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Short-term impacts of floods on enteric infectious disease in Qingdao, China, 2005–2011

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SUMMARY

The current study aimed to examine the relationship between floods and the three enteric infectious diseases, namely bacillary dysentery (BD), hand-foot-mouth disease (HFMD) and other infectious diarrhoea (OID) in Qingdao, China. Relative risks (RRs) and 95% confidence intervals (CIs) of floods on BD, HFMD and OID were calculated using a quasi-Poisson generalized linear model, adjusting for daily average temperature, daily average relative humidity, and seasonal and long-term temporal trends. Two separate models within two different periods were designed. Model 1 for the summer period showed that floods were positively associated with BD for 4- to 12-day lags, with the greatest effects for 7-day (RR 1·41, 95% CI 1·22–1·62) and 11-day (RR 1·42, 95% CI 1·22–1·64) lags. Similar findings were found in model 2 for the whole study period for 5- to 12-day lags. However, HFMD and OID were not significantly associated with floods in both models. Results from this study will provide insight into the health risks associated with floods and may help inform public health precautionary measures for such disasters.

Key words: Bacillary dysentery, floods, hand-foot-mouth disease, other infectious diarrhoea, Poisson generalized linear model.

INTRODUCTION

Natural hazards, including floods, storms, typhoons and earthquakes, have posed great threats to human lives and property in recent decades. Of these, floods are considered to be the most serious and devastating type of natural disaster globally [1, 2]. In 2010, for example, floods affected 178 million people and led to losses of more than US$40 billion worldwide [3]. The Intergovernmental Panel on Climate Change projects that the areas affected by monsoon precipitation will increase over the 21st century, and that this will cause or amplify flood events [4]. Shandong Province, a coastal area in eastern China, experienced several floods from 2005 to 2011, with hundreds of people killed and millions more affected [5–11].

Floods have immediate and direct impacts on human health during the initiation phase, with people not only drowning but also experiencing heart attacks, various injuries and hypothermia. Further indirect impacts occur as the floodwaters recede, including water-borne infectious diseases, mental health disorders, respiratory diseases and allergies, and these should also be considered as significant effects [2]. The term ‘enteric infection’ describes a group of

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diseases caused by various bacterial, viral and parasitic organisms. The major infectious agents are mainly transmitted by the faecal–oral route, often via contaminated water. Several studies have shown that exposure to floods can be associated with high contamination of surface- or groundwater sources, with raw sewage flushed out alongside the deluge of flood waters [12, 13]. Subsequent transmission of enteric pathogens can then occur, with risk factors including inadequate access to potable water for drinking and washing, poor sanitation caused by the disruption of sanitation infrastructure, displacement of people and sustained exposure to a contaminated environment [13]. Post-flood outbreaks of enteric infectious diseases are common in both developing and developed countries. For example, a community-based case-control study conducted in Indonesia revealed that flooding was a major risk factor for increased paratyphoid prevalence [comparison with community controls: odds ratio (OR) 4·52, 95% confidence interval (CI) 1·90–10·73] [14]. In Mozambique, the incidence of endemic diarrhoea increased following flooding in 2000, due to a deterioration in water quality during the event [15]. Another study from UK also found that individuals exposed to floods had a higher risk of gastroenteritis [16].

Although previous studies have found a high risk of enteric infection following floods, there is a lack of systematic research quantifying the association between flooding and infection in China. Qingdao is a coastal city located in the northeast region of Shandong Province. More than 70% of the total water supply in Qingdao is obtained from local groundwater and surface-water sources [17]. Excessive precipitation during flooding may pollute local drinking-water sources. Therefore, this study aimed to explore the association between floods and enteric infectious disease in Qingdao, Shandong Province, China.

METHODS

Study area

Figure 1 shows the geographical location of Qingdao in Shandong Province. Qingdao is located between longitude 119° 30′–121° 00′ E and latitude 35° 35′–37° 09′ N, and covers an area of ~11 282 km^2. The registered population was 9·04 million in 2015. Qingdao has a typical temperate continental monsoon climate, with an annual average temperature (T_{av}) of 12·7 °C and annual average rainfall of 662·1 mm. There are three water systems in Qingdao: the Dagu River, the Northern Jiaolai River and coastal rivers. The main source of all three systems is rainfall.

Data collection

Disease surveillance

Bacillary dysentery (BD), hand-foot-mouth disease (HFMD) and other infectious diarrhoea (OID) are the three predominant notifiable enteric infectious diseases in Qingdao; the other six species of gastrointestinal disease (i.e. cholera, hepatitis A, hepatitis E, typhoid and paratyphoid fever, poliomyelitis, and acute haemorrhagic conjunctivitis) are quite rare [18–20]. Therefore, this study only examined the impact of floods on BD, HFMD and OID.

Daily disease surveillance data on BD, HFMD and OID from 2005 to 2011 in Qingdao were obtained from the Shandong Center for Disease Control and Prevention (CDC). HFMD was made statutorily notifiable in 2008, therefore the study period for this disease covered only 4 years (2008–2011) [21]. In China, the surveillance system for notifiable infectious diseases is mainly hospital based. Hospitals at the county level or above are equipped with reference laboratories that are capable of carrying out molecular surveillance. These hospitals form the front line of surveillance for the detection and notification of infectious disease outbreaks in China, combined with laboratories at academic institutions. There are currently 39 notifiable infectious diseases in China, which are classified as A, B or C according to their epidemic level and potential population threat [22]. BD is categorized as a class B notifiable communicable disease, while HFMD and OID are categorized as class C. Class B represents diseases with a high risk of outbreak or that are likely to spread rapidly once an outbreak has occurred, while class C diseases are epidemiologically less severe during outbreaks [22]. According to the measures for administration of public health emergencies and communicable disease monitoring information reporting, all hospitals and clinics are obliged to report every case of class B and C notifiable communicable diseases to their nominated CDC within 24 h through the Direct Network Report system [23]. A recent study showed that the CDC reports were of high quality, with 99·84% completeness and 92·76% accuracy [24]. The information collected includes the patient's address,

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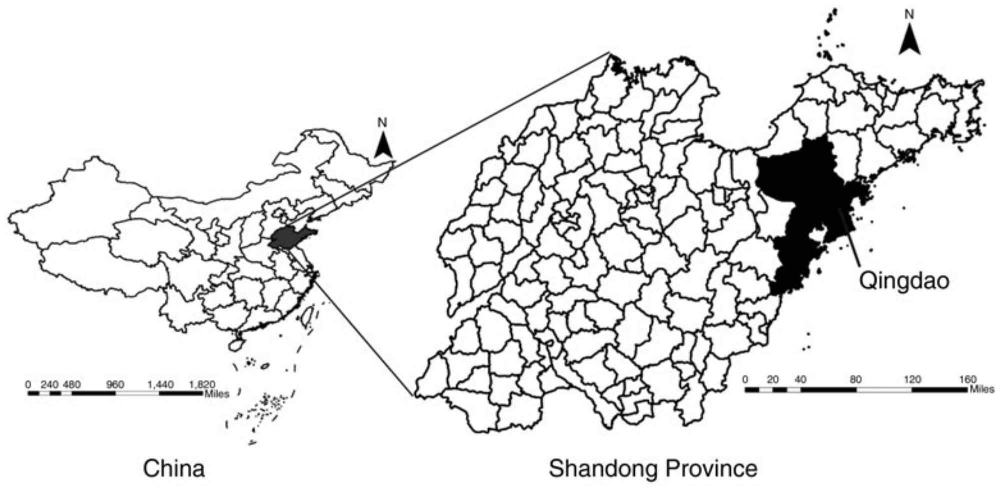

Fig. 1. Location of Qingdao in Shandong Province, China.

reporting unit/hospital, age, sex, name of disease, classification of disease and date of morbidity. We selected patients residing in Qingdao according to their address or the reporting unit/hospital. The date of morbidity was used to calculate the daily case count.

All cases of notifiable communicable diseases were diagnosed according to the unified diagnostic criteria issued by the Chinese Ministry of Health. Only cases that were confirmed clinically and by laboratory tests were included in our study. The diagnostic criteria for the three enteric infectious diseases are as follows:

(1) *Clinical diagnosis of BD*. An enteric infectious disease with fever, stomach-ache, diarrhoea, tenesmus and bloody mucopurulent stool; *laboratory diagnosis*: cultivation of faeces for *Shigella* [25].
(2) *Clinical diagnosis of HFMD*. An infectious gastrointestinal disease with fever, vesicles and sores in the mouth and on the palms, soles and buttocks, with or without neurological abnormalities such as meningitis, encephalitis, and polio-like paralysis [26]; *laboratory diagnosis*: with enterovirus infection (including EV71, CAV16 or other non-EV71 and non-CAV16 enteroviruses) detected by reverse transcriptase–polymerase chain reaction (RT–PCR), real-time RT–PCR, or virus isolation [21].
(3) *Clinical diagnosis of OID*. A group of diseases caused by a variety of causative agents, such as rotavirus, *Salmonella, Vibrio parahaemolyticus and Escherichia coli*, and excluding *Vibrio cholerae, Shigella* and *Amoeba*, as well as *Salmonella typhi* and *Salmonella paratyphi*, with typical clinical symptoms of watery, bloody or mucus stool on more than three occasions per day, with or without dehydration, shock and haemolytic uraemic syndrome [27]; *laboratory diagnosis*: cultivation of faeces for relevant pathogens.

Flood events

Data on floods from 2005 to 2011 were collected from the Yearbooks of Meteorological Disasters in China [5–11]. The extent and intensity of floods, as well as the damage to the population, crops and economy ascribed to one specific event, are approximately described in the book. According to the Comprehensive Study Group of Major Natural Disasters of the State Science and Technology Commission in China, a flood is an overflow of surface runoff that submerges towns and farmland [12]. Qingdao experienced 18 floods from 2005 to 2011, which affected hundreds of hectares of crops (Table 1). Because all of the floods were described as city-wide and no information was provided about the specific county or towns affected, all areas of the city were considered to be exposed when a specific flood occurred.

Meteorological data

Daily meteorological data from 2005 to 2011 were obtained from the China Meteorological Data Sharing Service System (http://cdc.nmic.cn/home.do). Meteorological variables included daily T_{av}, daily average relative humidity (RH_{av}), and daily rainfall.

Statistical analysis

We examined the short-term effects of floods on three enteric infectious diseases within two different periods:

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Table 1. *Description of 18 floods from 2005 to 2011 in Qingdao*

Flood no.	Year	Date	Duration (days)	Rainfall (mm)
1	2005	3–5 Aug.	3	50–100
2	2005	7–9 Aug.	3	50–150
3	2005	12–13 Sept.	2	50–100
4	2005	19–21 Sept.	3	50–100
5	2005	28–30 Sept.	3	50–100
6	2006	25–26 Aug.	2	440
7	2007	27 June	1	150
8	2007	19 July	1	50–100
9	2007	10–12 Aug.	3	50–250
10	2007	19–20 Sept.	2	50–200
11	2008	18–20 July	3	50–200
12	2008	23–24 July	2	50–200
13	2008	31 Aug.	1	50–100
14	2009	9 July	1	50–100
15	2009	12–14 July	3	50–100
16	2010	2 July	1	50–100
17	2010	26–28 Aug.	3	50–100
18	2011	2–3 July	2	50–150

summer (April–September) and the whole study period from 2005 to 2011. The reason we chose summer was that all floods and nearly 90% of enteric infection cases occurred during this period. Subsequent analysis through the entire year was performed to verify our results.

We first performed descriptive analyses of the distribution of daily cases and meteorological factors during both periods. Second, relative risks (RRs) and 95% CIs of the flood effects on BD, HFMD and OID were derived by using a quasi-Poisson generalized linear model to allow for over-dispersion in the case count. Meteorological variables that might influence the incidence of enteric infectious diseases were included in the model. Several studies have explored the associations between diarrhoeal diseases and climate variation such as temperature, rainfall and relative humidity. These variables could directly affect the rate of replication of bacterial and viral pathogens, and the survival of such pathogens in the environment [28, 29]. Because of the collinearity between flood and daily rainfall, only T_{av} and RH_{av} were adjusted, using two smooth functions of natural spline with three degrees of freedom (D.F.).

We designed two models for the two periods: model 1 for summer and model 2 for the whole study period from 2005 to 2011. In the raw data, long-term patterns including seasonality were likely to dominate the daily case count. As our interest was in short-term associations, the aim was to remove (i.e. control for) these long-term patterns, and to see whether the exposure of interest (i.e. flood) could explain some of the remaining short-term variation. One possible strategy to control for long-term patterns is to fit a spline function of time [30]. In model 1, two natural splines for the day of the year (D.F. = 4) and time (D.F. = 3) were incorporated to control for seasonality and long-term trends [28]. In model 2, seasonality and long-term trends were controlled by a natural spline for time (7 D.F. per year) [31]. The week effect was controlled by an indicator of the day of the week, with a reference of Sunday in both models. Akaike's Information Criterion and analysis of residuals were used to assess the model fit, and to check the autocorrelation of the models. Considering the incubation period of enteric infectious diseases, a lagged effect up to 14 days was assessed [32]. The regression models were described as follows:

Model 1

$$\begin{aligned}\log[E(Y_t)] = \beta_0 &+ \beta_1(\text{floodlag}_{1-14}) \\ &+ \text{ns}(T_{\text{av}}\text{lag}_{1-14}, \text{D.F.} = 3) \\ &+ \text{ns}(\text{RH}_{\text{av}}\text{lag}_{\,1-14}, \text{D.F.} = 3) \\ &+ \text{ns}(\text{doy}, \text{D.F.} = 4) + \text{ns}(t, \text{D.F.} = 3) \\ &+ \text{dow}.\end{aligned}$$

Model 2

$$\begin{aligned}\log[E(Y_t)] = \beta_0 &+ \beta_1(\text{floodlag}_{1-14}) \\ &+ \text{ns}(T_{\text{av}}\text{lag}_{1-14}, \text{D.F.} = 3) \\ &+ \text{ns}(\text{RH}_{\text{av}}\text{lag}_{\,1-14}, \text{D.F.} = 3) \\ &+ \text{ns}(t, \text{D.F.} = 7/\text{year}) + \text{dow},\end{aligned}$$

where $E(Y_t)$ denotes daily cases of BD, HFMD and OID at time t, with t equal to the day from 1 January 2005 to 31 December 2011 (from 1 to 2556); β_0 represents the intercept; floodlag represents flooded and non-flooded days using a dummy variable (1 and 0); T_{av}lag and RH_{av}lag represent daily T_{av} and RH_{av}, respectively; doy represents the day of the year and ns denotes a natural spline function with corresponding D.F..

All statistical analyses were performed using R v. 3.1.1 (The R Project for Statistical Computing, Vienna, Austria).

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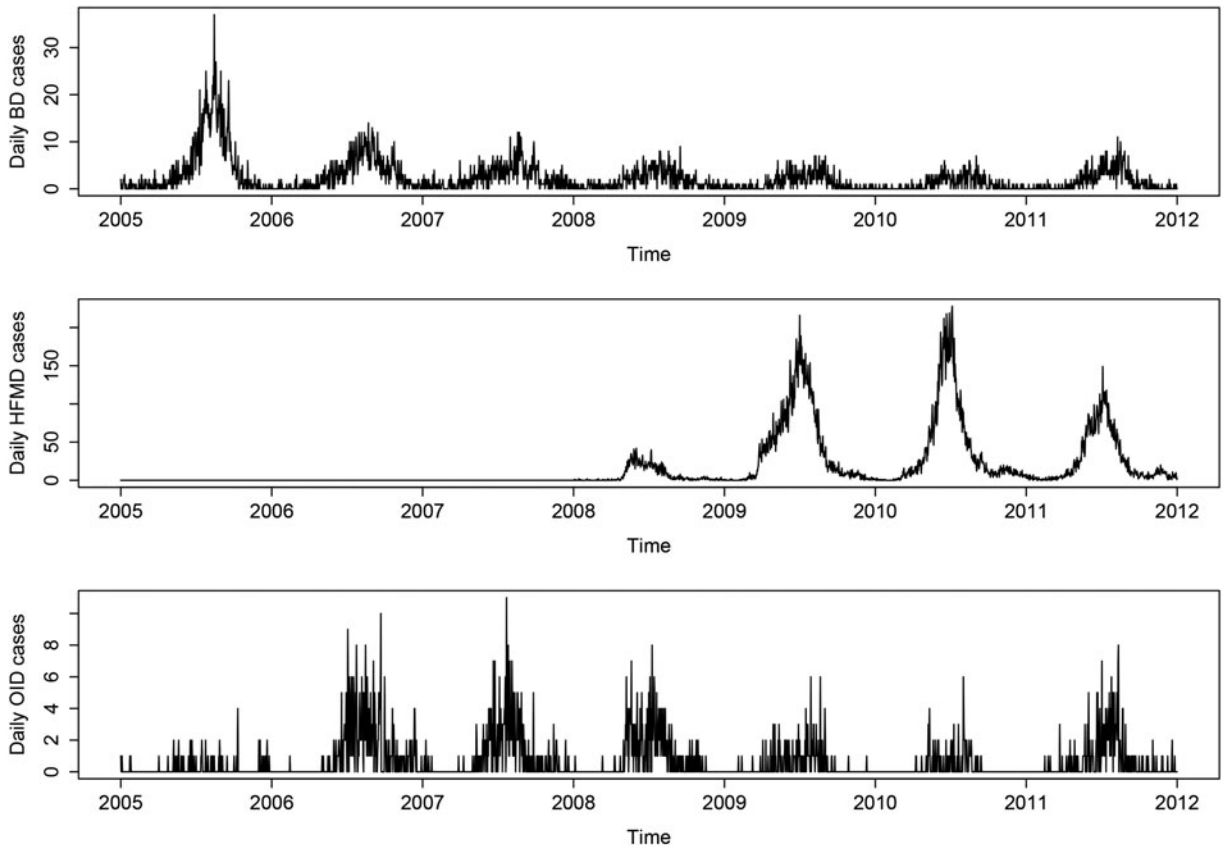

Fig. 2. Daily incidence of enteric infectious disease in Qingdao, 2005–2011. BD, Bacillary dysentery; HFMD, hand-foot-mouth disease; OID, other infectious diarrhoea.

Table 2. *Description of daily enteric infectious diseases and meteorological factors during two periods in Qingdao, 2005–2011*

	Summer						Whole study period					
Variable	Mean ± s.d.	Min	P_{25}	Median	P_{75}	Max	Mean ± s.d.	Min	P_{25}	Median	P_{75}	Max
Daily BD cases	3·76 ± 4·05	0·0	1·0	3·0	5·0	37·0	2·25 ± 3·35	0·0	0·0	1·0	3·0	37·0
Daily HFMD cases*	52·72 ± 49·91	0·0	15·0	33·5	79·0	228·0	28·66 ± 42·94	0·0	2·0	9·0	35·0	228·0
Daily OID cases	1·08 ± 1·60	0·0	0·0	0·0	2·0	11·0	0·62 ± 1·27	0·0	0·0	0·62	1·0	11·0
Rainfall (mm)	3·89 ± 14·48	0·0	0·0	0·0	0·4	241·2	2·23 ± 10·57	0·0	0·0	0·0	0·0	241·2
T_{av} (°C)	20·18 ± 5·19	4·7	17·0	21·5	24·3	29·0	13·16 ± 9·34	−8·8	4·9	14·4	21·6	29·0
RH_{av} (%)	76·74 ± 15·85	25·0	67·0	81·0	89·0	100·0	69·76 ± 17·19	22·0	56·0	71·0	84·0	100·0

s.d., Standard deviation; Min, minimum; P_{25}, 25th percentile; P_{75}, 75th percentile; Max, maximum; BD, bacillary dysentery; HFMD, hand-foot-mouth disease; OID, other infectious diarrhoea; T_{av}, daily average temperature; RH_{av}, daily average relative humidity.
* From 2008 to 2011.

RESULTS

Disease characteristics and meteorological data

Figure 2 shows a distinct seasonal distribution of the three enteric infectious diseases. In summer, a total of 4812 BD cases, 38 588 HFMD cases and 1388 OID cases were notified by local hospitals, accounting for 83·7%, 92·2% and 88·0%, respectively, of the total reported cases throughout the whole period from 2005 to 2011 (from 2008 to 2011 for HFMD). Table 2 shows the distributions of the three enteric infectious diseases and meteorological factors for the two different periods. There were some variations in these variables during the two periods. The number of

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Table 3. *Flood parameters on the risk of bacillary dysentery in a generalized linear model during two periods in Qingdao, 2005–2011*

	Summer					Whole study period				
Lag (days)	Estimate	S.E.	z	P	RR (95% CI)	Estimate	S.E.	z	P	RR (95% CI)
Lag 0	0·02	0·08	0·23	0·821	1·02 (0·87–1·19)	−0·09	0·07	−1·30	0·194	0·91 (0·79–1·05)
Lag 1	−0·04	0·08	−0·51	0·608	0·96 (0·82–1·13)	−0·15	0·07	−2·06	0·039	0·86 (0·75–0·99)
Lag 2	−0·10	0·09	−1·21	0·227	0·90 (0·76–1·07)	−0·21	0·07	−2·86	0·004	0·81 (0·70–0·94)
Lag 3	0·06	0·08	0·73	0·467	1·06 (0·91–1·24)	−0·06	0·07	−0·80	0·424	0·95 (0·82–1·08)
Lag 4	0·22	0·08	2·83	0·005	1·24 (1·07–1·45)	0·10	0·07	1·54	0·123	1·11 (0·97–1·27)
Lag 5	0·23	0·08	3·05	0·002	1·26 (1·09–1·47)	0·14	0·07	2·04	0·042	1·15 (1·01–1·30)
Lag 6	0·33	0·07	4·45	0·000	1·39 (1·20–1·60)	0·24	0·06	3·67	0·000	1·27 (1·12–1·44)
Lag 7	0·34	0·07	4·69	0·000	1·41 (1·22–1·62)	0·26	0·06	4·00	0·000	1·29 (1·14–1·46)
Lag 8	0·31	0·07	4·11	0·000	1·36 (1·17–1·57)	0·20	0·07	3·08	0·002	1·23 (1·08–1·39)
Lag 9	0·28	0·08	3·77	0·000	1·33 (1·15–1·54)	0·19	0·07	2·90	0·004	1·21 (1·06–1·38)
Lag 10	0·32	0·07	4·28	0·000	1·38 (1·19–1·60)	0·22	0·07	3·39	0·001	1·25 (1·10–1·42)
Lag 11	0·35	0·08	4·61	0·000	1·42 (1·22–1·64)	0·25	0·07	3·78	0·000	1·28 (1·13–1·46)
Lag 12	0·25	0·08	3·09	0·002	1·28 (1·10–1·50)	0·17	0·07	2·43	0·015	1·18 (1·03–1·35)
Lag 13	0·07	0·09	0·81	0·419	1·07 (0·90–1·27)	0·00	0·07	0·07	0·947	1·00 (0·87–1·16)
Lag 14	0·09	0·09	1·00	0·316	1·09 (0·92–1·30)	0·03	0·07	0·48	0·634	1·04 (0·90–1·19)

RR, Relative risk; CI, confidence interval.

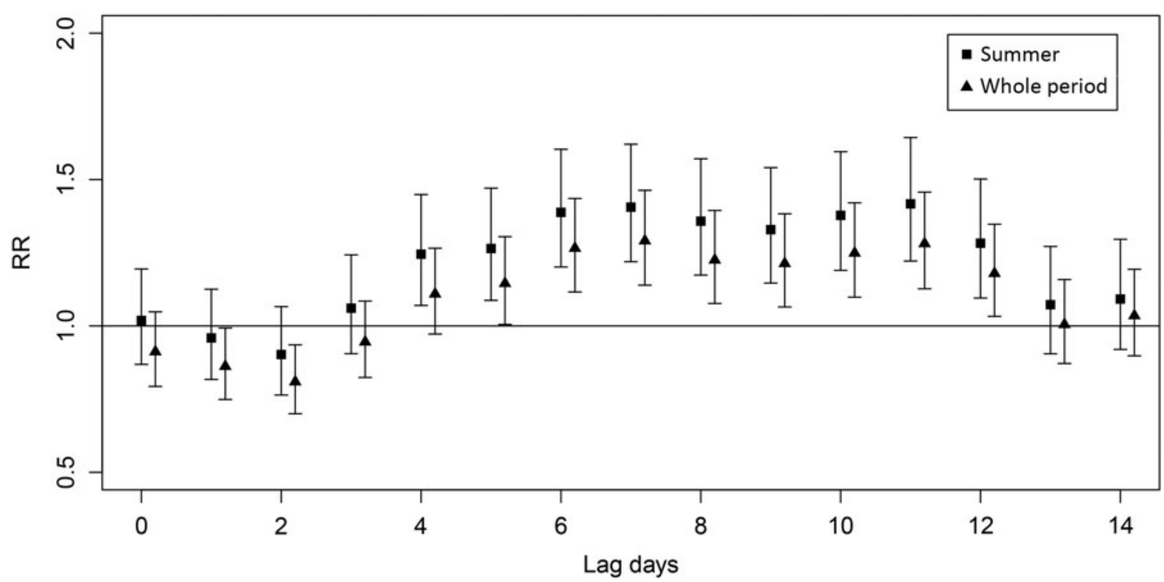

Fig. 3. Relative risk (RR) estimates of floods on bacillary dysentery at different lagged days within two periods in Qingdao, 2005–2011.

cases of daily enteric infectious diseases and all meteorological factors were higher during summer days than over the whole study period.

Regression analysis using a generalized linear model at different time lags

Table 3 and Figures 3–5 show the estimated RRs of floods on the three enteric infectious diseases for 1- to 14-day lags. The results shown in Table 3 and Figure 3 indicate broadly consistent increased risks for BD during floods across the two periods (summer: RR > 1 for 4- to 12-day lags; whole study period: RR > 1 for 5- to 12-day lags), while the two strongest lagged effects in model 1 for summer were slightly larger than those in model 2 for the whole study period (model 1, 7-day lag: RR 1·41, 95% CI 1·22–1·62; 11-day lag: RR 1·42, 95% CI 1·22–1·64; model 2, 7-day lag: RR 1·29, 95% CI 1·14–1·46; 11-day lag: RR 1·28, 95% CI 1·13–1·46). HFMD

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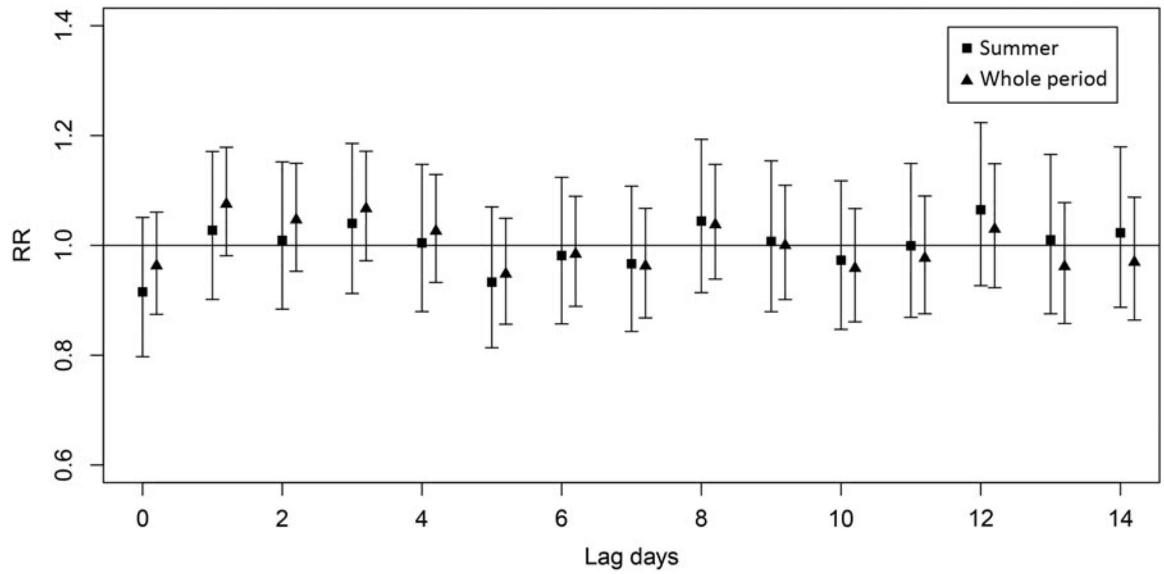

Fig. 4. Relative risk (RR) estimates of floods on hand-foot-mouth disease at different lagged days within two periods in Qingdao, 2005–2011.

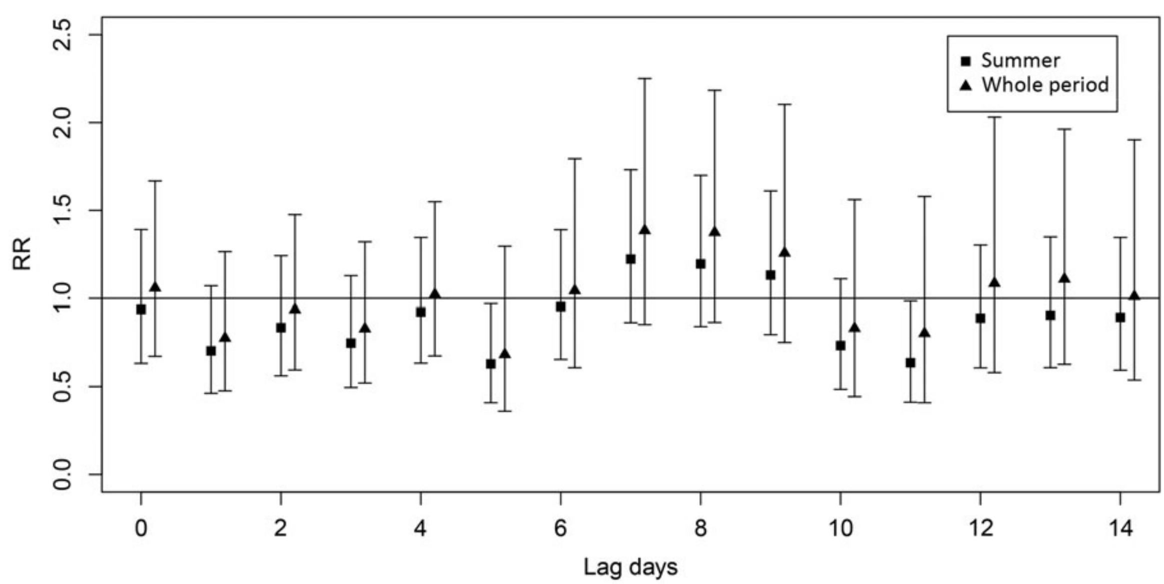

Fig. 5. Relative risk (RR) estimates of floods on other infectious diarrhoea at different lagged days within two periods in Qingdao, 2005–2011.

and OID were not significantly associated with floods (Figs 4 and 5).

DISCUSSION

In recent years, under the context of climate change, enteric infectious diseases are increasingly being recognized as a significant health problem. This study stands out from previous research by highlighting the critical role of floods in driving the transmission of BD. Our results indicate that floods are positively associated with the incidence of BD in the selected study area, while no significant flood effects were found for HFMD or OID. Results from this study will have significant implications for developing strategies to prevent and reduce the health impacts of floods.

BD is an enteric infectious disease that is transmitted through the faecal–oral route via contaminated water, food, daily contact and flies [25]. In China, BD is still an important public health problem, and

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has caused more than 300 deaths per year for the last decade [29]. Cases of BD usually occur in areas that are crowded and have poor sanitary conditions [28, 29, 33, 34]. However, limited studies have examined the effects of floods on BD and the results have varied across different studies. In the present study, we found that floods are associated with an increase in daily BD cases, echoing the study of Ni *et al.* [35]. Using longitudinal data from 2004 to 2009, Ni *et al*. examined the relationship between monthly dysentery cases and floods in three cities of Henan Province, and found higher morbidity from dysentery during flooded compared to non-flooded months (RR 1·66, 95% CI 1·52–1·82) [35]. There are several possible pathways by which floods might affect BD incidence. For example, excessive rainfall can move pathogens in the environment into rivers, coastal waters and wells. This can adversely affect water sources and supply systems, and thereby accelerate the transmission of enteric pathogens [36]. In urban areas, if the wastewater volume in a combined sewerage system exceeds the capacity of the sewerage system or treatment plant, then excess wastewater, containing not only storm water but also untreated human waste, can directly flow into nearby streams, rivers and other water bodies, and therefore pollute drinking water in these areas [36]. In addition, secondary effects of flooding, namely high population densities and forced migration from affected homes or workplaces in high-risk areas, might also contribute to the spread of BD [4].

The current study found that floods are positively associated with BD from 4- to 12-day lags, with the greatest effects at 7-day (RR 1·41, 95% CI 1·22–1·62) and 11-day (RR 1·42, 95% CI 1·22–1·64) lags. Although the incubation period of BD is 7 days, we believe that the positive effect at longer time lags is more biologically plausible, considering the time required for the pathogen to pollute water or food.

A positive relationship between floods and HFMD was not detected in this study. HFMD epidemics have been reported worldwide in recent decades, particularly in the Asia-Pacific region [24]. In mainland China, numerous HFMD outbreaks have recently been reported [21]. For example, in 2010, more than one million HFMD cases, resulting in 509 deaths, were reported [24]. To the best of our knowledge, the association between floods and HFMD has not previously been studied. However, the relationship between extreme precipitation and HFMD has been investigated in several studies, with inconsistent results. Cheng *et al.* reported a significantly positive association between extreme precipitation and childhood HFMD in Hefei, China [37]. In contrast, Hii *et al*. reported a negative correlation, with each millimetre increase in rainfall decreasing the HFMD incidence by 0·5% (95% CI 0·995–0·996) when the weekly cumulative precipitation was more than 75 mm in Singapore [38]. Moreover, Onozuka & Hashizume observed no relationship between precipitation and HFMD in Japan [39]. There is no clear explanation for such inconsistencies, which might be partially attributed to a threshold effect of precipitation on HFMD. It is possible that people living in coastal China and island countries such as Singapore, where there is high precipitation and humidity, might have a relatively higher adaptive capacity to extreme precipitation than those living in temperate cities [37]. Another potential explanation relates to the route of transmission of HFMD; aside from contact with contaminated environments such as water, food and surface, HFMD is mainly transmitted through direct contact with respiratory droplets and the blister fluid of infectious patients.

The incidence of OID is also high in China. In 2011, 836 591 cases of OID were reported, with an incidence rate of 62·39/100 000 population. Our study did not find a positive relationship between floods and OID, even though 88·0% of OID cases occurred during the peak flooding period (April–September) when the weather was rainy. The underlying mechanism behind this phenomenon remains unclear, and requires further study.

One advantage of our study is that we applied a generalized linear model to investigate the day-by-day impact of floods on three enteric disease in Qingdao, Shandong Province, allowing us to flexibly examine the possible relationships between weather conditions and disease. A previous study suggested that a day-by-day analysis is the best approach for diseases with a short incubation period, and that such results would be of greatest benefit for disease control and prevention by providing timely information [40].

Several limitations of this study must be acknowledged. First, information about the specific living conditions of patients, household size, family income, parents' literacy, availability of health services and individual behaviours were not available from our data sources. In addition, under-reporting is an inevitable issue, which could lead to an underestimation of the risk of enteric infectious diseases attributed to floods. Last, all floods were described as city-wide, which might also lead to an underestimated RR value if some towns were not affected by the flooding.

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CONCLUSIONS

In conclusion, our study has confirmed that floods can significantly increase the risk of BD in the study area, while no positive flood effects on HFMD and OID were detected. Results from this study will provide insight into the health risks associated with floods and may help inform public health precautionary measures for such disasters.

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DECLARATION OF INTEREST

None.

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