Science of the Total Environment 482–483 (2014) 214–221

Contents lists available at ScienceDirect

Science of the Total Environment

journal homepage: www.elsevier.com/locate/scitotenv

The effect of heat waves on mortality and effect modifiers in four communities of Guangdong Province, China

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HIGHLIGHTS

- Mortality effects of extreme heat were mainly explained by high temperature.
- Extreme heat effects were higher for the rural areas than urban areas.
- Extreme heat effects were higher for respiratory mortality, for the elderly and for females.

ARTICLE INFO

Article history:
Received 23 September 2013
Received in revised form 15 December 2013
Accepted 11 February 2014
Available online 17 March 2014

Keywords:
China
Climate change
Extreme temperature
Heat waves
Mortality

ABSTRACT

Background: Heat waves have been reported to be associated with increased mortality; however, fewer studies have examined the effect modification by heat wave characteristics, individual characteristics and community characteristics.

Methods: This study investigated the effect of extreme heat on mortality in 2 urban and 2 rural communities in Guangdong Province, China during 2006–2010. The effect of extreme heat was divided into two parts: main effect due to high temperature and added effect due to prolonged heat for several consecutive days. A distributed lag non-linear model was used to calculate the relative risk with consideration of lag days and potential confounding factors. Separate models were further fit by individual characteristics (cause of death, age and gender) and heat wave characteristics (intensity, duration and timing), and potential effect modification of community characteristics was examined using a meta-regression, such as educational levels, percentage of the elderly, Gross Regional Domestic Product (GDP).

Results: The overall main effects (ER = 8.2%, 95% CI: 3.4%, 13.2%) were greater than the added effects (ER = 0.0%, 95% CI: −3.8%, 4.0%) on the current day. The main effect peaked at lag0–2, and was higher for the two rural areas compared to the two cities, for respiratory compared to cardiovascular mortality, for those ≥75 years old and for females. The modifying effects of heat wave characteristics and community characteristics on mortality were not statistically significant.

Conclusion: This study suggests the effects of extreme heat were mainly driven by high temperature, which can be modified by some individual characteristics.

1. Introduction

There have been many studies examining the mortality risk from heat waves (Basagana et al., 2011; Gosling et al., 2007; Huynen et al., 2001; Knowlton et al., 2009; Whitman et al., 1997). Studies on associations of temperature with mortality could be divided into analyses of discrete events and time-series analyses of large arrays of consecutive daily data (Hajat et al., 2002; Wu et al., 2013). Recently, a few studies have brought these approaches together by assuming that the effect of heat may be described as the sum of two contributions: a “main effect” because of the independent effect of daily high temperature, and an “added effect” due to duration of sustained heat for several consecutive days (Gasparrini and Armstrong, 2011; Huang et al., 2012). For example, a study of 108 U.S. cities found that most of the excess death risk

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http://dx.doi.org/10.1016/j.scitotenv.2014.02.049
0048-9697/

with heat waves came from main effect rather than the added effect (Gasparrini and Armstrong, 2011).

Additionally, there may be some potential factors that can modify the effect of extreme heat on mortality, such as heat wave characteristics (Anderson and Bell, 2011; Barnett et al., 2012), individual characteristics and community characteristics (Basagana et al., 2011; Ma et al., 2012; O'Neill et al., 2003). Some previous studies showed higher mortality risk from heat waves with higher intensity, longer duration, or earlier occurrence in the summer (Anderson and Bell, 2011; Barnett et al., 2012; D'Ippoliti et al., 2010; Rocklov et al., 2012). Besides, studies showed that preexisting health status and demographic characteristics (e.g., age, gender and cause of death) could also modify the mortality effects of heat (Medina-Ramón et al., 2006). However, most of these studies were conducted in developed countries, and the findings remained inconsistent.

Moreover, some community characteristics might affect the relationship between heat and mortality across communities, such as educational level, socioeconomic status, and the percentage of the elderly (Curriero et al., 2002; O'Neill et al., 2003). People living in urban cities are possibly vulnerable due to the urban heat island effect and greater social isolation (Laaidi et al., 2012; Tan et al., 2009). However, rural residents in developing countries may also be vulnerable because of lower socioeconomic status and limited access to high quality health services and air conditioning. Although some studies have compared the heat wave effect on mortality between urban and rural areas, the results were inconsistent or contradictory (Laaidi et al., 2012; Sheridan and Dolney, 2003; Tan et al., 2009). For example, a European study found that heat-related mortality in urban cities was larger than that in rural areas (Hajat et al., 2007). However, the level of urbanization was not found to be a significant predictor in Ohio, U.S.A. (Sheridan and Dolney, 2003). Exploring this issue in more details through conducting a multi-community study in rural and urban areas of China will help to identify several vulnerable subpopulations and better establish protective health programs for the vulnerable population in the context of climate change.

Several studies have assessed the effect of heat waves on mortality in China (Huang et al., 2010; Levick, 1859; Liu Ling and Zhang, 2010; Pan et al., 1995; Tan et al., 2006). However, most of them mainly focused on a single city, and fewer have examined the possible effect modifiers (Tan et al., 2006). Better understanding on how heat events affected population in subtropical areas is useful for decision makers to better prepare and respond to heat events and more comprehensively to estimate the future burden of heat-related deaths. The current study aimed to assess the effect of heat events on mortality, and explore whether heat wave characteristics, individual characteristics and community characteristics could modify the effect.

2. Materials and methods

2.1. Study sites

Guangdong is one of China's southernmost provinces. It has a typical subtropical climate characterized by hot, humid summers, with an average annual temperature of 22 °C. In the current study, we selected two cities (Guangzhou and Zhuhai) and two rural communities (Nanxiong and Taishan) as study sites (Fig. 1). Guangzhou is the capital city of Guangdong Province with a developed economy, and Zhuhai is a coastal city near Guangzhou. Nanxiong is an undeveloped rural county, located in the northern part of Guangdong Province. Taishan, close to the South China Sea, is a coastal rural county. These four communities were chosen because Guangzhou and Zhuhai were relatively developed areas, with higher population densities and per capita GDP than Nanxiong and Taishan (Table 1) (National Bureau of Statistics of China 2010), which make it possible to compare the heat effect between urban and rural areas. Moreover, the mortality data from four communities are of high quality (Wu et al., 2013; Xie et al., 2013).

2.2. Data collection

For each study site, we obtained daily counts of all-cause mortality excluding external deaths (International Classification of Diseases, Tenth Revision ICD-10: A00-R99), as well as counts by age-of-death group during the period 2006–2010 from Guangdong Provincial Center for Disease Control and Prevention. The Guangzhou data only included 2 districts (Yuexiu and Liwan Districts) due to data availability and quality (Liu et al., 2013; Wu et al., 2013). Daily meteorological data from all

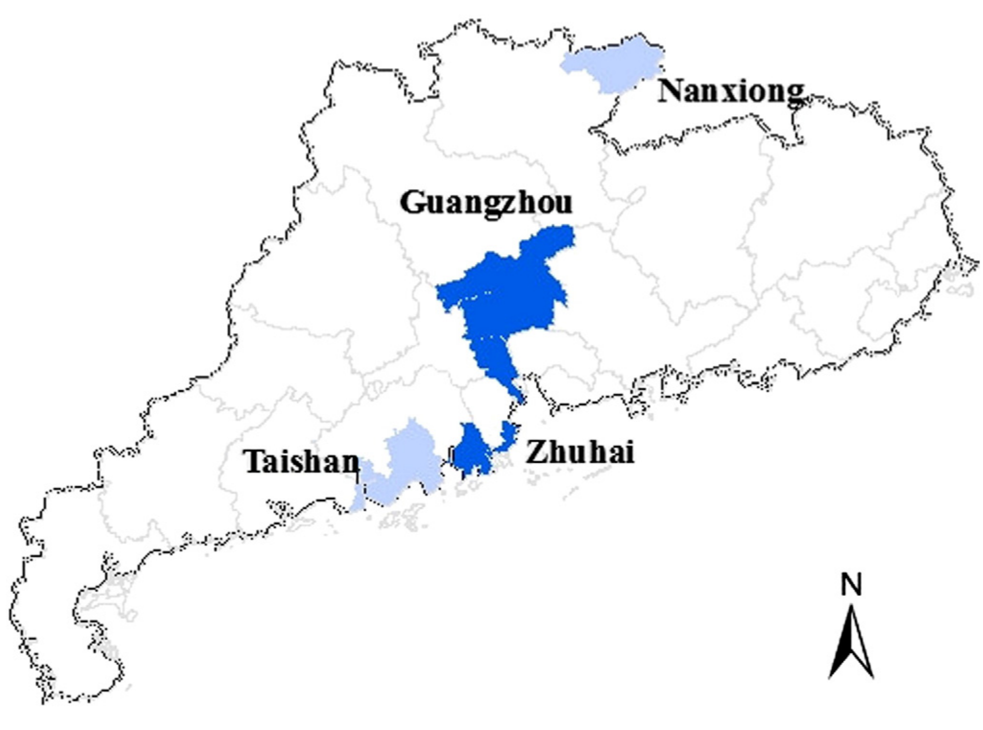

Fig. 1. The location of the study sites in Guangdong Province, China: two urban cities (Guangzhou, Zhuhai) and two rural communities (Taishan and Nanxiong).

Table 1
Meteorological factors, heat wave[a] characteristics and mortality summaries during the warm season (May–September) for four communities, 2006–2010.

	Guangzhou	Zhuhai	Nanxiong	Taishan
Latitude, °N	23°11′	22°18′	25°14′	22°16′
Population density (person/km^2)[b]	1715	637	203	301
Age >65 (%)[b]	10.98	5.01	11.98	10.90
Per capita GDP (person/Yuan)	89,082	69,900	11,380	19,480
Daily mortality counts [mean (SD[c])]				
Cause of disease				
Total death	30 (6)	9 (3)	6 (3)	18 (5)
Cardiovascular disease	10 (3)	3 (2)	2 (2)	10 (3)
Respiratory disease	5 (3)	1 (1)	1 (1)	2 (2)
Age				
0–64	7 (3)	3 (2)	2 (1)	4 (2)
65–74	6 (3)	2 (1)	1 (1)	3 (2)
75-	17 (5)	4 (2)	3 (2)	10 (4)
Gender				
Male	17 (5)	5 (2)	3 (2)	10 (3)
Female	13 (4)	4 (2)	3 (2)	8 (3)
Daily mean temperature (°C)				
Mean (SD)	28.2 (2.3)	27.8 (2.0)	27.0 (2.9)	27.5 (2.0)
Minimum	20.4	20.9	18.2	21.0
Maximum	33.5	32.1	32.2	32.0
Daily relative humidity (%)				
Mean (SD)	74.3 (9.8)	80.7 (8.6)	75.7 (10.0)	80.9 (7.9)
Minimum	44.0	47.0	46.0	46.0
Maximum	99.0	100.0	98.0	99.0
Heat wave characteristic				
NO./year [mean (min, max)]	3.8 (2, 5)	4.8 (3, 7)	4.6 (2, 6)	4.0 (3, 8)
Average heat wave intensity (°C) [mean (SD)]	31.6 (0.5)	30.5 (0.5)	31.1 (0.4)	30.2 (0.4)
Average heat wave duration (day) (min, max)	4.1 (2, 6)	3.5 (2, 6)	3.6 (2, 10)	3.5 (2, 10)
Start date of heat wave/year (earliest, latest)	June 19, August 1	June 2, July 25	June 22, July 23	June 17, July 11

[a] Heat waves defined: ≥2 days with mean temperature above the 95th percentile of the year-round community-specific distribution. Community-specific 95th percentile of daily temperature: Guangzhou: 31.0 °C; Zhuhai: 29.9 °C; Nanxiong: 30.5 °C; and Taishan: 29.7 °C.
[b] Number at the end of 2010. Percentage of the population >65 years of age.
[c] SD = standard deviation.

study sites were collected from Meteorological Department of Guangdong Province, including daily mean temperature and relative humidity. Daily air pollution data for Guangzhou and Zhuhai were collected from China National Environmental Monitoring Center, though no data were available for Nanxiong and Taishan. We used the daily Air Pollution Index (API) as an indicator of the overall daily air pollution level for a related community as described (Wu et al., 2013). For this study, we examined the effect of heat wave on mortality in warm season (May–September) (Sheridan and Dolney, 2003).

2.3. Definition and characterization of heat wave

We defined a heat wave as ≥2 consecutive days with daily mean temperature at or above the 95th percentile of the year-round community-specific distribution of daily mean temperature (Barnett et al., 2012; Gasparrini and Armstrong, 2011).

We described heat wave characteristics by intensity, duration and timing within the season. Heat wave intensity was defined as the difference between the temperature during the heat wave days and the community's heat threshold (0 on non-heat wave days). Heat wave duration was measured by the heat wave length in days, which was set to 0 on the first day, 1 on the second day, and so on. Heat wave timing was defined as the difference in days between the heat wave day and the start of the warm season on 1 May (0 on non-heat wave days) (Barnett et al., 2012).

2.4. Statistical analysis

A Poisson regression with distributed lag non-linear model (DLNM) was used to investigate the relationship between extreme heat and mortality (Gasparrini, 2011). According to the findings from previous studies, it was assumed that there was a strong effect of heat at very high temperatures (Gasparrini and Armstrong, 2011; Wu et al., 2013). First, we fitted the model controlling relative humidity, long time trend, seasonal trend and day of the week for each community. Then, community-specific risk estimates were further evaluated for combined effects using meta-analysis (Lin et al., 2011).

2.4.1. The main and added effects of heat

In order to examine whether there were any added effect of heat waves, we divided the effect of heat into a main effect and an added effect. The main effect was estimated as the percent increase in mortality predicted at the median temperatures among heat wave days relative to the 65th percentile of annual temperature distribution for each community. This reference was chosen as a temperature at which the effect of temperature on mortality is the lowest. The added effect was estimated as the percent increase in mortality during heat wave days compared to non-heat wave days. This method ensures us to estimate the extra effect of heat wave after removing the effect of isolated days of heat. To explore the relationship between heat and mortality at different lags, we plotted the main and added effects of heat to identify the lag structures. We limited the maximum lag to 10 days, because evidence indicates that the heat effect is acute and short (Gasparrini and Armstrong, 2011; Rocklov and Forsberg, 2008). The Akaike Information Criterion (AIC) was used to choose the optimal degrees of freedom (*df*).

$$\begin{aligned}\mathrm{Log}E[Y_t] &= \alpha + NS(T_1,2,3) + NS(T_2,2,3) + NS(RH,df) + NS(Time,df)\\ &\quad + NS(Season,df) + \beta DOW + API = \alpha + NS(T_1,2,3)\\ &\quad + NS(T_2,2,3) + COVs\end{aligned} \tag{1}$$

where Y_t refers to the number of deaths on day t; α is intercept; *NS* represents the natural spline function; T_1 refers to main effect, which is a two-dimensional natural spline with 2 *df* for temperature and 3 *df* for lagged temperatures, with maximum lag as 10. T_2 refers to added effect, which is a binary variable assuming value 1 during the heat wave period, with maximum lag as 10. *COVs* are the potential confounding factors.

RH refers to relative humidity, with 2 df; *Time* refers to time variable to adjust for long-term trends, with 5 *df*; *Season* refers to a variable describing the variation within warm season, with 7 *df*; *DOW* is a categorical variable for day of the week, and β is the coefficient for *DOW*; *API* refers to the air pollution index value. This term is only included in the sensitivity analysis.

To further examine the cumulative heat effects on mortality over different lag days, we examined the cumulative excess risks (CERs, %) with heat for lags of 0, 2, 4, 8 and 10 days, respectively. Through this lag model, we also explored the possible presence of short-term displacement of mortality as proposed in previous studies (Hajat et al., 2005; Kysely, 2004). Mortality displacement is characterized by positive coefficients at shorter lag days and negative coefficients at longer lag days.

2.4.2. The effect modifiers of heat wave

In our exploratory analysis, the largest cumulative effect of heat waves on mortality was observed at lag0–2. To examine whether the effect on mortality differed by cause of death, gender or age, we fitted the models for cardiovascular disease, respiratory disease, males and females, population below 65, 65–74 and ≥75 years, with a maximum lag of 2 days. We chose these effect modifiers because previous analyses showed that temperature effects differed according to gender or age (Ma et al., 2012; O'Neill et al., 2003). Cause of death was of interest because the identification of individuals at high risk of heat-related mortality is a key part for the prevention of heat effects (Gasparrini et al., 2011). To estimate the effects of the intensity, duration and timing of a heat wave, we replaced the regression model (1) with

$$\mathrm{Log}\, E[Y_t] = \alpha + NS(T_1, 2, 3) + NS(T_2, 2, 3) + \Sigma\gamma_i x_i + COVs \quad (2)$$

where: x_i is the heat wave characteristic, *i* refers to heat wave characteristic (intensity, duration, or timing) for heat waves, γ_i refers to the vector of regression coefficients.

In order to explore the effects of the community characteristics, a random effect meta-regression model was applied to the heat slopes in relation to several community-level characteristics (Lin et al., 2011, 2013b). Educational level (the percentage of persons not completing primary school), per capita GDP, the percentage of the elderly aged ≥65 years old were chosen as community characteristics, which have been commonly used as indicators of socioeconomic condition (Curriero et al., 2002; O'Neill et al., 2003). We didn't include the air conditioning coverage due to the data unavailability.

2.4.3. Sensitivity analysis

Sensitivity analyses were conducted using different definitions of heat waves. We reconstructed the model using the ≥95th or ≥97th percentile daily mean temperature and ≥2 or ≥3 day duration for the community-specific values. We also changed the *df* of the time and seasonal trends to rerun the model. The effects of air pollutants were also controlled for sensitivity analyses using the daily API.

We used the “dlnm” package in R software to derive the estimates. The meta-regression analysis was performed using a random effect model by “metafor” package. The results are expressed as a percentage increase in deaths for heat waves.

3. Results

Table 1 shows the features of the four communities and heat waves during the warm season of 2006–2010. The mean daily mortality counts ranged from 6 in Nanxiong to 30 in Guangzhou. Daily mean temperatures and relative humidity was similar across the four communities. The community-specific temperature–mortality curve appeared to be J-shaped (Supplementary Fig. S1). The hot thresholds were 26 °C, 25.9 °C, 24 °C, and 25.7 °C for Guangzhou, Zhuhai, Nanxiong and Taishan, respectively. In all the four communities, the mortality risk increased with temperatures above the hot threshold. The average number of heat waves ranged from 3.8 to 4.8 per year. Average heat wave intensity ranged from 30.2 °C in Taishan to 31.6 °C in Guangzhou. The temperature distribution during heat wave days and non-heat wave days are shown in Fig. S2. Most heat waves lasted for 3 or 4 days, and a few heat wave episodes lasted for more than 6 days. All heat waves occurred in June or July.

The heat and mortality relationship over different lags appeared to be U-shaped (Fig. 2). For the main effect in the four communities, we found an immediate effect that decayed during the first week, with the highest effect at lag0. The profiles of relative risk in the two cities (Guangzhou and Zhuhai) were flatter than the two rural communities (Nanxiong and Taishan). For the added effect, all results were not statistically significant.

Table 2 shows the cumulative excess risk (CER) due to the main and added effects of heat. The main effects (CER = 8.2% (95% CI: 3.4%, 13.2%)) were greater than the negligible, non-statistically significant added effects (CER = 0.0% (95% CI: −3.8%, 4.0%)) on the current days in all the four communities. The highest main and added effects in the two rural communities were much greater than that in the two cities. Mortality displacement was observed in Nanxiong, Taishan and Zhuhai. For the main effect, the overall excess risk effects were not only observed on the same day, but also in the subsequent days. The main effects peaked at lag0–2 (13.1% (95% CI: 7.1%, 19.5%)), then declined to negative at lag0–8 (−1.6% (95% CI: −14.1%, 12.8%)).

As shown in Fig. 3, the overall main effects on both respiratory mortality (CER = 34.5% (95% CI: 17.4%, 54.2%)) and cardiovascular mortality (CER = 19.3% (95% CI: 9.5%, 30.1%)) were higher than that for total mortality (CER = 13.1% (95% CI: 7.1%, 19.5%)). The ≥75 years old age group (CER = 20.9% (95% CI: 8.1%, 35.1%)) and females (CER = 16.6% (95% CI: 6.2%, 27.9%)) were higher than the younger age groups and males. The overall added effects were not statistically significant for cause of death, age or gender (Supplementary Fig. S3).

The estimated effects of the heat wave characteristics are shown in Table 3. On average, the overall mortality risk increased by 1.2% (95% CI: −5.6%, 8.5%), 1.4% (95% CI: −0.6%, 3.4%) and −0.1% (95% CI: −1.2%, 1.0%) for every 1 °C increase in average daily mean temperature, 1 day increase in heat wave duration and for every 10 days later in the season, but none of these results were statistically significant.

The analysis of the role of the community characteristics did not produce statistically significant results (Table 4), but the mortality risk increased with the lower educational levels and ages, with lower per capita GDP. For example, the mortality risk increased 50.1% for every 1% increase in the population not completing primary school. The mortality risk increased 1.19% for every 1% increase in the elderly aged 65 years or more. However, every 1000 Yuan increase in per capita GDP was associated with a 1.1% decrease in the mortality risks.

The sensitivity analyses yielded similar results when heat wave was defined as ≥3 consecutive days with temperature ≥95th percentile of distribution. However the effect was slightly greater when heat wave was defined as ≥2 consecutive days with temperature ≥97th percentile of distribution (Supplementary Tables S1–S2). When changed the *df* of long time and season trend or adjusted for API in the model, the results remained similar (Supplementary Tables S3–S4).

4. Discussion

Exposure to high temperature increases blood viscosity and may cause some well-described clinical syndromes such as heat stroke (Keatinge et al., 1986). A period of cumulative heat stress during a prolonged heat wave is more likely to cause dehydration and cardiovascular deaths (Rooney et al., 1998). In the present study, we found that most deaths with heat waves were attributed to high temperatures. This confirmed the results of a previous study from the United States (Gasparrini and Armstrong, 2011), which demonstrated that the added effect was small (0.2%–2.8%) compared with the main effect (4.9%–8.0%). In contrast with previous studies (Anderson and Bell,

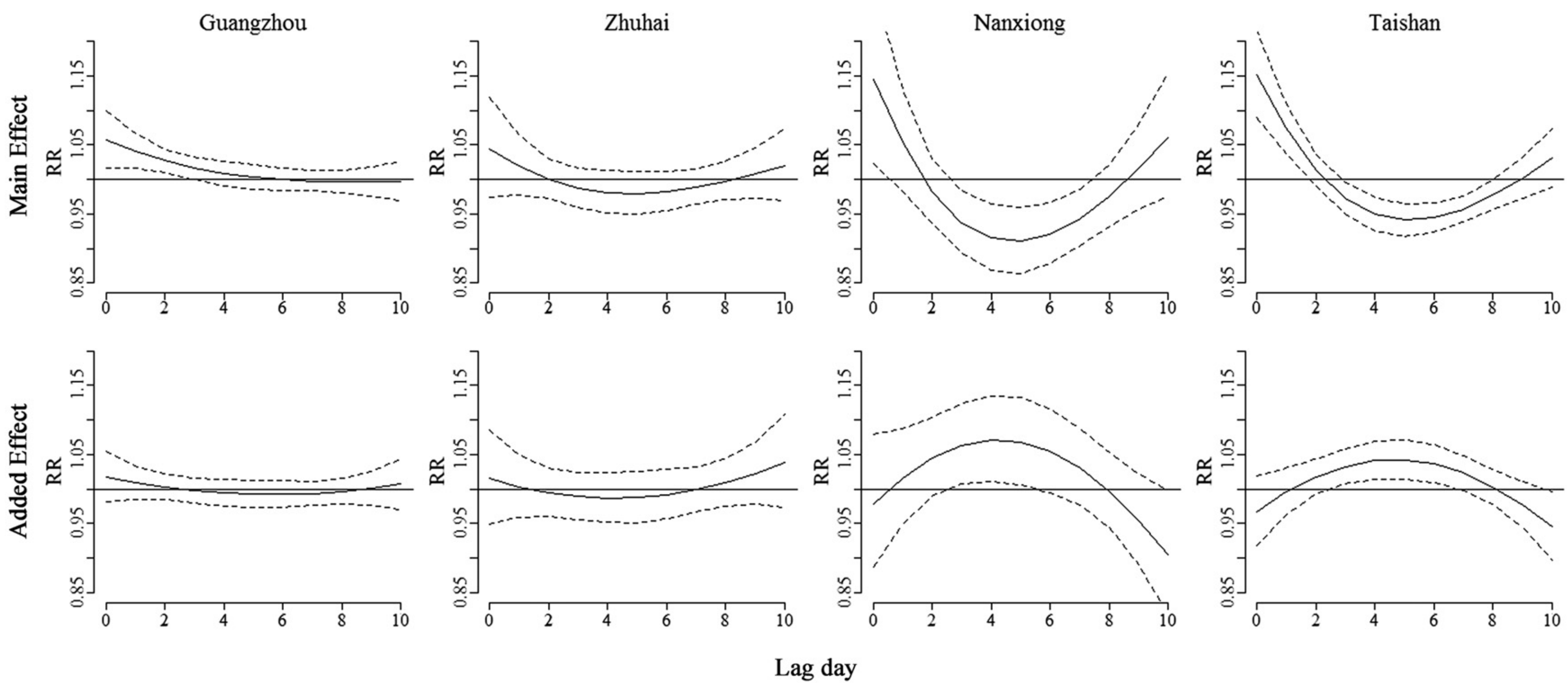

Fig. 2. Community-specific effects of extreme heat on mortality at different lags in four communities, 2006–2010. The black lines represent the relative risks, and the dotted lines represent 95% confidence intervals.

Table 2
Community-specific effects of extreme heat on daily mortality at different lags in four communities, 2006–2010.

Communities	Lag0		Lag0–2		Lag0–4		Lag0–8		Lag0–10	
	CER[a] (%)	95% CI[b]	CER (%)	95% CI	CER (%)	95% CI	CER (%)	95% CI	CER (%)	95% CI
Guangzhou										
Main effect	4.8*	0.6, 9.1	11.1*	2.9, 20.0	13.8*	4.4, 24.1	13.0*	1.7, 25.5	11.1	−1.6, 25.6
Added effect	2.5	−2.4, 7.7	3.8	−4, 12.2	2.8	−6.4, 12.9	1.9	−10.8, 16.3	3.0	−11.1, 19.4
Zhuhai										
Main effect	4.6	−2.7, 12.4	6.8	−6.8, 22.5	3.5	−11.3, 20.8	−0.7	−17.9, 20.2	3.7	−17.1, 29.7
Added effect	2.8	−5.5, 11.8	1.5	−12, 17.2	−2.2	−18.2, 17.0	−2.0	−23.9, 26.3	0.7	−24.1, 33.7
Nanxiong										
Main effect	15.4*	2.9, 29.4	19.6	−3.9, 48.9	1.9	−20.7, 30.8	−21.5	−42.9, 7.8	−14.1	−40.7, 24.4
Added effect	−4.3	−14.9, 7.6	3.5	−16.3, 28.0	21.5	−8.0, 60.5	36.8	−9.1, 105.9	19.5	−24.9, 90.0
Taishan										
Main effect	12.5*	6.4, 19.0	19.8*	7.7, 33.4	10.5	−2.0, 24.6	−8.1	−20.1, 5.8	−6.5	−20.1, 9.5
Added effect	−3.6	−9.4, 2.7	−1.8	−11.7, 9.3	6.7	−6.3, 21.5	20.1*	1.3, 42.3	12.3	−7.4, 36.2
Overall										
Main effect	8.2*	3.4, 13.2	13.1*	7.1, 19.5	10.5*	3.8, 17.5	−1.6	−14.1, 12.8	1.7	−9.0, 13.8
Added effect	0.0	−3.8, 4.0	1.9	−3.6, 7.7	4.1	−2.7, 11.4	9.1	−3.1, 22.7	6.2	−4.4, 18.0

[a] CER, cumulative excess risk.
[b] CI, confidence interval.
* $p < 0.05$.

2009; Gasparrini and Armstrong, 2011; Hajat et al., 2006), the added effect was not statistically significant in this study. One possible reason is the implementation of a high temperature early warning system in Guangdong Province, which has been progressively refined since 2006. Such a system informed and encouraged people to take adequate protective measures following high temperature warning messages issued for extreme heat event, including reducing activity, going to air-conditioned public places and wearing light clothing to obtain relief from hot weather. Another explanation is that the population physiologically and behaviorally adapt to high temperatures when they are sustained for a few days (Lin et al., 2013a).

Our results showed that the heat wave effects were greater in both respiratory mortality and cardiovascular mortality, and results in respiratory mortality were higher than cardiovascular mortality. Similarly, some investigators have reported greater risks for deaths during heat waves from respiratory, cardiovascular, cerebrovascular and pre-existing disorders (Lin et al., 2011; Medina-Ramon and Schwartz, 2007). Liu observed a greater effect on respiratory disease than on cardiovascular disease in Beijing (Liu et al., 2011), which revealed that the magnitude of effect on chronic respiratory disease mortality was as high as 98% of respiratory disease mortality. This may imply that people with some chronic diseases especially for respiratory disease might be more vulnerable, and preparedness of the health system for primary and second prevention during heat wave periods should be improved.

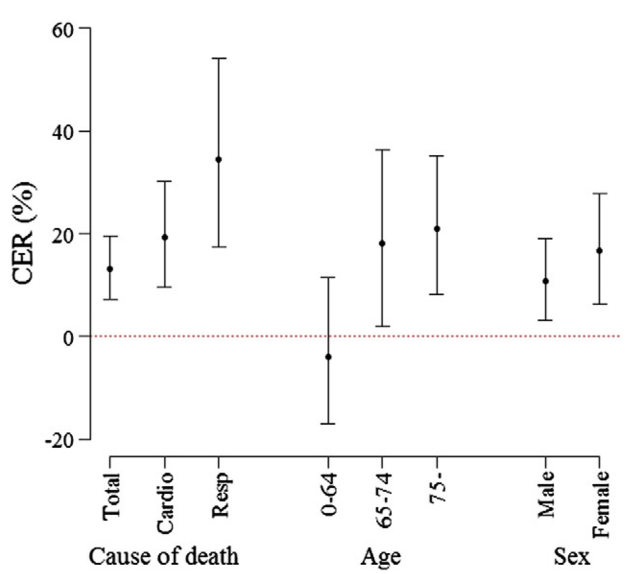

Fig. 3. The main effects of extreme heat on mortality at lag0–2 by cause of death, age and gender in four communities, 2006–2010. The points represent the cumulative excess risks, and the vertical lines represent 95% confidence intervals.

When stratified by age, the overall heat effects in four communities were stronger for the elderly (≥75 years old). This is consistent with findings from other countries (Bell et al., 2008; Lin et al., 2011; Son et al., 2012; Yu et al., 2011). A reduced temperature regulation capacity in the elderly, combined with being on medication that may interfere with the normal sweating process or less social contact, may partly explain their increased susceptibility (Basagana et al., 2011; Schifano et al., 2009). We found stronger associations among females than that among males, which is consistent with some previous studies (Son et al., 2012). However, another study found that men in Santiago and Sao Paulo (Bell et al., 2008) were at higher mortality risk (Hajat et al., 2005). The effect modification of gender is complex, and may be attributed to several socio-economic factors related to gender such as living conditions, social and cultural contexts.

Although our study found that the overall estimate between heat wave intensity and mortality was not statistically significant, the positive 1.2% increase in mortality for a 1 °C increase in average daily mean temperature implies that intensive heat waves may strengthen the health effect of heat waves. The community-specific effect of heat wave duration on mortality ranged from 0.3% to 3.5%, although results were not statistically significant. This was consistent with a study estimated effect modification by heat wave characteristics in 43 U.S. communities, with the result that mortality increased 0.38% for every 1-day increase in heat wave duration (Anderson and Bell, 2011). Another 14 year study of 99 U.S. cities reported that for every 5 days longer of heat wave duration the mortality increased by 0.14% (95% CI: 0.01%, 0.27%) (Barnett et al., 2012). It has also previously been suggested that heat waves early in the summer may have greater effects on mortality compared with those in later periods (Baccini et al., 2008; Hajat et al., 2002; Kalkstein and Smoyer, 1993). Our results found that the heat waves that began 10 days later in the summer, were associated with a 0.1% decrease (though not statistically significant) in the mortality risk. The differences of the community-specific effects of heat wave duration, intensity and timing in the season are likely to reflect the

Table 3
Percentage changes in daily mortality associated with the per unit increase in heat wave characteristics, 2006–2010.

Communities	1 °C increase in intensity		1 day increase in duration		10 days later in the season	
	ER[a] (%)	95% CI	ER (%)	95% CI	ER (%)	95% CI
Guangzhou	6.4	−2.9, 16.6	0.3	−2.7, 3.3	0.0	−1.8, 1.8
Zhuhai	−4.1	−17.0, 10.8	0.7	−4.4, 6.1	−1.1	−3.5, 1.4
Nanxiong	−16.2	−35.7, 9.2	3.5	−1.1, 8.4	−1.2	−5.4, 3.1
Taishan	1.5	−11.0, 15.8	2.1	−1.8, 6.1	0.7	−1.3, 2.7
Overall	1.2	−5.6, 8.5	1.4	−0.6, 3.4	−0.1	−1.2, 1.0

[a] ER, excess risk.

geographic variation of the heat waves and adaptive behaviors (Medina-Ramon and Schwartz, 2007; Vandentorren et al., 2006).

Our results showed that the heat wave effects increased with the percentages of lower educational level and the elderly, with lower per capita GDP. However, none of effects was statistically significant, consistent with a study conducted in Taiwan (Lin et al., 2011). The possible reason is that the four communities in our study are not big enough, which means future large-scale multisite studies should be conducted to address this issue. Besides, the air conditioning may be a very important adaptive measure to reduce the heat effect. Our previous studies showed that the percentage of household with air-conditioners was 74.45% in urban areas, while 28.16% in rural areas, and the risks for heatstroke in rural areas was 2.62 times greater than that in urban areas (Hu et al., 2013; Yan, 2011). However, the information on AC prevalence in the four communities included in the present research was not available.

Previous studies have shown that heat wave effects are particularly severe in urban cities (Liu et al., 2011; Tan et al., 2009). This is probably due to a heat-island effect whereby greater heat retention occurs in more heavily built-up areas. However, we observed a stronger effect in rural areas than in urban cities. One explanation is the lower adaptive capacity for people living in rural communities. For instance, air conditioning systems are relatively common in urban cities, whereas in rural communities few households have such cooling systems (Xie et al., 2013). Moreover, other factors in rural areas such as poor housing, low quality health services and higher exposure levels to heat wave might be related to high vulnerability (Bell et al., 2008; Gouveia et al., 2003). Climate change will increase health inequity especially through negative effects on the social determinants of health in the poorest communities without the mitigation and adaptation. So it is important to protect vulnerable populations in rural communities, particularly given the projected increases in heat wave events related to climate change in the future.

One limitation of our study is that we did not consider the interaction between air pollution and temperature in the model fitting. If air pollution and high temperature have synergistic effects on mortality, our results may have been overestimated (Katsouyanni et al., 1993). In addition, we could not exclude the possibility that there were unmeasured confounding factors that might be associated with both heat waves and mortality. For example, we did not have the data on air conditioning, which have been reported to be related with mortality by a few studies proposed (Curriero et al., 2002; O'Neill et al., 2003). Finally, because we only included 2 cities and 2 communities in the present study, it may not be possible to extrapolate our findings to China, and further study involving multisite across China is needed in the future.

Table 4
Percentage changes in daily mortality associated with the per unit increase in community characteristics, 2006–2010.

	ER (%)	95% CI	p
% Primary school	50.1	−20.1, 183.7	0.211
Per capita GDP	−1.1	−2.8, 0.6	0.201
% 65+	1.19	−1.32, 3.75	0.357

5. Conclusion

Extreme heat effects on mortality are significant in four communities of Guangdong Province in China, which are mainly explained by individual days' high temperature rather than a sustained heat effect for consecutive days. The effects of extreme heat are higher in rural areas compared with urban areas and are modified by individual characteristics such as age, gender and cause of death. However, the extreme heat effect appears to be less modified by particular heat wave characteristics and community characteristics, suggesting that the initial high temperature within the heat wave event is primarily responsible for the reported mortality in the four communities of Guangdong Province.

Competing interests

The authors declare no competing interests.

Funding statement

This study is funded in part by the Climate and health sub-project of Adapting to climate change in China project—Guangdong health risk assessment and adaptive measures research (ACCC/20100528) and the Natural Science Foundation of Guangdong Province (no. S2013010014670) and the National Basic Research Program of China ("973 Program") (no. 2012CB955500).

Acknowledgments

We thank the Guangdong Provincial Environmental Protection Bureaus for providing air pollution data and the Guangdong Provincial Meteorological Bureau for providing meteorological data.

Appendix A. Supplementary data

Supplementary data to this article can be found online at http://dx.doi.org/10.1016/j.scitotenv.2014.02.049.

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