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Identifying different types of flood–sensitive diarrheal diseases from 2006 to 2010 in Guangxi, China

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ABSTRACT

Floods may influence different types of diarrheal diseases and epidemiological studies of pathogen-specific diarrhea due to floods in China are still needed. In addition, few studies have been conducted to quantify the lag and cumulative risk of diarrheal disease due to floods in Guangxi, China. Our study aimed to identify different types of diarrheal diseases that were sensitive to floods and to quantify their lag and cumulative impact. A matched analysis based on time series data of floods and infectious disease from 2006 to 2010 was conducted in Guangxi, China. Each flood day was treated as an independent unit in our study. A simplified assumption that each day of the flood confers the same risk was adopted before analysis. Each flood day was matched to a non–flood day by city and time. Log–linear mixed–effects regression models were used to quantify the association between different types of diarrheal diseases and floods. Lag and cumulative effects were also calculated to get delayed and overall effects. A total of 45,131 diarrhea cases were notified in the study area over the study period. After controlling for the long–term trend, seasonality, and meteorological factors, floods caused a significantly increased risk of total diarrheal diseases. The RR was highest at lag 2 days (RR = 1.24, 95% CI: 1.11–1.40). Floods caused a significantly increased risk in bacillary dysentery and in other infectious diarrhea, but not in typhoid fever and paratyphoid fever. Floods were significantly associated with total diarrheal diseases and other infectious diarrhea for both cumulative lag 0–7 and 0–14 days. Our study provides strong evidence of a positive association between floods and diarrheal diseases including bacillary dysentery and other infectious diarrhea in study area. Public health interventions should be taken to prevent a potential risk of these flood–-sensitive diarrheal diseases according to the different lag period after floods.

1. Introduction

Floods are the most common type of disaster globally, responsible for almost 53,000 deaths in the last decade alone (Alderman et al., 2012). Floods and other hydrological events accounted for over 50% of the disasters from 2001 to 2010 in the world (Guha-Sapir et al., 2012). Floods are expected to increase in frequency and intensity due to more frequent and extreme precipitation events all over the world (Parry, 2007). Guangxi, located in the area of tropical and subtropical monsoon climate, is one of those provinces often suffering from flood disasters in China (Chen and Li, 2004). The geographic location and local weather characteristics brought abundant rainfall to Guangxi, where there are more than six rivers meandered. Consequently, persistent and heavy precipitation brought several floods in Guangxi from 2006 to 2010 (Song, 2011).

The health impacts of floods, e.g. direct death, injury, infectious disease, non–communicable disease, psychosocial health and malnutrition, are complex and far–reaching (Alderman et al., 2012). Although incidences of many infectious diseases have dropped down significantly in China, source of infections and favorable conditions for disease transmission still exist during and after floods. Diarrheal diseases, one of the leading causes of children death worldwide, are still a

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serious threat to the public health in China (Liu et al., 2012). The incidence of infectious diarrhea each year ranged from 64.3 to 99.5 per 100,000 during 2006–2010, which was the top 3 common disease among the 39 kinds of notified infectious diseases in Guangxi (http://www.gxcdc.com/ywzd/tjxx/).

During floods, living environment like temperature, humidity and surface vegetation may change after heavy precipitation. Some pathogens could grow faster and reproduce more rapidly under a suitable environment. Thus, pathogens may spread quickly through the contaminated water (De Man et al., 2014). In addition, flooded areas usually have crowded environments, poor access to basic needs such as safe water and sanitation, adequate shelter, and primary healthcare services, which can bring more susceptible population. Therefore, there is a potential for increased transmission of waterborne infectious disease after floods.

An increased risk of diarrheal disease following floods has been reported. For example, Schwartz reported, that *vibrio cholera* was the most commonly identified cause of diarrhea during flood–associated epidemics in Bangladesh (Schwartz et al., 2006). A study from the United States revealed that a 29% increase in morbidity of diarrhea was found during the flooding (Wade et al., 2004). Two studies from China showed that floods were significantly associated with an increased risk of infectious diarrhea (Ding et al., 2013; Gao et al., 2016). A recent systematic review showed that a significant positive association was noted in most (76%) of the articles examining the relationship between floods and diarrhea (Levy et al., 2016). Several studies have examined the relationships between pathogen-specific diarrhea and floods, which indicate that flood was associated with diarrhea caused by *Vibrio cholera*, rotavirus, norovirus, and enterotoxigenic *Escherichia coli* (Harris et al., 2008; Hashizume et al., 2008; Setzer and Domino, 2004; Schmid et al., 2005). Floods may influence different types of diarrheal diseases and epidemiological studies of pathogen-specific diarrhea due to floods are still needed (Levy et al., 2016). Most of previous studies about floods and diarrheal diseases were based on one city or one flood event while research in larger spatial scales is sparse (Ahern et al., 2005). In addition, few studies have been conducted to quantify the lagged and cumulative risk of diarrheal disease dues to floods (Alderman et al., 2012). The effects of the Guangxi floods remain unknown.

Our study aimed to identify different types of diarrheal diseases that were sensitive to floods and to quantify the lagged and cumulative impacts of floods on sensitive diarrheal diseases using the data of floods from 2006 to 2010 in Guangxi. Our findings will contribute to a better understanding of the relationship between floods and diarrheal diseases and provide epidemiological evidences for developing local strategies to reduce the potential risks of diarrheal diseases related to floods.

2. Materials and methods

2.1. Study area

Guangxi province, located in the Pearl River basin of southern China (see Fig. 1), has abundant water source with four river systems (i.e. Pearl river system, Yangtze river system, Guinan water system and Baidu river system). It is generally characterized by a tropical and subtropical monsoon climate with annual average temperature between 16 °C and 23 °C and annual average rainfall of 1000–2800 mm (http://www.gxzf.gov.cn/mlgx.shtml). Guangxi has an area of 236,700 square kilometers between longitude 104°26′– 112°04′E and latitude 20°54′–26°24′N (Yu et al., 2018). Most of local residents are ethnic Han or Zhuang. Guangxi has 14 cities with a total population of 46 million at the end of 2010.

2.2. Data Collection

Daily data of diarrheal diseases from 2006 to 2010 for Guangxi were collected from the National Notifiable Disease Surveillance System (NNDSS) (DCFPH, 2011). Diarrheal disease from the NNDSS included cholera, dysentery, typhoid, paratyphoid, and other infectious diarrhea. The term "other infectious diarrhea" is used for infectious diarrhea other than cholera, dysentery, typhoid and paratyphoid, which is categorized as a notifiable category C infectious disease in China (NHFPC, 2007). Main pathogens of "other infectious diarrhea" included rotavirus, norovirus, enterointestinal *Escherichia coli*, salmonella, yersinia enterocolitica, enteropathogenic *vibrio*, and enteric adenovirus (Kang et al., 2015). In the dataset, the incidence of the cholera and amebic dysentery over the study period was too low to be included in the analysis. Thus, four types of diarrheal diseases, including bacillary dysentery, typhoid fever, paratyphoid fever and other infectious diarrhea, were included as our outcomes. Only the diarrheal cases confirmed clinically or by laboratory tests, including microscopic examination and biochemical identification, were included in our study. All notified diarrheal disease cases were defined by the diagnostic criteria and principles of management for infectious diarrhea (WS 271–2007), which was issued by the Ministry of Health of the People's Republic of China (NHFPC, 2007).

The Yearbooks of Meteorological Disasters in China recorded the occurrence of floods and their consequences, including deaths, damaged areas and economic loss (Song, 2011). According to the Yearbooks, floods must fulfill at least one of the three following criteria: (1) More than ten people were killed. (2) More than 50,000 ha of farmland were damaged. (3) Caused a direct economic loss of more than 100 million Chinese yuan. According to this definition, there were 6 floods recorded in Guangxi from 2006 to 2010, occurred in the north and med–east areas. According to the Yearbooks, detailed information (including the number of deaths, damaged areas, occurrence time, and economic loss) of the floods were not available from 2011 to 2015 in Guangxi, thus 2010 was chosen as our end study point (Song, 2012, 2015, 2013; Song and Fan, 2014, 2016).

Daily meteorological data were collected from the China Meteorological Data Sharing Service System (http://cdc.cma.gov.cn/). The meteorological variables included daily average temperature, daily average relative humidity, and daily average precipitation over the study period.

2.3. Study design

Each flood day was treated as an independent unit in our study which is different from a study design that defined each flood as an event. A simplified assumption that each day of the flood confers the same risk was adopted before analysis. Each flood day was matched to a non–flood day by city and time to control the potential confounding of any long–term trend, seasonality, and geographic variations (Bobb et al., 2014; Wang et al., 2016). A single non–flood day was randomly selected from a set of candidate non–flood days to achieve 1:1 matching. The candidate non–flood days were defined as all days within 3 days of the flood day in the previous year and the year after in the same city, but not within one month of a different flood event. For example, for flood days occurred on July 11–12, 2008, candidate non–flood days could be any day in that same city during the period July 8–15 and during the years 2007 and 2009, provided those days were not within one months of a different flood event. Only those days that were either a flood day or a matched non–flood day were included in our analysis.

2.4. Statistical analysis

A descriptive analysis was performed to describe the characteristics of flood events and meteorological factors. For each city and each type of diarrheal disease, the number of cases was described in both flood and matched non–flood days.

Log–linear mixed–effects regression models were used to quantify the association between different types of diarrheal diseases and floods

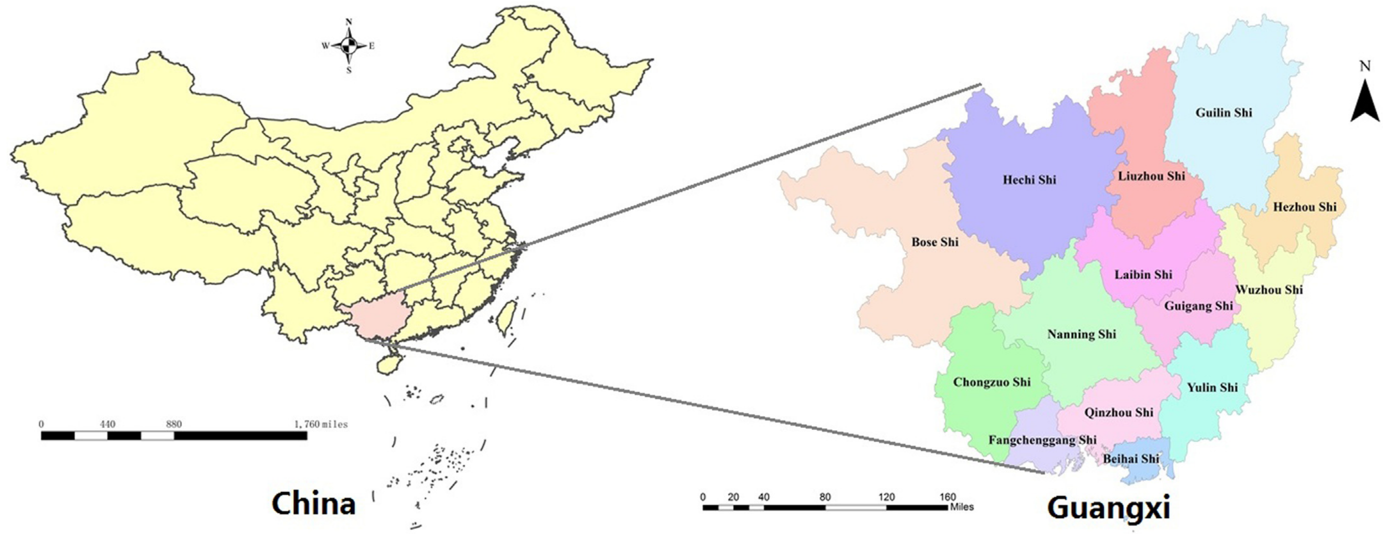

Fig. 1. Location of the study area in China.

Table 1
Characteristics of flood events from 2006 to 2010 in Guangxi.

Flood periods	Number of stricken cities * Duration (days)	Affected population (million)	Death	Missing	Economic loss (million dollars)
Jul 7–9, 2006	7*3	1.5	10	2	71.2
Jun 6–10, 2007	5*5	2.2	13	2	81.4
Jun 8–18, 2008	6*11	9.2	31	1	1068.0
Jul 11–12, 2008	4*2	0.5	1	0	27.6
Oct 31–Nov 5, 2008	4*6	1.4	11	0	107.5
May 28–Jun 3, 2010	8*7	2.3	20	28	122.1
Total	200	17.0	86	33	1763.5

with city–level random intercepts, adjusting for the confounding of meteorological factors, long–term trends, and seasonality (Bobb et al., 2014). Temperature and humidity were adopted as potential confounders in our model because previous studies showed that these meteorological factors were usually associated with diarrheal diseases (Chou et al., 2010; Onozuka et al., 2010). To avoid collinearity, rainfall was not included in the main models because of the strong correlation between floods and rainfall, but we examined the potential confounding of rainfall in the sensitivity analysis. Relative Risks (RR) and 95% CI of floods to different types of diarrheal diseases were estimated. To investigate possible delayed effects of floods on diarrheal diseases, an analysis on lagged effect was conducted. We estimated the RRs on days 0–14 following a flood day based on the time required for the reproduction of pathogens and the incubation of diarrheal diseases (Parsonnet et al., 1989). The cumulative effects of floods on diarrheal diseases at lag 0–7 and 0–14 days were also calculated to estimate the overall effects. According to the study design, cumulative effect in our study is the total increase in diarrhea over a 7 or 14-day lag for a single day of flooding, which is different from the cumulative effect of a flood event, which may last several days.

The log–linear mixed–effects regression models were described as follows:

$$\begin{aligned} \text{Log}\,[E(Y_t^c)] \;=\; & \gamma^c \;+\; \beta_0 + \beta_1 Floods_t^c + ns(tem_t,\, 3) \\ & + ns\ (hum_t,\, 3) \;+\; \beta_2 Strata \end{aligned}$$

Where Y_t^c denoted the number of diarrhea cases on day *t* in city *c*, assumed to follow a *Poisson* distribution.$\gamma^c \sim N\ (0,\ \sigma)$ is the random intercept for city *c*. $Floods_t^c$ indicated if day t in city c is a flood day. *ns* was natural cubic splines designed to control the non–linear effect of meteorological factors. *Strata*, set as a dummy variable, was an indicator for different pairs of flood and matched non–flood days designed to achieve matching. The flood and non–flood days in a specific level of *Strata* were matched to control the long–term trend and seasonality.

Residual analysis was performed to evaluate the developed model. Several sensitivity analyses were conducted with respect to: (1) unadjusted model; (2) a model that adjusted for temperature and relative humidity as a linear form; (3) a model that adjusted for temperature, relative humidity, and rainfall as a linear form; (4) a model that adjusted for temperature, relative humidity, and rainfall as a natural cubic spline function. Statistically significance level was set at 0.05. The statistical analysis was performed using R 3.1.3 (R Foundation for Statistical Computing, Vienna, Austria).

3. Results

3.1. Descriptive analysis of floods, climate variables, and diarrhea cases

There were 200 flood days in 14 cities from 2006 to 2010 in Guangxi. Table 1 indicated the characteristics of six flood events from 2006 to 2010 in Guangxi. Fig. 2 showed the impact scope of floods in Guangxi from 2006 to 2010. In total, the floods affected 17.0 million people and killed 86 people. At least 33 people disappeared. The economic damage was estimated at approximately 1.76 billion dollars. Table 2 shows the description of cumulative diarrhea cases in flood and matched non–flood days from 2006 to 2010. A total of 45,131 diarrhea cases were notified in the study area over the study period. Most of them were bacillary dysentery and other infectious diarrhea. Table S1 presents the description of climate variables in flood and matched non–flood days.

3.2. Analysis for lag and cumulative effects of floods on diarrheal diseases

Fig. 3 showed the lag effects of floods on total diarrheal diseases from the log–linear mixed–effects regression models. After controlling

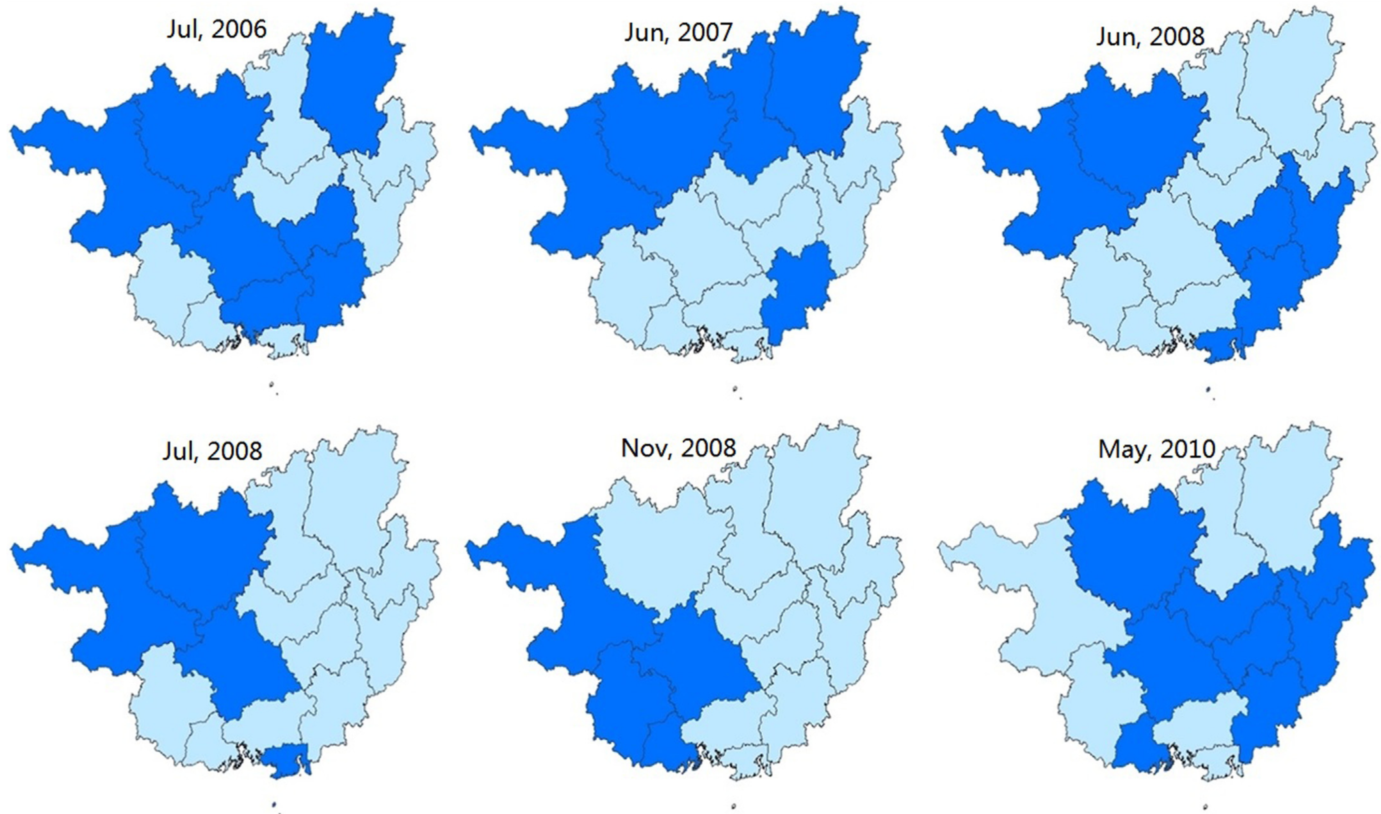

Fig. 2. The impact scope of floods in Guangxi from 2006 to 2010 (flood affected cities are indicated in dark blue). (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.).

Table 2
Description of cumulative number of diarrheal cases in flood and matched non–flood days from 2006 to 2010 in Guangxi.

Category	Cumulative cases at lag0–7		Cumulative cases at lag0–14	
	Flood days	Matched non–flood days	Flood days	Matched non–flood days
Bacillary dysentery	26 ± 20	22 ± 22	46 ± 36	41 ± 41
Typhoid fever	2 ± 4	2 ± 5	5 ± 8	4 ± 9
Paratyphoid fever	1 ± 1	1 ± 3	1 ± 3	1 ± 5
Other infectious diarrhea	37 ± 32	33 ± 39	66 ± 56	62 ± 72
Total diarrheal diseases	66 ± 47	58 ± 51	118 ± 82	108 ± 96

for the long–term trend, seasonality, and meteorological factors, floods caused a significantly increased risk of the total number of diarrheal diseases. The risks remained statistically significant at lag 0–5 days. The RR was highest at lag 2 days (RR = 1.24, 95% CI: 1.11–1.40).

Fig. 4 indicated the lag effects of floods on different diarrheal diseases. The results indicated that the floods caused a significantly increased risk in bacillary dysentery at lag 4–5 days and in other infectious diarrhea at lag 0–4 days, but not in typhoid fever and paratyphoid fever. Fig. 5 presented the cumulative effects of floods on different types of diarrheal diseases in Guangxi. Results indicated that the floods were significantly associated with total diarrheal diseases and other infectious diarrhea for both cumulative lag 0–7 and 0–14 days.

3.3. Sensitivity analyses

The sensitivity of our results was assessed using the total diarrheal

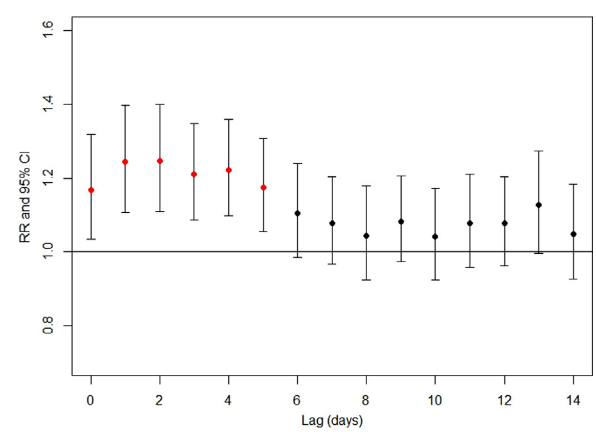

Fig. 3. Lag effects of floods on total diarrheal diseases in Guangxi (Red means statistically significant). (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.).

diseases as an example. Supplementary Fig. S1 showed that model residuals were approximately independent over time and obeying the normal distribution. Supplementary Fig. S2 showed the sensitivity of the flood–related effect estimates to adjustment for confounders in different types. When changing the number and forms of different confounders, we found that the effect estimates did not change substantially.

4. Discussion

Our research has revealed a positive association between floods and total diarrheal diseases in the study area. Lag effects of floods on bacillary dysentery and other infectious diarrhea, cumulative effects of

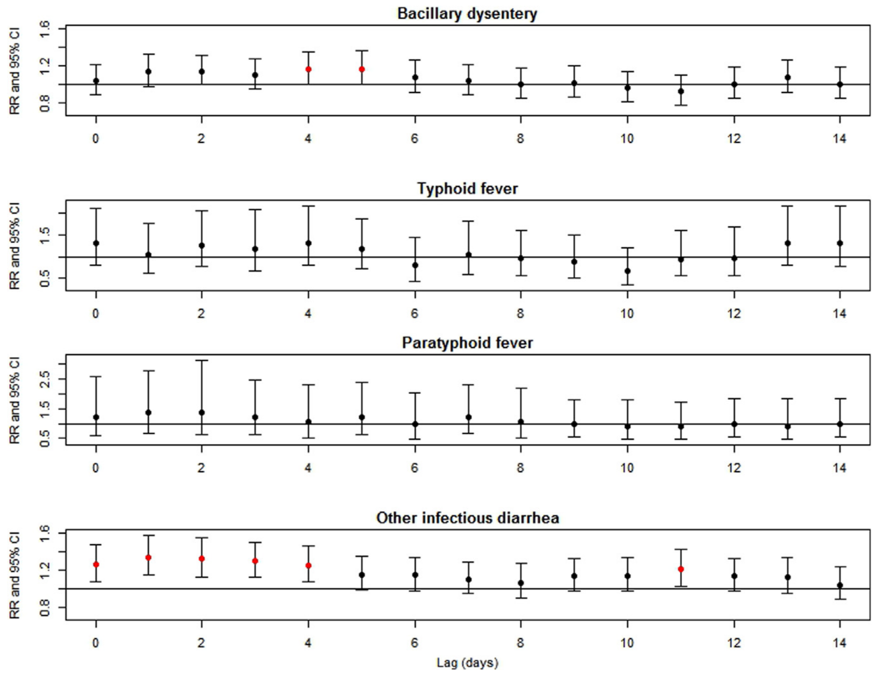

Fig. 4. Lag effects of floods on different diarrheal diseases in Guangxi (Red means statistically significant). (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.).

total diarrheal diseases and other infectious diarrhea have also been identified. To our knowledge, this was the first study systematically examined different types of diarrheal diseases related to floods in Guangxi, China. Our results confirm that floods play an important role in the epidemic of the diarrheal diseases, which should be considered for public health resource allocations during public health disaster emergency preparation.

Floods are associated with an increased risk for water–borne diseases (Ahern et al., 2005). The risk increases when infrastructure is heavily impacted, populations are displaced and water supply systems are damaged, leading to the contamination of drinking water facilities (Watson et al., 2007). Studies on diarrheal diseases and floods, which has been developed in both developing countries and developed countries, showed that floods significantly increased the risk of diarrhea in Brazil (Heller et al., 2003), German (Schnitzler et al., 2007), and Ethiopia (Wakuma Abaya et al., 2009). Several similar time series studies conducted in China have also indicated that floods were associated with bacillary dysentery or infectious diarrhea (Ding et al., 2013; Gao et al., 2016; Liu et al., 2015, 2016, 2018b). Results found in our study were consistent with these previous studies.

The underlying mechanisms by which floods influence the diarrheal infectious diseases have not been fully clarified. Several studies showed that pollution of water sources for drinking have been associated with water–borne disease outbreaks such as dysentery, cholera, hepatitis A, typhoid fever, and other gastrointestinal diseases after floods (McMichael et al., 2006; Patz et al., 2001, 2008). A study from Pakistan tested drinking water samples collected during flood period from 10 sites in Peshawar, while twenty percent of the samples were contaminated with *Shigella*, *Vibrio cholerae*, *Salmonella*, *Staphylococcus aureus* and others (Khan et al., 2013). During the beginning of floods, intense precipitation can mobilize pathogens in the environment and transport them into the aquatic environment, increasing the microbiological agents on surface water (Cann et al., 2013). With the increase of precipitation, floods can destroy the sewage system and waste–disposal systems with contaminations washed into water source, causing the local water quality seriously deteriorated and lead to a lack of clean water and food supply. These changes increased the transmission of enteric pathogens (Hodge et al., 2016; Wolf et al., 2014).

A study from Yongzhou, China shows that floods could significantly increase the risks of typhoid fever which is inconsistent with our study (Liu et al., 2018a). The reason for the insignificant association between floods and typhoid fever, paratyphoid fever from our study is unclear. A plausible explanation is due to the very small number of cases of these diseases, leading to a sample size too small to reach a statistical

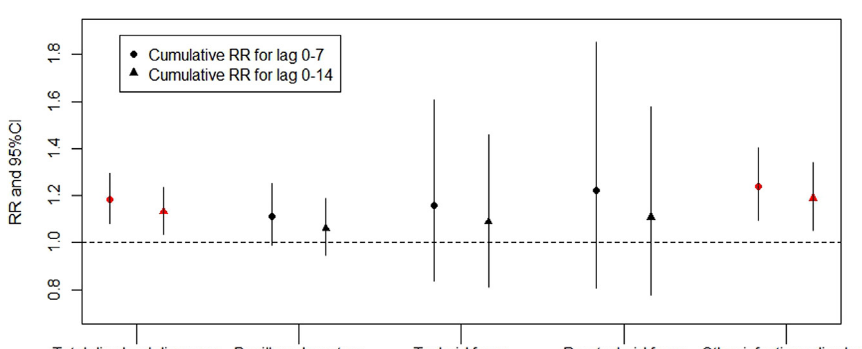

Fig. 5. Cumulative effects at different lag periods of floods on different diarrheal diseases in Guangxi (Red means statistically significant). (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.).

significance.

Our study has contributed to a better understanding of the impact of floods on diarrheal diseases in Guangxi, China. Detected lagged effect of floods on diarrheal diseases could assist in developing local strategies to prevent and reduce the risks of diarrheal diseases due to floods. For example, public health strategies carried out by local CDC should last at least for two weeks plus the flood period and more attention should be paid for the first week after floods. To prevent and control a potential risk of these flood–sensitive diarrheal diseases, some improvements, such as using water filters, improving latrine infrastructure, and provision of high-quality drinking water, are recommended because these measures can reduce the prevalence of diarrheal diseases during floods (Wolf et al., 2014; Denslow et al., 2010). For individuals especially children, washing hands with soap are strongly recommended because one study has shown that it can reduce the risk of diarrheal diseases by 42–47% (Curtis and Cairncross, 2003).

Limitations of this study should be acknowledged. Firstly, outcome data used in our study were obtained from NNDSS, which is a nationwide and well-documented reporting system. However, the major gaps of NNDSS are that it was a passive reporting system, and cannot actively monitor any new type of infectious disease until a clear definition and diagnostic criteria are made. We can't get detailed data including information of pathogens or laboratory test from NNDSS while detailed pathogen-specific analysis is helpful for decision-making. Secondly, potential confounding factors, such as the variability of pathogen and different immune levels, could not be included in our study. A simplified assumption that each day of the flood confers the same risk was adopted before analysis because our model can only calculate the average effect. Thirdly, underreporting of the diarrheal diseases is inevitable. It may be more serious during flood period than usual since some hospitals which are responsible for reporting infectious diseases may be destroyed or damaged by floods. Therefore, the correlation between floods and flood–sensitive diarrheal diseases may be underestimated. Lastly, the study period was short due to data unavailability of floods in the study area. Thus more studies with a longer study period and more recent data especially in areas with different climates are needed.

5. Conclusions

Our study provides strong evidence of a positive association between floods and diarrheal diseases, including bacillary dysentery and other infectious diarrhea, in the study area, with various lagged and cumulative effects. Public health interventions should be developed to prevent and control the potential risk of the flood–sensitive diarrheal diseases.

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Competing financial interests

The authors declare no competing financial interests.

Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at doi:10.1016/j.envres.2018.12.067.

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