Epidemiol. Infect. (2017), **145**, 1567–1576. © Cambridge University Press 2017
doi:10.1017/S0950268817000280

Impacts of ambient temperature on the burden of bacillary dysentery in urban and rural Hefei, China

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Received 12 November 2015; Final revision 23 November 2016; Accepted 26 January 2017; first published online 15 March 2017

SUMMARY

Bacillary dysentery continues to be a major health issue in developing countries and ambient temperature is a possible environmental determinant. However, evidence about the risk of bacillary dysentery attributable to ambient temperature under climate change scenarios is scarce. We examined the attributable fraction (AF) of temperature-related bacillary dysentery in urban and rural Hefei, China during 2006–2012 and projected its shifting pattern under climate change scenarios using a distributed lag non-linear model. The risk of bacillary dysentery increased with the temperature rise above a threshold (18·4 °C), and the temperature effects appeared to be acute. The proportion of bacillary dysentery attributable to hot temperatures was 18·74% (95 empirical confidence interval (eCI): 8·36–27·44%). Apparent difference of AF was observed between urban and rural areas, with AF varying from 26·87% (95% eCI 16·21–36·68%) in urban area to −1·90% (95 eCI −25·03 to 16·05%) in rural area. Under the climate change scenarios alone (1–4 °C rise), the AF from extreme hot temperatures (>31·2 °C) would rise greatly accompanied by the relatively stable AF from moderate hot temperatures (18·4–31·2 °C). If climate change proceeds, urban area may be more likely to suffer from rapidly increasing burden of disease from extreme hot temperatures in the absence of effective mitigation and adaptation strategies.

Key words: Ambient temperature, attributable fraction, bacillary dysentery.

INTRODUCTION

Health consequences of climate change have attracted increasing attention from both health practitioners and policy makers [1–3]. Ongoing climate change with anticipated more frequent, more intense and longer lasting extreme temperature events, coupled with rapid globalization will pose a significant threat to infectious disease occurrence [4, 5]. High temperatures, particularly the prolonged high temperature events (e.g. heat waves), can directly influence individual's circulatory system, and trigger the alteration of behavior patterns (e.g. eating habits and physical

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activity), which jointly make people more susceptible to infectious pathogens [6–8]. Additionally, high temperature can also affect the whole food chain including food preparation, process, and storage, prompt the survival, reproduction, and growth of pathogens and possibly resulting in more food-borne diseases [9, 10]. A growing body of studies suggests that warmer temperature conditions increase the risk of infectious disease transmission [7–12].

Bacillary dysentery (BD), a severe form of shigellosis primarily transmitted by fecal-oral route via contaminated food, water or person-to-person contacts, continues to be a major public issue and remains endemic in many developing countries [8, 13, 14]. *Shigella* infection accounts for approximately 5% of diarrheal episodes, and incidence of treated shigellosis even exceeds 2 episodes per 1000 residents in Asian countries [13]. To date, the progress of *Shigella* vaccine has been hampered due to emerging multi-drug resistance in *Shigella* [15]. Therefore, developing the state-of-the-art control and preventive strategies for BD and assessing its priority is urgently needed.

Most previous studies using the time-series analysis to examine the link of ambient temperature and BD showed that increased temperature was significantly associated with elevated relative risk (RR) of BD [8, 16]. However, this risk offers limited information on the actual impact of temperature, and is largely influenced by the extent of coverage of exposure [17, 18]. For example, a high RR may not be interpreted as a great adverse impact on human health because of unusually low prevalence of exposure or very few exposed population. By contrast, attributable fraction (AF), a measure of disease burden that combines RR and the prevalence of exposure to measure the public health burden of a risk factor [17], represents the fraction of a specific disease that would not have occurred if the exposure to a specific risk factor is absent either in the exposed population or the population as a whole. AF thereby has the advantage of providing sufficient evidence for causal inference, and is essential for the planning and evaluation of public health interventions [18]. To provide scientific evidence for policy decision, resource allocation and development of disaster response strategies, it is of paramount importance to have an accurate estimation of burden of BD attributable to temperature.

In recent years, rapid urban sprawl with low density land use and high population density is an inevitable consequence, which has brought a huge challenge for local health agencies to develop corresponding policies in response to climate change [4, 19, 20]. Whether global climate change, plus the urbanization progress will exacerbate the burden of BD has not been examined yet.

In this paper, we attempted to answer two key research questions: (i) the difference of temperature effects on BD across urban and rural areas of Hefei, China; and (ii) the extent to which the burden of BD can be attributed to increased ambient temperature under the projected climate change scenarios.

METHODS

Data collection

This study was carried out in Hefei, the capital city of Anhui Province, China. It covers 11 408 km^2 with a population of 95 75 568 in 2010. Hefei is an inland city and located in the east-central China (31°52′N, 117°17′E), with a temperate climate and four distinct seasons. The annual average temperature and rainfall is 15·7 °C and 2·7 mm, respectively. All local residents of Hefei city from four urban district areas (Shushan, Baohe, Yaohai, and Luyang) and four rural counties (Feidong, Feixi, Changfeng, Chaohu, and Lujiang) were selected in this study. We mapped the annualized average BD incidence matched to the administrative districts to identify high incidence area. Figure 1*a* shows the geographical location of Hefei city.

BD is a national legally notifiable infectious disease in China. All clinical and hospital doctors are required to report BD cases to local Center for Disease Control and Prevention (CDC) through internet-based Chinese Information System for Disease Control and Prevention within 24 h. Daily BD records from 1 January 2006 to 31 December 2012 were provided by Hefei CDC. This dataset included name, gender, age, residential address, and date of onset. All extracted BD cases were limited to residents of Hefei city. Daily meteorological data covering the same period were supplied by the Hefei Bureau of Meteorology. The meteorological variables included daily maximum temperature, mean temperature, minimum temperature, relative humidity, and rainfall.

Data analysis

We used a distributed lag non-linear model (DLNM) to examine the AF of BD attributable to temperature, and to quantify the temperature-related morbidity risk [18, 21]. The warm season (May–October) was

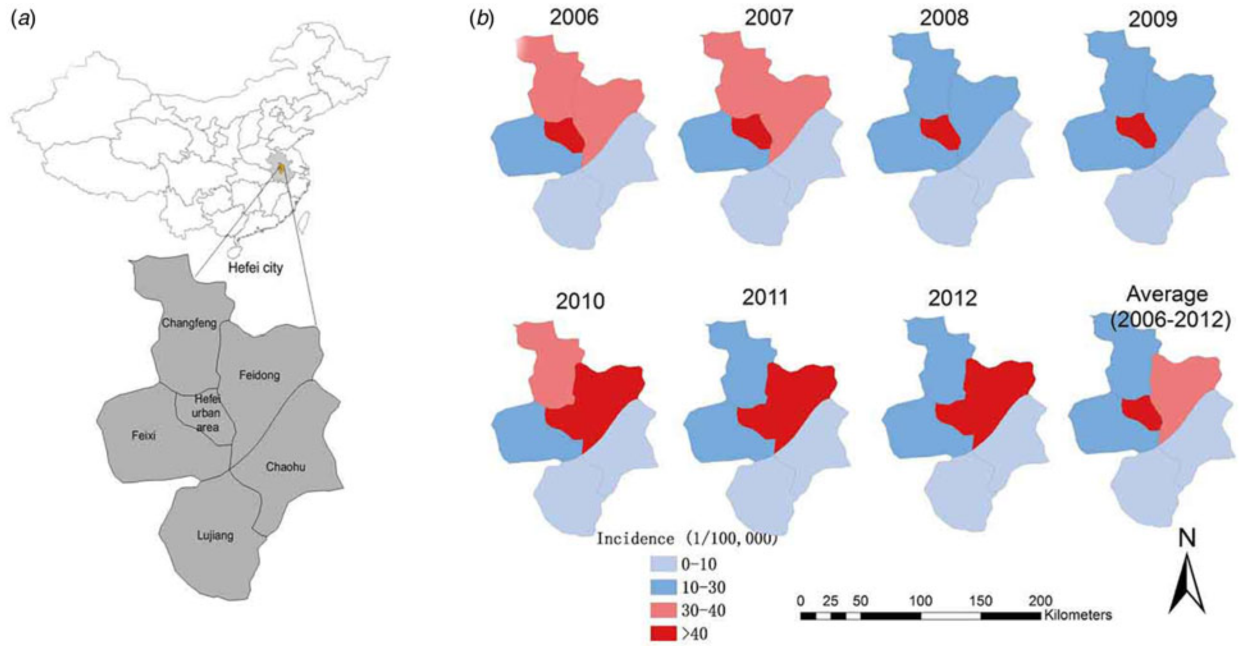

Fig. 1. The geographical location of Hefei city in China (*a*), and annual average incidence of bacillary dysentery at district level in Hefei, during 2006–2012 (*b*). Hefei city consists of four urban areas (Shushan, Baohe, Yaohai, and Luyang districts) and five rural areas (Feidong, Feixi, Changfeng, Chaohu, and Lujiang counties). Urban areas are in the central part of Hefei city and have the highest bacillary dysentery incidence rate, while rural areas are centered around the city that have the bacillary dysentery incidence rate.

selected as the study period because it usually has the highest BD incidence (Supplementary Fig. S1).

Stage 1: Quantifying the general effects of daily temperature

To detect whether the data followed an over-dispersed distribution, we fitted the Poisson regression model, quasi-Poisson regression model and negative binomial regression model, each of which was integrated with DLNM [9, 22, 23]. We found that the negative binomial regression combined with DLNM had the best model fit (having the lowest Bayesian information criterion (BIC) value), this model was thereby applied to examine the non-linear and delayed effects of temperature. To adjust for potential confounding factors, the day of week was included as the categorical indicator variables in the model [8]. We also controlled for long-term trend using a 'natural cubic spline' function with four degree of freedom (*df*) per year and daily relative humidity with three *df* [8, 22]. Based on previous studies [9], temperature was included in the model using 'natural cubic spline' function to model its non-linear and delayed effects. As the high correlations among maximum temperature, mean temperature, and minimum temperature, we separately fitted the model with these three variables. Using the mean temperature with three *df* and nine lag days in the model generated the lowest BIC value and the temperature effects on BD was negligible for lags above 9 days. Thus, we calculated and plotted the RR of BD and corresponding 95% confidence interval (CI) with lags up to 9 days. The adequacy of the model was checked by verifying whether the model residuals were normally distributed and independent over time. Sensitivity analyses were also performed by altering the *df* for trend and relative humidity.

We initially observed that the temperature–BD relation curve was linear, but the risk of BD appeared not to increase within a certain temperature range, because the 95% CI of RR contained or was lower than value 1. Therefore, we can assume that there is a temperature threshold, below which adverse temperature impacts are non-existent (adverse effects range), and above which the risk of BD starts to increase (no adverse effects range). After visually checking the temperature–BD relation curve using different temperature references, we could identify the potential temperature threshold within 17–20 °C (Supplementary Fig. S2). Following previous studies [24, 25], the temperature threshold was determined through Akaike's information criterion (AIC). Specifically, we fitted two models

Table 1. *Summary statistics for daily bacillary dysentery and climatic variables during warm season (May–October) in Hefei, China, from 2006 to 2012*

				Percentile			
Variables	Mean	s.d.	Min	25	50	75	Max
Total cases	9·9	4·5	0	7·0	9·0	12·3	30
Children, 0–14 years	4·3	2·7	0	2·0	4·0	6·0	15
Adult, 15–64 years	4·7	2·8	0	3·0	4·0	6·0	19
Elderly, ⩾65 years	0·9	1·0	0	0	1·0	1·0	8
Urban cases	6·7	3·5	0	4·0	6·0	9·0	25
Rural cases	3·2	2·1	0	2·0	3·0	4·0	13
Mean temperature (°C)	24·6	4·4	10·6	21·6	24·9	28·1	34·0
Relative humidity (%)	76·2	12·1	30·0	69·0	77·0	85·0	100·0
Rainfall (mm)	4·0	11·7	0	0	0	1·7	146·6

using a list of temperature thresholds (17–20 °C, per 0·1 °C increment). Based on the minimum sum of AIC value of the two models [24, 25], 18·4 °C was finally selected as the temperature threshold and the focus of this study is on the impact of temperature above 18·4 °C. The temperature effects on BD were presented as the RR and 95% CI associated with a 1 °C increase above the threshold.

Stage 2: Estimating the AF of BD under projected temperature scenarios

Although several approaches for calculating the AF are available [17], the estimation of AF did not take in account the complexity of potential non-linear and delayed effects in time-series analysis. In this case, Gasparrini and Leone recently proposed the extended definitions of attributable risk within the framework of DLNM [18]. In this paper, the AF was estimated using forward and backward perspectives. The former indicates future burden due to exposure by looking from current exposure to future risks, while the latter summaries the current burden by looking from current risks to past exposure [18]. Therefore, we reported both backward AF (b-AF) and forward AF (f-AF) for BD. The 95% empirical CI (eCI) for b-AF and f-AF was derived by simulating 5000 samples from the assumed distribution based on Monte Carlo simulations [21, 26]; and the related 2·5th and 97·5th percentiles of simulating distributions were interpreted as 95% eCI [21, 26].

As the extreme temperature events are projected to increase in frequency, duration and intensity in the context of climate change [1], the AF due to extreme temperatures was singled out. The hot temperatures were defined as temperature above the temperature threshold (18·4 °C), with extreme hot temperatures referring to above 95th percentile of temperature (31·2 °C) and mild hot temperatures between 18·4 and 31·2 °C. In addition to estimating the AF due to hot temperatures, the AF composition related to both extreme and mild hot temperatures was also extracted from temperature–BD association.

There are a number of factors, such as temperature and population size could be used to predict the future burden of BD, but with great uncertainty. According to Intergovernmental Panel on Climate Change [27], there is sparse evidence for future temperature changes in variability, and the major pattern of changes in extreme temperatures is shown in accordance with a general warming trend. Therefore, we assumed that climate change would cause increasing mean temperature but no change in variability [20, 28]. The future daily temperatures were simulated by adding 1–4 °C to the observed daily temperature from 2006 to 2012. The increase of 1–4 °C was used to simulate daily temperatures in the year 2050 [20, 28]. We also assumed that other meteorological variables (e.g. relative humidity) will remain constant because temperature was consistently recognized as the key factor affecting the BD incidence [8, 29]. Any future changes in the vulnerability of the population to climate change, such as human physiological acclimatization to higher temperatures, population size, and socio-economic status were assumed to be unchanged [8, 29]. We calculated the projected AFs attributable to hot temperatures, including mild hot temperatures and extreme hot temperatures in 2050.

All visual maps were created using ArcGIS 9·3 (ESRI Inc., Redlands, CA, USA), and related models were fitted using R software (version 3.2.2, R Development Core Team, Austria).

RESULTS

Characteristics of daily BD and meteorological variables

In Hefei, there were a total of 12 717 BD cases during warm season (May–October) from 2006 to 2012. Table 1 shows summary statistics for daily BD cases and weather factors. The average daily number of BD cases was 9·9 (range 0–30). Majority of cases occurred among children (0–14 years, mean 4·3) and adults (15–64 years, mean 4·7). The daily BD incidence in urban area was 0·22/1 00 000, which is much higher than that in rural area (0·05/1 00 000). The average values for mean temperature and relative humidity were 24·6 °C (range 10·6–34·0 °C) and 76·2% (range 30–100 %), respectively. During the study period, there were 166·6 days with temperature above 18·4 °C (temperature threshold) annually.

Figure 1*b* shows the spatial distribution of BD incidence annually in Hefei over 7 years (2006–2012). Compared with rural areas, urban districts were consistently found to have the higher number of BD cases across the study period, and the average annual BD incidence in urban districts was higher than 40/1 00 000.

Morbidity risk of BD associated with mean temperature

Figure 2 indicates the exposure–response curve between daily mean temperature and BD. The curve reveals that temperature effects elevated linearly above 18·4 °C (temperature threshold). The RR associated with a 1 °C increase in temperature was 1·04 (95% CI 1·00–1·07).

Considering that BD has a short incubation period (1–2 days) [30], we estimated the risk of BD at lag 0–1, and compared it at longer lags by gender, age, and area (Table 2). Temperature had the similar effects on males and females (RR 1·03, 95% CI 1·01–1·06, lag 0–1), while the effects lasted longer for females. Children were found to be more vulnerable to hot temperatures than the adult and the elderly, and the RR was 1·05 (95% CI 1·02–1·08, lag 0–1). We also found that urban residents were more likely to be affected by increased temperature than rural residents, and the temperature effects were acute (RR 1·04, 95% CI 1·02–1·06, lag 0–1).

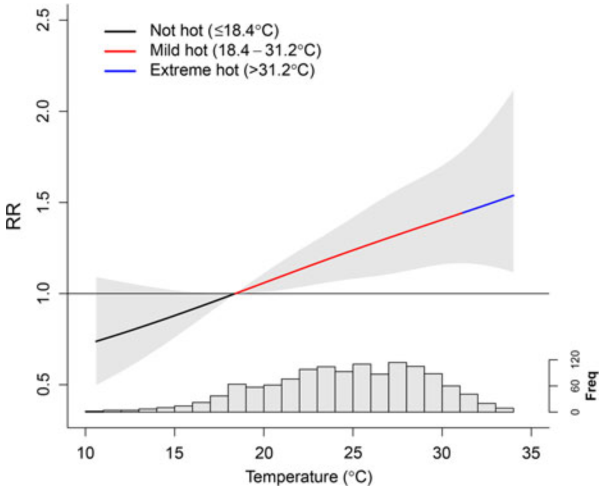

Fig. 2. The over effect of mean temperature on bacillary dysentery in Hefei, China, 2006–2012. The solid line shows the relative risk (RR), with gray areas representing the corresponding 95% confidence intervals. Reference temperature is 18·4 °C.

The residuals were checked to assess the adequacy of the model, and they were normally distributed and independent over time (Supplementary Fig. S3). Sensitivity analyses were performed to check the robustness of our findings. We found similar temperature effects when changing the *df* (5–7) for long-term trend (Supplementary Fig. S4) and the *df* (4–7) for relative humidity (Supplementary Fig. S5), and controlling for rainfall (Supplementary Fig. S6).

Attributable proportion of BD under various temperature scenarios

Figure 3 presents the AF due to different temperature ranges for population by gender, age, and area. Compatible results were observed using backward and forward perspectives for AF calculation. From a backward perspective, the AF due to hot temperatures for total population was 18·74% (95% eCI 8·36–27·44%), and the AF from mild hot temperatures (17·12%, 95% eCI 7·34–25·32%) was far greater than that from extreme hot temperatures (2·07%, 95% eCI 0·75–3·25%). Both males and females shared similar patterns of AF due to hot temperatures, and most BD cases were attributable to mild hot temperatures. There was a marked difference in AF across urban and rural areas, with AF ranging from 26·87% (95% eCI 16·21–36·68%) in urban area to −1·90% (95% eCI −25·03% to 16·05%) in rural area.

The attributable number of BD cases from hot temperatures, including mild hot temperatures and

Table 2. *The cumulative effects of temperature on bacillary dysentery, reported as 1 °C increase of temperature (reference temperature = 18·4 °C)*

Variables	Relative risk (95% CI)				
	Lag 0–1	Lag 0–3	Lag 0–5	Lag 0–7	Lag 0–9
All ages	1·03 (1·02–1·05)*	1·05 (1·02–1·07)*	1·05 (1·02–1·07)*	1·04 (1·01–1·07)*	1·04 (1·01–1·07)*
Child, 0–14 years	1·05 (1·02–1·08)*	1·07 (1·03–1·10)*	1·06 (1·02–1·10)*	1·06 (1·01–1·10)*	1·08 (1·02–1·13)*
Adult, 15–64 years	1·01 (0·99–1·04)	1·03 (1·00–1·06)	1·04 (1·00–1·07)*	1·03 (0·99–1·07)	1·00 (0·96–1·05)
Elderly, >65 years	1·04 (0·99–1·09)	1·05 (0·98–1·12)	1·04 (0·97–1·11)	1·02 (0·95–1·11)	1·02 (0·93–1·12)
Males	1·03 (1·01–1·06)*	1·04 (1·02–1·07)*	1·04 (1·01–1·07)*	1·03 (1·00–1·07)	1·02 (0·98–1·06)
Females	1·03 (1·01–1·06)*	1·05 (1·02–1·08)*	1·05 (1·02–1·09)*	1·05 (1·01–1·09)*	1·06 (1·01–1·11)*
Urban	1·04 (1·02–1·06)*	1·06 (1·03–1·09)*	1·06 (1·03–1·09)*	1·06 (1·03–1·09)*	1·05 (1·01–1·09)*
Rural	1·02 (0·99–1·05)	1·02 (0·98–1·06)	1·01 (0·97–1·05)	1·00 (0·96–1·05)	1·01 (0·96–1·06)

* *P*-value < 0·05.

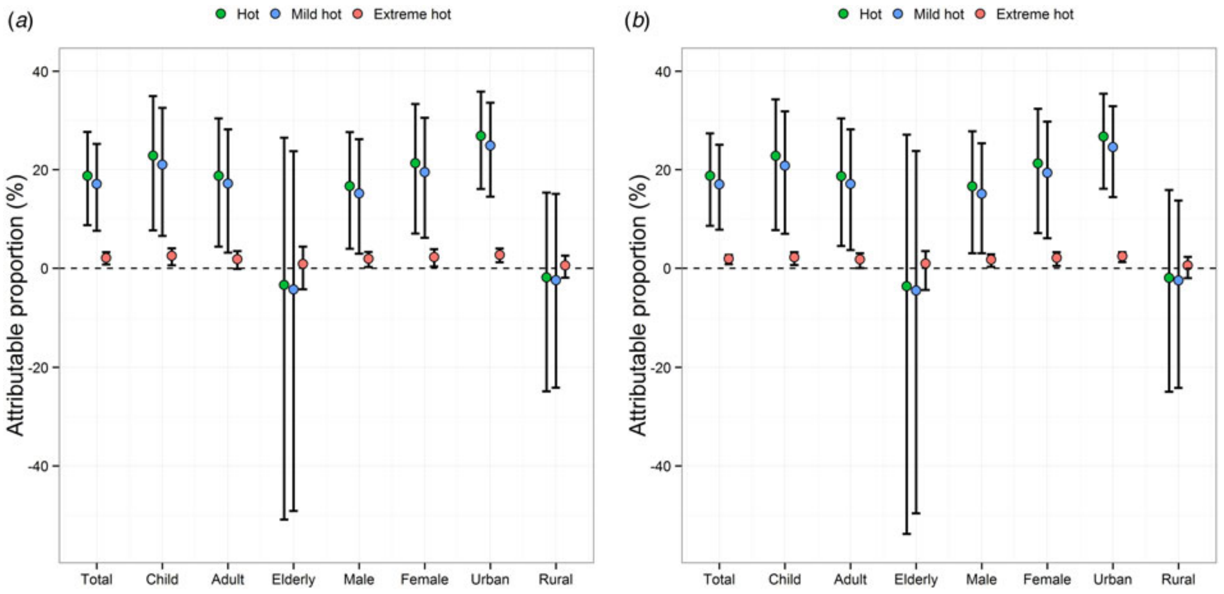

Fig. 3. The attributable proportion of bacillary dysentery (BD) from hot temperatures, including mild hot temperatures and extreme hot temperatures. The attributable proportion is calculated from backward perspective (*a*) and forward perspective (*b*).

extreme hot temperatures is shown in Supplementary Fig. S7. Substantial number of BD cases occurred on days with mild hot temperatures. This pattern was consistent across males, females, children, adults, and urban residents.

We estimated the projected AF of BD from hot temperatures based on the assumption of 1–4 °C temperature increase in 2050. Table 3 shows the area-specific AF of BD. Assuming 1 °C temperature increase in 2050, the projected AF due to hot temperatures is 21·19% (95% eCI 9·89–30·68%) for the total population, meaning an increase of 1·45% from extreme hot temperatures and a 1·05% increase from mild hot temperatures. For urban residents, the proportion attributable to hot temperatures is 29·63% (95% eCI 17·09–39·56%), as a 2·04% increase of AF from extreme hot temperatures and a 0·91% increase from mild hot temperatures. Assuming a temperature increase of 2 °C, the AF from hot temperatures would rise up to 24·11% (95% eCI 10·71–35·28%) and 32·79% (95% eCI:18·59–44·23%) for the total and urban population, because of a rapid increase in AF from extreme hot temperatures and a slight increase in AF from mild hot temperatures. For temperature increase above 2 °C, we projected that the AF due to extreme hot temperatures would have more than

Table 3. *Projected total morbidity fraction (%) attributable to temperature, reported as hot, mild hot, and extreme hot temperature components with 95% empirical confidence intervals among urban and rural areas*

	AF	Temperature change scenarios			
		1 °C increase	2 °C increase	3 °C increase	4 °C increase
		Urban area			
Hot	b-AF	**29·63 (17·09–39·56)**	**32·79 (18·59–44·23)**	**35·76 (17·85–49·49)**	**38·57 (18·02–53·67)**
	f-AF	**29·51 (17·57–39·23)**	**32·68 (18·48–43·89)**	**35·65 (18·53–48·99)**	**38·46 (17·88–53·62)**
Mild hot	b-AF	**25·81 (14·39–35·08)**	**24·91 (12·04–35·00)**	**23·45 (9·35–34·05)**	**20·69 (5·74–31·94)**
	f-AF	**25·32 (14·78–34·20)**	**24·41 (12·92–33·97)**	**22·88 (9·95–32·89)**	**20·20 (6·90–30·34)**
Extreme hot	b-AF	**4·74 (2·55–7·20)**	**8·17 (4·55–11·94)**	**10·99 (6·29–16·17)**	**13·59 (6·77–20·13)**
	f-AF	**4·20 (2·59–5·89)**	**7·29 (4·60–9·83)**	**9·8 (5·97–13·34)**	**12·30 (7·43–16·86)**
		Rural area			
Hot	b-AF	−0·66 (−27·38 to 19·42)	1·28 (−31·99 to 24·84)	3·54 (−36·81 to 31·08)	6·05 (−40·46 to 36·77)
	f-AF	−0·72 (−27·18 to 19·48)	1·22 (−31·73 to 24·39)	3·48 (−35·10 to 30·74)	5·99 (−41·08 to 36·68)
Mild hot	b-AF	−1·27 (−24·49 to 16·86)	0·26 (−24·94 to 18·89)	2·00 (−25·74 to 21·23)	3·65 (−24·52 to 23·41)
	f-AF	−1·30 (−25·24 to 16·14)	0·25 (−25·40 to 18·89)	2·00 (−26·23 to 21·70)	3·67 (−24·93 to 23·05)
Extreme hot	b-AF	0·66 (−3·59 to 4·06)	0·73 (−5·92 to 6·05)	0·69 (−8·66 to 8·12)	0·83 (−12·43 to 10·96)
	f-AF	0·66 (−3·88 to 3·60)	0·71 (−6·45 to 5·49)	0·69 (−9·91 to 7·26)	0·88 (−13·33 to 9·84)
		Total			
Hot	b-AF	**21·19 (9·89–30·68)**	**24·11 (10·71–35·28)**	**26·97 (10·07–40·41)**	**29·77 (9·87–44·83)**
	f-AF	**21·18 (9·79–30·41)**	**24·10 (10·69–35·07)**	**26·97 (10·80–40·15)**	**29·77 (10·09–45·21)**
Mild hot	b-AF	**18·17 (7·18–27·04)**	**18·05 (6·19–27·61)**	**17·55 (4·83–27·49)**	**16·03 (2·73–26·56)**
	f-AF	**18·01 (7·82–26·88)**	**17·87 (6·94–27·12)**	**17·31 (5·15–27·01)**	**15·79 (3·12–25·45)**
Extreme hot	b-AF	**3·52 (1·59–5·69)**	**5·93 (2·65–9·23)**	**7·88 (3·56–12·48)**	**9·89 (3·57–15·90)**
	f-AF	**3·22 (1·64–4·83)**	**5·45 (2·74–7·91)**	**7·27 (3·47–10·73)**	**9·25 (4·13–13·74)**

b-AF, backward attributable fraction; f-AF, forward attributable fraction. *P*-value <0·05 for bold figures.

a threefold increase, accompanied by a slight decrease in AF from mild hot temperatures, and consequently contributing to a rapid increase in total AF.

Supplementary Table S1 presents the AF under the temperature warming scenarios by gender and age. Significant upward trend of AF due to hot temperatures was observed for females and children along 1–4 °C in 2050. Noticeably, the AF from extreme hot temperatures would rise greatly, accompanied by the relatively stable AF from moderate hot temperatures.

DISSCUSSION

There is a considerable burden of disease from BD in many Asian countries [13], and temperature is a key weather factor influencing the BD occurrence [8, 29]. However, the impact of temperature on the burden of BD has not been well characterized in the context of climate change. In this study, we quantified the temperature effects on BD during the warm season (May–October) from 2006 to 2012 in Hefei, China, and estimated the AF of BD attributable to temperature under the temperature rising scenarios. This study has yielded several novel findings: (i) temperature was positively associated with BD, and morbidity risk linearly increased with temperature increase above 18·4 °C; (ii) children and urban residents were more vulnerable to temperature rise; (iii) most BD cases was attributable to mild hot temperatures; (iv) along the 1–4 °C increase of temperature in 2050, AF from extreme hot temperatures would rise greatly, while AF from mild hot temperatures would remain relatively stable; and (v) urban area was projected to suffer from increasing disease burden from temperature increase, particularly from extreme hot temperatures.

Previous studies of BD and temperature found that higher temperature was associated with higher risk of BD [8, 24], which is similar to our findings. However, temperature threshold, above which the risk of BD is likely to rise significantly, varied geographically [8, 16]. For example, in this study, we found an elevated risk of BD above 18·4 °C in a southern city of China (Hefei). Another study in a northern city of China (Beijing) identified a lower threshold (12·5 °C) for the temperature effects on BD [24]. Temperature threshold offers accurate and timely information for local policy makers and health practitioners to identify the level of population susceptibility and make optimal health resource allocation. Before temperature rises up to a certain threshold, the BD occurrence was sporadic and possibly attributed to non-climatic factors. When temperature goes above a certain threshold, the exposed population, especially children and urban residents, would be affected and more BD cases attributable to increased temperature could occur (Supplementary Fig. S8). Therefore, the detection of such starting point of temperature effects could be used as an additional criterion in the early warning system for BD [16].

In consideration of short incubation period of BD (1–2 days), understanding the lag time between temperature exposure and BD occurrence is critical in developing target response plans. This study adds to previous evidence that temperature rise had acute effects on BD [8, 24]. Currently, the exact mechanism by which exposure to higher temperature can increase the risk of BD is still poorly understood. Higher temperature affects the susceptibility of population to contract BD, possibly through direct and indirect ways. High temperature can promote the growth, persistence or survival of the bacteria in the surrounding environment (e.g. contaminated food and water), and thus exposing population to greater risk of being infected. In addition, the change in individual behaviors and immunity level associated with high temperature [9], such as increased demand for water and electrolyte imbalance could trigger BD epidemic among people. Hence, health agencies and health care providers should promote relevant health education in local community and make adequate preparedness for potentially rapid increases in emergency department visits and hospital admissions for BD during hot weather.

To identify the vulnerable subgroups, we further conducted stratified analyses by gender, age, and area. Usually, children and the elderly are considered to be at the highest risk of morbidity after exposure to high temperature [31, 32]. Concerning BD, in China, there was a general U-shaped morbidity pattern with children and the elderly having the highest BD incidence [33]. However, in this study, children, but not the elderly, were found to be more sensitive to hot temperatures, suggesting that age-specific temperature effects might vary across regions. We also found that urban residents showed higher vulnerability of developing BD (Table 2). With the city sprawl, urban residents live in a crowded environment with relatively higher population density than rural residents, which facilitates the transmission of BD. Previous studies provided evidence that population density could modify the association between temperature and BD, and an increase of 1000 persons per square kilometers was associated with 240% increase of BD [34]. These findings indicate that specific measures should be in place for high risk population and area.

In this study, we also applied attributable risk measure to estimate the burden of BD due to hot temperatures. Based on the RR and prevalence of exposure, AF reflects the fraction of BD cases attributable to temperature [17]. It also indicates potential benefits of interventions and can be used by public health organizations as guidelines for prioritizing interventions. As climate change continues, the frequency, intensity, and duration of extreme temperature events are expected to increase [1]. Concerns about the dynamic change for the impact of temperature composition (mild hot temperatures and extreme hot temperatures) on BD need to be addressed. Currently, mild hot temperatures were responsible for the majority of BD cases, and a minor proportion of BD cases was due to extreme hot temperatures (Fig. 3). However, under the temperature rising scenarios (1–4 °C rise), the extreme hot temperature days will become more frequent, increasing the possibility of population's exposure to extreme hot temperatures. In this study, we also assumed no improvement in human acclimatization to extreme hot temperatures, and the findings revealed multi-fold increases of AF from extreme hot temperatures and relatively stable AF from mild hot temperatures (Table 3). Therefore, it is of great importance to strengthen the awareness of the huge threat of hot temperatures, particularly extreme hot temperatures, to inform the public how to minimize their risks. Some advices on avoiding and managing the temperature-related BD infection could be distributed through the media. More related polices and health resources allocation should also be scheduled ahead to counteract increasing burden of BD in the context of climate change.

China, the biggest developing country in the world, is experiencing rapid urbanization progress. Urban sprawl characterized by warmer temperature and higher population density than the surrounding countryside is now challenging the public health system. We found that urban area was the hardest hit spot of BD (Fig. 1*b*), and hot temperatures have triggered substantial number of BD (Supplementary Fig. S7). In addition, extreme hot temperatures will induce the deterioration of this situation if there is no effective interventions. Appropriate urban planning and associated public health management play an indispensable role in reducing population vulnerability. A variety of actions, including creating high density communities with mixed land use, enhancing green coverage, using reflective paving and roofing materials, and reinforcing the management of food and tap water, are suggested to be effective approaches to alleviate the adverse impact of hot temperatures [20].

Some limitations should be acknowledged. First, the data we collected were from one city, which limits the generalizability of our findings to other communities, as the temperature effects on BD may vary by location. Second, the contemporary temperature–BD relation was applied to project the future AF of BD attributable to temperature, which overlooks the possibility that this pattern may change over time because of future reinforced sanitation management, increased air travel, improved housing design and increased coverage of health resources. Third, there are wide confidence ranges in the factors used to predict BD with increased temperature scenarios. In this study, the temperature scenarios taken in this study did not strictly adhere to projection from the IPCC [27]. We assumed an increase of 1–4 °C to model the temperature distribution in 2050 with no temperature variation [20, 28]. Some other uncertain factors, such as future changes in demographic characteristics, socioeconomic features, and other weather variables, which may influence the transmission of BD were assumed to be constant [8, 14, 34]. Therefore, these uncertainties, to some extent, influence our findings. Fourth, prior studies showed the urban area was warmer than rural areas due to urban heat island effect [20]. In this study, the obtained temperature data were the average of Hefei, meaning that we might have underestimated the burden of BD attributable to hot temperatures in urban area. Fifth, as previous studies suggested that attributable risk of a disease has significant spatial variation [35], a spatial analysis of temperature-related AF of BD is needed in future work to help locate the area at the greatest risk. Sixth, as the information on causative agents for BD cases or outbreak is not available, we are unable to analyze the impact of temperature on BD by *Shigella* species, which may be useful for developing target monitoring and control measures.

In conclusion, this study suggests that there is a threshold (18·4 °C) for temperature effects on BD, and the risk of BD linearly increased above the threshold. Currently, majority of BD cases is attributable to mild hot temperatures. Under the projected temperature rising scenarios (1–4 °C), extreme hot temperatures will be responsible for increasing proportion of BD, while the contribution of mild hot temperature will remain relatively stable. Notably, urban area was projected to suffer from rapid increasing burden of disease from BD, mainly due to extreme hot temperatures. Relevant public health strategies should be developed in advance to lower the impact of climate change on BD.

SUPPLEMENTARY MATERIAL

The supplementary material for this article can be found at https://doi.org/10.1017/S0950268817000280.

ACKNOWLEDGEMENTS

This research was funded by Anhui Natural Science Fund (Grant No. 1408085MH159). The authors thank the Hefei Bureau of Meteorology and Hefei Center for Disease Control and Prevention for providing relevant dataset. J.C. and H.S. conceived and designed the study. K.F.Z., J.C., X.W., K.S.L., H. H.Y., L.Y.W., J.S., and M.Y.X. collected and arranged the data. J.C., X.W., H.S., and D.S.Z. conducted data analysis. J.C. and K.F.Z. drafted the manuscript. H.S., Z.W.X., S.L.T., J.J.W., and J.C. revised the manuscript.

DECLARATION OF INTEREST

None.

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