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Short-term effects of moderate and severe floods on infectious diarrheal diseases in Anhui Province, China

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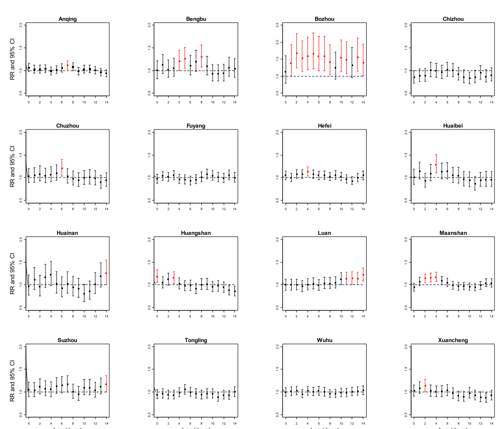
HIGHLIGHTS

- Floods significantly increased the diarrhea risks within one week period.
- Severe floods brought higher risks of diarrhea compared with the moderate ones.
- Short-term effects (0–14 days) varied in different cities with various lagged days.

GRAPHICAL ABSTRACT



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ABSTRACT

Background: Previous studies showed that floods can lead to diarrheal diseases outbreaks; however, the short-term effects of different severity floods on diarrheal diseases are not clear. This study aims to examine 0–14 days lagged effects of moderate and severe floods on diarrhea in Anhui Province, one heavily flood-prone area in China.
Methods: Daily diarrheal cases from January 1, 2013 to August 31, 2017 in 16 cities of Anhui were extracted from the National Notifiable Disease Surveillance System. Meteorological data were obtained, and moderate or severe floods were identified according to Comprehensive Study Group of Major Natural Disasters of the State Science and Technology Commission in China. The quasi-Poisson generalized linear models were applied to evaluate effects of floods on daily diarrheal cases in each city with 0–14 days lag, and we divided post-flood periods into week 1 and week 2, further conducted provincial-level meta-analysis.
Results: Immediate effects of floods on diarrheal diseases were observed within 7 days, and at provincial level moderate floods had a RR of 1.05 (95% CI: 1.02–1.09) and severe floods RR = 1.04 (95% CI: 1.01–1.08) controlling

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Infectious diarrhea
Quasi-Poisson generalized linear model

for population size, temperature and relative humidity etc., but less effects appeared in the second week. Impacts of flooding on diarrheal diseases varied among cities. Moderate floods in week 1 had a RR of 1.51 (95% CI: 1.29–1.78) in Bozhou, and severe floods had a RR = 1.31 (95% CI: 1.05–1.64) in Chuzhou. The severe floods may have higher RR in week 1 compared with moderate floods in Anqing (1.10 vs 1.06), Chuzhou (1.31 vs 1.07) and Luan (1.18 vs 1.00).

Conclusions: Both moderate and severe floods can significantly increase diarrheal risks in one week with regionally varied effects, and severe floods may lead higher risks. The findings have implications for preparing emergent interventions in hazard periods to reduce health risks of floods.

1. Introduction

Floods are identified as the most pervasive hydro-meteorological hazard in both developed and developing countries. It is believed that climate change can significantly alter the patterns of severe weather events, and increase the extreme precipitation, flooding events (IPCC, 2013). In fact, diarrheal diseases are one of the leading morbidity and mortality causes worldwide especially for the low- and middle-countries, existed as the eighth leading cause of death among all ages (G. B. D. Diarrhoeal Disease Collaborators, 2018). Diarrhea causes approximately 700 thousand deaths in each year among children under 5 years old (Walker et al., 2013). The prominent concerns as waterborne disease and infectious diarrhea are expected to worsen under future climate change projections.

Flooding or extreme rainfall have been found to increase the risk of diarrheal diseases, but considerable uncertainty remains. Flooding has been associated with increased diarrhea in Bangladesh (Schwartz et al., 2006), China (Liu et al., 2018), and the United States (Wade et al., 2004; Wade et al., 2014). Curriero et al. and Thomas et al. found positive associations between heavy rainfalls and waterborne disease outbreaks in North America (Curriero et al., 2001; Thomas et al., 2006). Carlton et al. found heavy rainfalls were associated with increased diarrhea incidence following dry periods and decreased diarrhea incidence following wet periods in Ecuador (Carlton et al., 2014). Increased gastrointestinal illness has been associated with any rainfall in the United States (Drayna et al., 2010), and with low rainfall in a global cross-sectional study (Lloyd et al., 2007). However Milojevic et al. found no evidence of flooding-associated diarrhea risks in Bangladesh (Milojevic et al., 2012). Across individuals of all ages in Botswana, diarrheal outbreaks occurred regularly in both wet and dry seasons. Increases in diarrheal case were closely tied to flood recession, with the highest number of cases occurring in the dry season (Alexander et al., 2018).

There is very limited understanding about the short-term lagged effects of floods on the diarrheal disease and gastrointestinal illness. A lagged health impact seems very localized with different nature of watersheds and communities according to a few studies, like the greatest effects for 7-day and 11-day lags of bacillary dysentery in Qingdao, China (Zhang et al., 2016) and within 5 days of diarrhea cases outbreak following flooding events in northwest of Anhui (Ding et al., 2013). Flooding was associated with an increased risk for emergency room visits for gastrointestinal illness in the 0–4 day period after flooding in Massachusetts of the U.S.A. but not in the 5–9 and 10–14 days after flooding (Wade et al., 2014). Internationally the exact hazard period of diarrheal diseases after floods is not clear. Furthermore, there is lack of studies addressing the effects of flood with different severities on diarrheal diseases.

It is unknown when the hazard time window for diarrheal diseases is after floods, and whether the impact patterns in the hazard period are related to different flood severities. An effect within the immediate hazard period could be consistent with direct contact with pathogen contaminated water soon after the flood event. It is said that the health consequences of floods depend on geographic and socio-economic factors, as well as the baseline vulnerability of the populations affected (Ahern et al., 2005; Du et al., 2010). Thus, researches are really needed in flood affected regions with different weather and socio-economic conditions to have a better understanding of the health risks hazard period of floods.

The aim of this study was to quantitatively examine the short-term effects of floods with different severities on diarrheal diseases in the flood-prone areas based on a time series data, and discuss the public health implications and climate preparedness needs in the hazard period after floods.

2. Materials and methods

2.1. Study settings

This study included diarrheal cases that occurred in 16 cities of Anhui Province from January 1, 2013 to August 31, 2017 (around 4 years and a half). Anhui Province, located in the Yangtze River Basin, with a total area of 140,100 km^2 and a total population of 62.5 million in 2017, is one of the most flood-prone provinces in China. It has a warm temperate climate and a subtropical climate, with abundant heavy rainfall in summer, namely plum rain season, accounting for 40–60% of the annual total precipitation (Fig. 1).

2.2. Data collection

Infectious diarrheal disease is a group of infectious diseases which caused by panel of microbes (including bacteria, viruses, and parasites) and have diarrhea as the typical symptom, including dysentery, cholera, paratyphoid and typhoid, and other infectious diarrhea. In our study, all diarrhea cases were defined based on the diagnostic criteria and principles of management for diarrhea. Personal data of diarrhea, which contain information of gender, date of birth, date of onset and type of disease cases from January 1, 2013 to August 31, 2017, were extracted and verified from the China's National Notifiable Disease Surveillance System (NDSS). We aggregated personal data and counted the daily number of diarrhea cases. Population data of each city in each year were obtained from Statistical Yearbook of Anhui (http://www.ahtjj.gov.cn/).

Daily meteorological data were collected from the China's National Meteorological Information Center (https://data.cma.cn) and Anhui Public Meteorological Service Center (http://www.ahqxfw.cn/). The meteorological variables included daily average temperature, daily average relative humidity, and daily precipitation. We calculated means of each meteorological variable in each city with more than one meteorological station.

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 100 mm for one day or >80 mm for three consecutive days or > 250 mm for ten consecutive days; cumulative rainfall of >150 mm for three consecutive days or > 350 mm for ten consecutive days is defined as a severe flood (X. Liu et al. 2016).

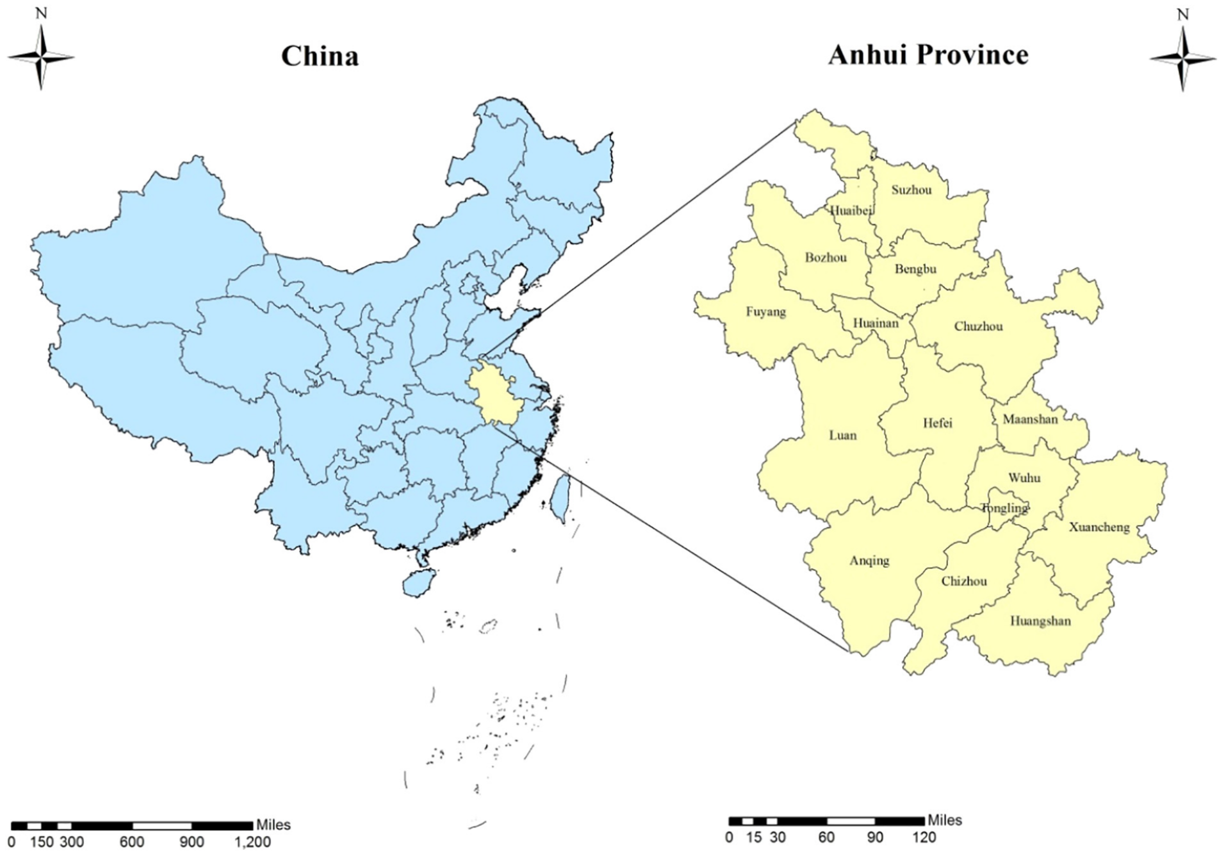

Fig. 1. Location of study site - Anhui Province in China.

2.3. Statistical analysis

Two phases were involved in the statistical analysis. In first stage, we evaluated the effects of floods on daily cases of diarrheal diseases. We separately examined the influence of moderate floods and severely floods by fitting the respective model. Secondly, to figure out the time windows of diarrheal risks posed by flood, we examined the effects of flood on diarrhea cases occurred in the first and second week after flood, and a provincial level meta-analysis was conducted to evaluate the total effects of floods in further. We also take the magnitude of floods into consideration in this stage by setting moderate floods or severed floods events as an independent variable included into models.

The effects of floods on daily cases of diarrheal diseases were calculated by a quasi-Poisson generalized linear model with the consideration of excessive dispersion tendency of infectious diarrheal disease data (model 1).

Model 1:

$$\log(Y_t) = \alpha + \text{offset}(\log(pop)) + \beta_1 Flood_{t-i} + \beta_2\, AT_{t-i} + \beta_3\, ARH_{t-i} + \beta_4\, strata_{t-i} + \epsilon$$

In model 1, where Y_t denoted the daily cases of diarrhea in day t, an offset for city population in specific year was included in the model to interpret the results in terms of the daily rate of diarrhea in the specific city. With the consideration of potential lagged effects on diarrheal disease of the floods, lagged effects up to 14 days ($i \in [0,14]$) were evaluated. $Flood_{t-i}$ is a categorical variable indicating flood occurred (code as 1) or not (code as 0) at i days before day t, thus the β_1 was the estimate effects of the flood occurred on i days before day t. After adding the lags, we adjusted for daily average temperature (AT), daily average relative humidity (ARH), and controlled seasonal and long-term temporal trends by including a variable $strata_{t-i}$, which is a combination of year, month and day of week. Relative Risks (RR) and 95% confidence intervals (CI) of floods on the daily cases of diarrheal diseases were estimated by the models.

To compare the effects of different magnitude of floods, we detected the effects of severe floods by using the same model described above and changing $Flood_{t-i}$ into $SFlood_{t-i}$, which indicated severe flood occurred (code as 1) or not (code as 0) at i days before day t.

In the second phases, with the aim to gain insights on the time window between floods and increased risk of diarrheal diseases, we divided hazard periods into mutually exclusive time windows of 0–7 days (week 1) and 8–14 days (week 2) following the flood events. We hypothesized that effects in the first week following the flood would likely be due to direct contact with flood waters and/or infections with short incubation periods (e.g., enteric viruses), whereas as the second week could represent indirect exposure (e.g., through population displacement, drinking water, contaminated food) or infections with longer incubation periods (Carlton et al., 2014; Levy et al., 2016; Wade et al., 2014; Zhang et al., 2016).

The effects of moderate floods or severe floods on daily rate of diarrhea in these two time windows were estimated by the model 2 and model 3, respectively.

Model 2:

$$\log\left(\sum\nolimits_t^{t+7} Y_t\right) = \alpha + \text{offset}(\log(pop)) + \beta_1 Flood_t + \beta_2\, AT_t + \beta_3\, ARH_t + \beta_4\, strata_t + \epsilon$$

Model 3:

$$\log\left(\sum\nolimits_{t+8}^{t+14} Y_t\right) = \alpha + \text{offset}(\log(pop)) + \beta_1 Flood_t + \beta_2\, AT_t + \beta_3\, ARH_t + \beta_4\, strata_t + \epsilon$$

Table 1
Flood events and daily diarrhea incidence in Anhui Province, January 2013 to August 2017.

City	Population (million)[a]	Daily diarrhea cases	Daily diarrhea incidence[b]	No. of moderate floods	No. of severe floods
Anqing	4.59	17.97	3.67	65	20
Bengbu	3.29	5.23	1.59	30	1
Bozhou	5.05	5.04	0.99	14	0
Chizhou	1.44	2.96	2.06	75	20
Chuzhou	4.02	5.64	1.4	44	3
Fuyang	7.9	25.74	3.27	27	0
Hefei	7.79	62.58	8.05	33	13
Huaibei	2.18	5.39	2.48	38	20
Huainan	3.43	4.63	1.59	23	4
Huangshan	1.37	5.22	3.81	89	18
Luan	4.74	15.39	3.02	38	6
Maanshan	2.26	24.07	10.69	40	14
Suzhou	5.54	34.67	6.27	10	0
Tongling	1.59	11.08	10.01	63	21
Wuhu	3.65	17.77	4.88	50	19
Xuancheng	2.59	15.87	6.14	35	2

[a] Population in the year of 2015.
[b] Daily diarrhea incidence (per million people).

In model 2 and model 3, the cumulative number of incident diarrhea cases in a given time window (0–7 days or 8–14 days) in the specific city is the outcome, and relative risks (RR) and 95% confidence intervals (CI) of floods on diarrheal diseases for each time window in the specific city were estimated.

Data management, analyses and graphics production were performed in R version 3.4.4 using "tsModel", "Epi" and "plotrix" packages.

Ethical approval

The disease data do not contain identifiable private information, and they are completely anonymous thus informed consent was not needed. This research and all protocols were approved by Ethical Review Board of School of Public Health, Sun Yat-sen University.

3. Results

3.1. Descriptive analysis for the diarrheal disease and floods

Daily diarrhea incidence during the study period was 4.29 cases per million people in Anhui Province, and it ranged from 0.99 to 10.69 per day across the 16 cities with highest incidence in Maanshan and Tongling cities (Table 1). Fig. 2 showed the daily diarrheal cases per million people and daily precipitation in Anhui Province of China. (More information about daily diarrheal diseases in each city and daily rainfall in each city were detailed in Supplementary materials.)

As shown in Table 1, Moderate floods were most frequent in Huangshan (n = 89) and Chizhou (n = 75) cities, and severe floods were most frequent in Tongling (n = 21).

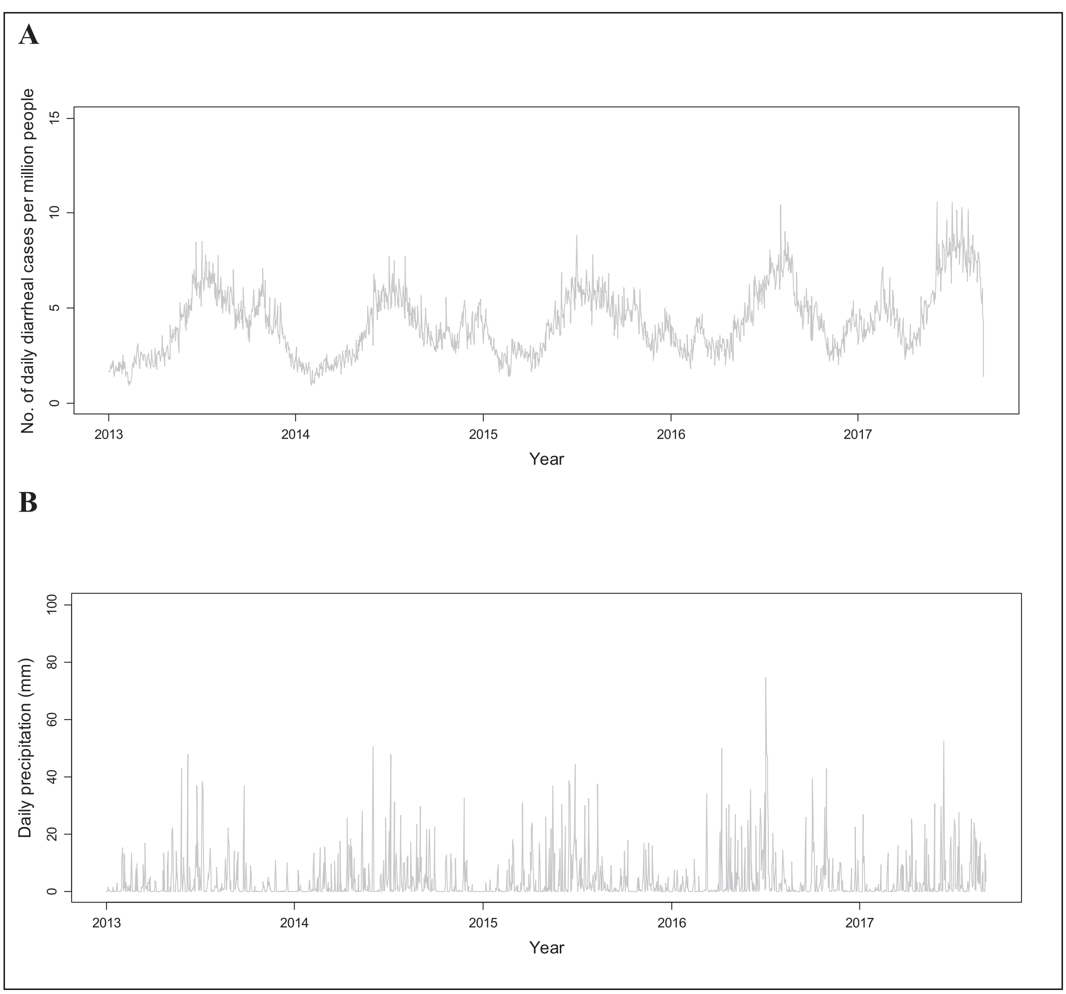

Fig. 2. Daily diarrheal cases per million people (A) and daily precipitation (B) in Anhui Province of China, January 2013 to August 2017.

3.2. Analysis for each lagged day effects after floods

RRs for each lagged day from 0 to 14 days following moderate floods by cities are illustrated in Fig. 3. Effects of moderate floods on diarrheal diseases varied by cities with the strongest associations observed in Bozhou, Bengbu, Luan and Maanshan cities. In general, moderate floods increased the risk of diarrheal diseases.

RRs for each lagged day from 0 to 14 days following severe floods by 12 cities are illustrated in Fig. 4. Effects of floods varied by cities with the strongest associations observed in Luan and Chuzhou cities. In general, severe floods also increased the risk of diarrheal diseases.

3.3. Week 1 and week 2 effects of floods

According to the estimated Risk Ratios (RRs) for hazard period week 1 (0–7 days) and week 2 (8–14 days), both moderate floods and severe floods significantly increased diarrhea risks in general (RRs > 1.00 in 10 of 16 cities, $p < 0.05$). Especially in the week 1, moderate floods have a RR of 1.05 (95% CI: 1.02–1.09) and severe floods have a RR of 1.04 (95% CI: 1.02–1.09) at the provincial level. The impacts of flooding on diarrheal diseases varied in the different cities. Regarding to effects of moderate floods on diarrheal diseases within 7 days, RRs ranged from 1.06 to 1.51 in 8 of 16 cities ($p < 0.05$). Immediate effect pattern, namely "one-week effect" was observed in more than half of all cities (9/16) within 7 days after both a moderate flood and severe flood In the first week after floods, moderate floods lead to a RR of 1.51 (95% CI: 1.29–1.78) in Bozhou, and severe floods had a RR = 1.31 (95% CI: 1.05–1.64) in Chuzhou (Table 2). The evaluation of goodness-of-fit of 64 models for 16 cities was shown in Supplementary materials Fig. S3.

There were less significant effects appeared in the second week after floods, and a relatively longer lagged effect was observed after the moderate floods. It seems that severe floods brought higher risks of diarrheal diseases in the first week compared with moderate flood in Anqing (RR 1.10 vs 1.06), Chuzhou (RR 1.31 vs 1.07), Huaibei (RR 1.16 vs 1.07) and

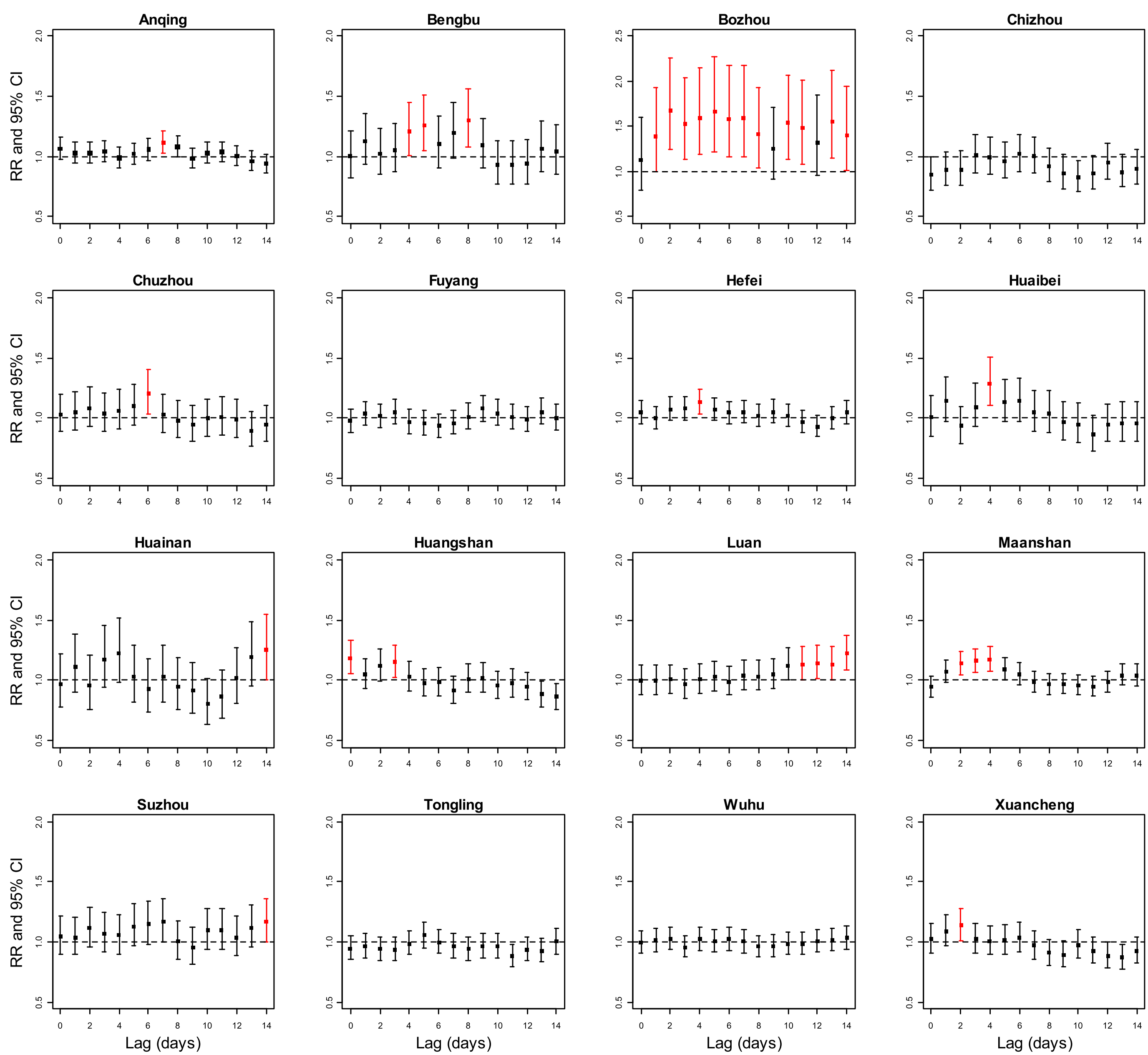

Fig. 3. RR estimates of the moderate floods on the risk of diarrhea in different lagged days in Anhui Province, China (lag0–14).

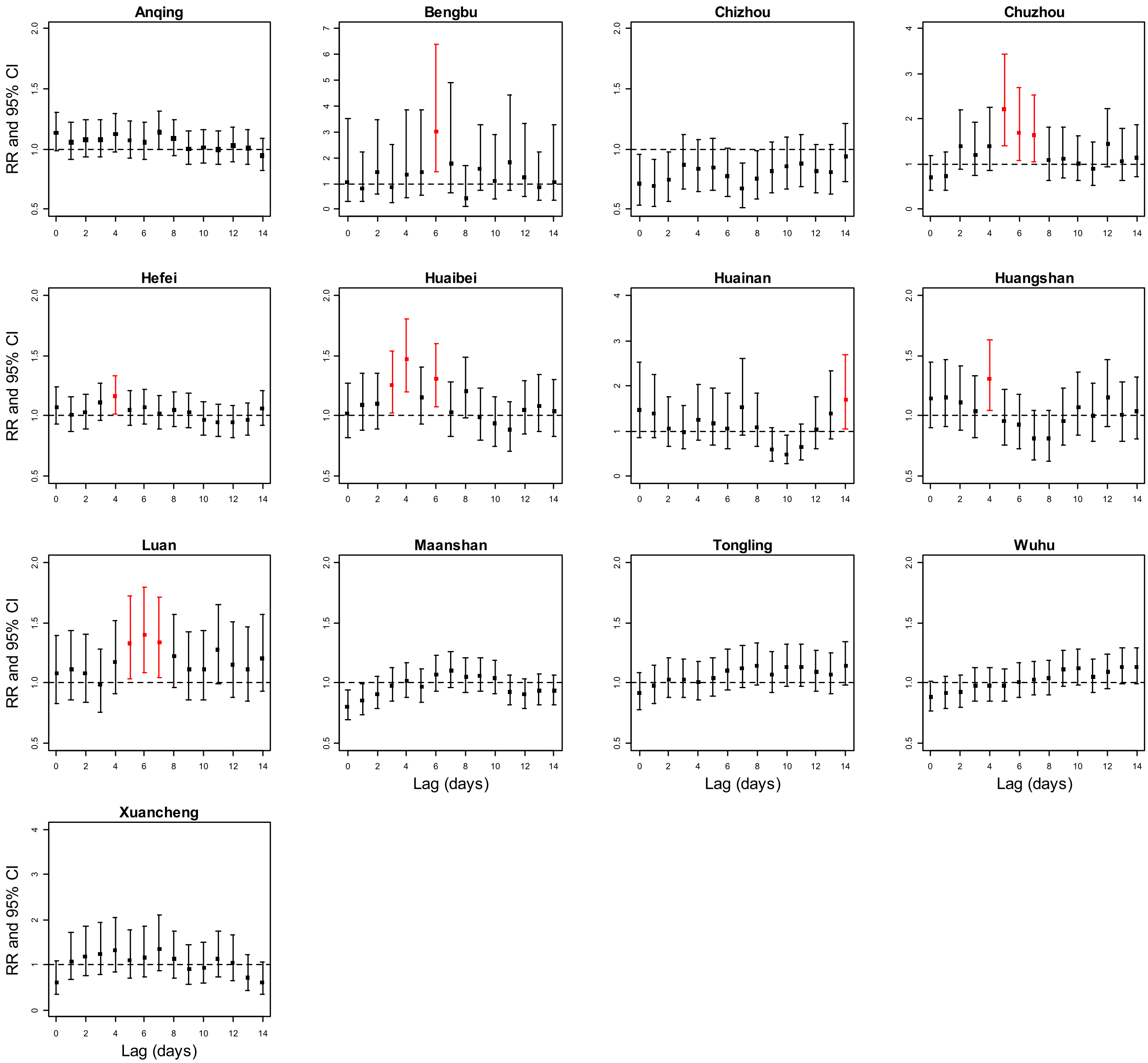

Fig. 4. RR estimates of the severe floods on the risk of diarrhea in different lagged days in Anhui Province, China (lag0–14).

Luan (RR 1.18 vs 1.00) cities. Both moderate and severe floods showed negative effects (RRs < 0.8, $p < 0.05$) on diarrheal diseases in Chizhou city unexpectedly (Table 2).

4. Discussion

Floods can directly affect transport of pathogens, and can affect the flow of water and sanitation treatment infrastructure, altering human exposure patterns even with population displacement. Our study found that both moderate floods and severe floods significantly increased diarrhea risks in most cities of Anhui province, China. Immediate effect patterns, namely "one-week effect" was observed in many cities just within 7 days after both a moderate flood and severe flood, and less significant effects appeared in the second week after floods. We also found that impacts of flooding on diarrheal diseases varied in the different cities with different lagged days. It seems that severe floods brought higher risks of diarrheal diseases in the first week compared with moderate floods. These findings gave insights to better understanding the very short-term public health risks of floods with different severities.

Floods mainly showed significantly positive effects on diarrhea incidence in our study. This is consistent with main findings of a few previous studies in China (X. Liu et al. 2016; Liu et al., 2018; Z.D. Liu et al. 2016). Internationally, the systematic review work showed a significant positive association between flooding and diarrhea was found in most of the studies in which conducted quantitative analyses to evaluate all-cause diarrheal diseases (Cann et al., 2013; Levy et al., 2016). Flooding can directly change transport of different pathogens, such as *E. coli* (Alexander et al., 2018), and can affect the existing water and sanitation infrastructure, altering the patterns of individual exposure, then increase the risks of getting people infected (Cann et al., 2013; de Man et al., 2014). Contacts with flood waters and flood contaminated items can be fairly frequent during the flooding periods. Pathogen-specific transmission pathways and host exposure and infection dynamics interact in particular ways with environmental and socio-ecological factors to influence the diarrheal disease incidence. Alexander et.al

Table 2
Short-term effects (0–14 days) of moderate floods and severe floods on diarrheal diseases in Anhui Province.[a]

City	Week 1 (0–7 days)				Week 2 (8–14 days)			
	Moderate floods		Severe floods		Moderate floods		Severe floods	
	RR	95% CI	RR	95% CI	RR	95% CI	RR	95% CI
Anqing	**1.06**	**(1.01, 1.12)**	**1.10**	**(1.01, 1.20)**	**1.06**	**(1.00, 1.13)**	1.04	(0.94, 1.15)
Bengbu	**1.12**	**(1.03, 1.24)**	1.43	(0.94, 2.18)	1.03	(0.95, 1.13)	1.13	(0.73, 1.75)
Bozhou	**1.51**	**(1.29, 1.78)**	–	–	**1.40**	**(1.15, 1.72)**	–	–
Chizhou	0.92	(0.84, 1.01)	**0.75**	**(0.64, 0.89)**	**0.79**	**(0.70, 0.89)**	**0.77**	**(0.64, 0.93)**
Chuzhou	**1.07**	**(1.00, 1.15)**	**1.31**	**(1.05, 1.64)**	0.96	(0.88, 1.04)	1.10	(0.84, 1.44)
Fuyang	1.00	(0.94, 1.06)	–	–	1.05	(0.99, 1.12)	–	–
Hefei	**1.09**	**(1.02, 1.16)**	1.08	(0.98, 1.19)	1.06	(0.97, 1.15)	1.01	(0.89, 1.15)
Huaibei	1.07	(0.98, 1.16)	**1.16**	**(1.04, 1.30)**	0.93	(0.84, 1.03)	1.02	(0.89, 1.16)
Huainan	1.04	(0.91, 1.18)	1.19	(0.89, 1.59)	0.95	(0.81, 1.13)	0.88	(0.59, 1.31)
Huangshan	1.04	(0.99, 1.10)	1.05	(0.94, 1.17)	0.95	(0.89, 1.01)	1.00	(0.88, 1.13)
Luan	1.00	(0.93, 1.08)	**1.18**	**(1.01, 1.38)**	**1.13**	**(1.03, 1.24)**	1.18	(0.97, 1.44)
Maanshan	**1.10**	**(1.04, 1.16)**	0.97	(0.89, 1.06)	1.03	(0.97, 1.10)	0.98	(0.89, 1.08)
Suzhou	**1.10**	**(1.00, 1.21)**	–	–	1.09	(0.98, 1.21)	–	–
Tongling	0.98	(0.93, 1.03)	1.03	(0.95, 1.12)	0.94	(0.89, 1.00)	**1.11**	**(1.01, 1.22)**
Wuhu	1.02	(0.96, 1.08)	0.96	(0.88, 1.05)	0.99	(0.92, 1.06)	1.09	(0.99, 1.21)
Xuancheng	1.04	(0.93, 1.17)	1.12	(0.72, 1.73)	0.90	(0.79, 1.03)	0.90	(0.53, 1.52)
Total[b]	**1.05**	**(1.02, 1.09)**	**1.04**	**(1.01, 1.08)**	1.00	(0.96, 1.05)	1.03	(0.99, 1.07)

[a] Numbers in bold indicate $p < 0.05$.
[b] Meta-analysis for flood effects in all cities in Anhui Province.

illustrated schematic of linked processes across the aquatic-terrestrial interface in a flood pulse river (Alexander et al., 2018). Levy and colleagues also presented a conceptual diagram trying to illustrate mechanisms by heavy rainfall events and flooding expected to be impacted by climate change could potentially lead to positive relationships (Levy et al., 2016). Both biophysical and behavioral explanatory mechanisms were involved in the framework to explain these positive relationships, as a way to show the overall trends concluded in the systematic review.

Variation in the association between flooding and diarrhea incidence was observed across the 15 cities. The effects differed across 15 cities in Anhui province, strongly suggesting local variations in the diarrheal diseases risk of flooding. It seems more vulnerable to floods in Anqing, Chuzhou and Luan cities with the highest RRs for diarrhea incidence. But in Chizhou cities, a negative effect of floods was observed. The causes for local variations are not studied in this research, but may be affected by the variability in diarrhea pathogens exposure, the different nature of floods in different cities, the regional population size and structure, the watersheds affected, and the extent of contamination and impacts on communities, fundamental sanitation infrastructure, drinking water treatment and public health interventions (Cann et al., 2013; Levy et al., 2016). During the period after flood, the risk of noncholera diarrhea was significantly higher for population with lower educational level, more frequently drinking tube-well water (vs tap water), receiving a distant water source, living in households with unsanitary toilets and nonconcrete roofs in Bangladesh (Hashizume et al., 2008). The low socio-economic groups, poor hygiene and sanitation groups were more vulnerable to flood-related diarrheal diseases (Hashizume et al., 2008).

We found that the hazard period for diarrheal diseases was mainly in the first week after floods. In another previous study, positive associations were demonstrated between flood days and diarrhea incidence in in northwest of Anhui province, China. The strongest effect was shown with a 2-day lag in Fuyang and a 5-day lag in Bozhou (Ding et al., 2013). It was also demonstrated that floods were positively associated with bacillary dysentery within the first week but not the hand-foot-mouth disease and other infectious diarrhea in Qingdao, China (Zhang et al., 2016). Immediate effects within the first week hazard period could be consistent with potential contacts with pathogen contaminated water immediately or very soon after the flood events (Wade et al., 2014). Since the associations were more evident in the first week after flooding in most of the studied cities, this observation may implicate infections by organisms with relatively short incubation period (e.g., enteric viruses) and direct contact with contaminated waters. A 1-week lag is consistent with the incubation periods of common diarrheal pathogens and a 2-week lag would account for secondary transmission of pathogens within the neighborhood and among residents, but lags beyond 2 weeks seems not to be biologically meaningful for the diarrheal diseases (Carlton et al., 2014). Outbreaks of diarrheal diseases are common just following floods, most notably in underdeveloped areas, often caused by waterborne pathogens, such as Vibrio cholerae (Schwartz et al., 2006). Because the pathogens data of diarrheal diseases are unavailable to us, it is unable to examine the different patterns of viral and bacterial diarrhea following the flooding. The mechanisms of viral and bacterial pathogens resulting infectious diarrhea could be different, so it is interesting to explore the seasonal patterns, peaks of different viral and bacterial diarrheal diseases in the next.

This study has identified a larger effect of severe floods on infectious diarrhea compared with the moderate ones. But a relatively longer lagged effect was observed after the moderate floods. Floods can break down water and exacerbate sanitation systems, causing backflows that lead to contamination of groundwater and other drinking water sources. Severe flooding can also lead to population displacement, displacing populations to temporary or permanent communities with inadequate infrastructure, promoting the intake of contaminated drinking water (Alderman et al., 2012). Therefore, severe floods create more chances for residents than those in moderate floods to contact with floodwater, and flooded items. This was cited as an explanation for the highly elevated diarrhea and cholera rates observed in Bangladesh after a severe flood (Hashizume et al., 2008). Evidence of dose-response effect related to explicit contact with floodwaters was noted in previous studies, including flooding explicitly in the subject's house or yard (Wade et al., 2004), increasing association with increasing flood depth (Reacher et al., 2004), explicit skin contact with floodwater (Schnitzler et al., 2007).

This study evidently found that both moderate and severe flooding can increase risk of diarrheal diseases. These findings have implications for areas of the world that are expected to experience higher variability in precipitation, and extreme heavy rainfall in the future. Extreme rainfall events such as 100-year floods, which are also predicted to increase under future climate scenarios (IPCC, 2013, 2014). More and more evidence suggests that the changing climate may alter the incidence of waterborne diseases, and especially the diarrheal diseases (Levy et al., 2018). Cann et al. reviewed extreme water-related weather events and waterborne disease outbreaks and found that in both developing and developed countries, the most common cause of outbreaks was contamination of the water source through flooding (52.9% of studies). In developing countries this was usually associated with untreated water, while in developed countries, this was associated with contamination of a treated water source in the majority of all cases (Cann et al., 2013).

Therefore, the adaptation strategies should be localized. Many environmental, social components and human factors can modify the associations between diarrheal diseases and flooding, through impacting pathogen exposure, host susceptibility, and the local community's ability to respond to the risks. Developing the public health interventions and strategies should take all the above factors into considerations (Levy et al., 2018). It is urgent to understand these social and environmental modifying factors within the communities.

We should pay more attention to the hazard period of diarrheal diseases, namely the first week just after the flooding. It may implicate that infections by pathogens and organisms are relatively in short incubation period and direct contact with contaminated waters. Public health interventions and infrastructures, like flood control infrastructure, sanitation/wastewater systems, hygiene education, drinking water treatment system and drinking water treatment at the point of use are essential during the short period after floods (Jenkins et al., 2017; Levy et al., 2016). Although this is an observational study, such associations we found could generate a better understanding of the short-term effects of floods overall and other relevant extreme weather events potentially altered by climate change, and help the government authority and the general public make appropriate public health response.

Our study has some limitations should be addressed as follows. Firstly, this may be an underestimate of the total impacts of flooding. Data was extracted from the National Notifiable Disease Surveillance System (NDSS), which are the patients visited the hospitals and being reported by the clinicians. Some diarrheal illnesses are usually not severe enough to require immediate medical treatments and hospital seeking behaviors. Furthermore, the actual number of pathogens affected population may be larger, because asymptomatic carriers of diarrheal diseases were not recorded in the report system. In spite of the limitations of this measurement of diarrheal diseases, we observed increased diarrhea incidence 0–7 days following a flood. Secondly, many factors may modify the associations between diarrheal diseases and flooding. We lacked consistent detailed information on the flood events, and were unable to study the mechanisms involved the exposure-disease response relationships. Future research work could focus on determining the factors influencing the relationship between diarrheal diseases and flooding by specifically focusing on the nature of watersheds and community vulnerability, and the potential types of exposure pathways regarding how flooding events increase health risk and how these risks could be reduced by relevant interventions. Finally, there should be cautious in interpreting the findings because of the ecological nature of this study, and individual level factors, such as individual exposure evaluation, response behaviors, and other potential factors e.g. socioeconomic status, availability of health services etc. had not been included in this study.

5. Conclusion

Floods as the most pervasive hydro-meteorological disaster affect the billions of people in the world, which are expected to increase under climate change posing more severe threats to the global health. Our study has quantified that both moderate and severe flooding can significantly increase the risks of diarrhea within a short period - only one week after floods. Regionally varied effects of floods on diarrheal diseases could be linked to population size/density of city, sanitation index, local infrastructure and city planning. In addition, a severe flooding may bring higher risks of diarrheal diseases than a prolonged and moderate flooding. Our findings have significant implications for emergent responses to prevent and reduce public health risks in the hazard periods of floods.

Competing financial interests

The authors declare no competing financial interests.

Ethics statement

The disease data do not contain identifiable private information, and they are completely anonymous thus informed consent was not needed. This research and all protocols were approved by Ethical Review Board of School of Public Health, Sun Yat-sen University.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.scitotenv.2019.04.248.

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