balakrishnan, S., Mishra, A., 2013. Climate change and waterborne diarrhoea in northern India: impacts and adaptation strategies. Sci. Total Environ. S139–51.

Muirhead, R.W., Davies-Colley, R.J., Donnison, A.M., Nagels, J.W., 2004. Faecal bacteria yields in artificial flood events: quantifying in-stream stores. Water Res. 38, 1215–1224.

Ni, W., Ding, G., Li, Y., Li, H., Jiang, B., 2014a. Impacts of floods on dysentery in Xinxiang city, China, during 2004–2010: a time-series Poisson analysis. Glob Health Action 7, 23904. http://dx.doi.org/10.3402/gha.v7.23904.

Ni, W., Ding, G., Li, Y., Li, H., Liu, Q., Jiang, B., 2014b. Effects of the floods on dysentery in north central region of Henan Province, China from 2004 to 2009. J. Infect. 69, 430–439.

Poulton, M., Colbourne, J., Dennis, P.J., 1991. Thames water's experiences with *Cryptosporidium*. Water Sci. Technol. 24, 21–26.

Ramin, B., McMichael, A., 2009. Climate change and health in sub-Saharan Africa: a case-based perspective. Ecohealth 6, 52–57.

Reacher, M., McKenzie, K., Lane, C., Nichols, T., Kedge, I., Iversen, A., Hepple, P., Walter, T., Laxton, C., Simpson, J., 2004. Health impacts of flooding in Lewes: a comparison of reported gastrointestinal and other illness and mental health in flooded and non-flooded households. Commun. Dis. Public Health 7, 39–46.

Semenza, J.C., Menne, B., 2009. Climate change and infectious diseases in Europe. Lancet Infect. Dis. 9, 365–375.

Viera, A.J., 2008. Odds ratios and risk ratios: what's the difference and why does it matter? South. Med. J. 101, 730–734.

Wade, T.J., 2004. Did a severe flood in the midwest cause an increase in the incidence of gastrointestinal symptoms? Am. J. Epidemiol. 159, 398–405.

Wakuma Abaya, S., Mandere, N., Ewald, G., 2009. Floods and health in Gambella region, Ethiopia: a qualitative assessment of the strengths and weaknesses of coping mechanisms. Glob Health Action 2.

Wang, X., Tao, F., Xiao, D., Lee, H., Deen, J., Gong, J., Zhao, Y., Zhou, W., Wi, L., Shen, B., Song, Y., Ma, J., Z, L., Wang, Z., Su, P., Chang, N., J, X., Ouyang, P.-y., Seidlein, L.v., Xu, Z., Clemens, J.D., 2006. Trend and disease burden of bacillary dysentery in China (1991–2000). Bull. World Health Organ. 84, 561–568.

Wang, Y., Gao, C., Zhai, J., Li, X., Su, B., Heike, H., 2015. Spatio-temporal changes of exposure and vulnerability to floods in China. Advances in Climate Change Research. http://dx.doi.org/10.1016/j.accre.2015.03.002.

Waring, S.C., Reynolds, K.M., D'Souza, G., Arafat, R.R., 2002. Rapid assessment of household needs in the Houston area after Tropical Storm Allison. Disaster Manag. Response 3–9.

Waring, S., Zakos-Feliberti, A., Wood, R., Stone, M., Padgett, P., Arafat, R., 2005. The utility of geographic information systems (GIS) in rapid epidemiological assessments following weather-related disasters: methodological issues based on the Tropical Storm Allison Experience. Int. J. Hyg. Environ. Health 208, 109–116.

Wilby, R.L., Hedger, M., Orr, H., 2005. Climate change impacts and adaptation: a science agenda for the Environment Agency of England and Wales. Weather 60, 206–211.

Wu, J., Rees, P., Storrer, S., Alderisio, K., Dorner, S.M., 2009. Fate and transport modeling of potential pathogens: the contribution from sediments. J. Am. Water Resour. Assoc. 45, 35–44.
World Health Organization (WHO), 2004. Introduction and methods: assessing the environmental burden of disease at national and local levels. Available at: http://www.who.int/quantifying_ehimpacts/publications/en/9241546204.pdf.
Xu, Y., Zhang, B., Zhou, B., Dong, S., Yu, L., Rouke, L., 2014. Projected flood risks in China based on CMIP5. Adv. Clim. Chang. Res. 5 (2), 57–65.
Zhang, Y., Bi, P., Hiller, J.E., Sun, Y., Ryan, P., 2007. Climate variations and bacillary dysentery in northern and southern cities of China. J. Infect. 55, 194–200.
Zhang, Y., Bi, P., Janet, E., 2012. Hiller. Projected burden of disease for *Salmonella* infection due to increased temperature in Australian temperate and subtropical regions. Environ. Int. 44, 26–30.