Health & Place 50 (2018) 119–129

Contents lists available at ScienceDirect

Health & Place

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

Different response of human mortality to extreme temperatures (MoET) between rural and urban areas: A multi-scale study across China

Chenzhi Wang[a], Zhao Zhang[a,*], Maigeng Zhou[b], Pin Wang[c], Peng Yin[b], Wan Ye[a], Lingyan Zhang[a]

[a] State Key Laboratory of Earth Surface Processes and Resource Ecology, Faculty of Geographical Science, Beijing Normal University, Beijing 100875, China
[b] The National Center for Chronic and Noncommunicable Disease Control and Prevention, Beijing 100050, China
[c] Institute of Remote Sensing and Earth Sciences, Hangzhou Normal University, No.1378, Wenyi West Street, Hangzhou 311121, China

A R T I C L E I N F O

Keywords:
Extreme temperature
Public health
Difference between rural and urban areas
China
Air pollution effect

A B S T R A C T

Background: The environmental variation in mortality due to extreme temperatures has been well-documented by many studies. Mortality to extreme temperatures (MoET) was recognized to vary geographically, either by countries within a region or by areas within a country. However, so far, little attention has been paid to rural residents, with even lesser attention on the potential rural-urban differences. The aim of our study was to offer a quite comprehensive analysis on the differences in temperature-mortality relationship between rural and urban areas across China.

Method: A distributed lag nonlinear model was built to describe the temperature-mortality relationship, based on the mortality data and meteorological variable of 75 communities in China from 2007 to 2012. Subsequently, a meta-analysis was applied to compare the differences in the temperature-mortality relationship between rural and urban areas at various levels.

Results: Distinct responses regarding MoET between rural and urban areas were observed at different spatial scales. At regional level, more U-shaped curves were observed for temperature-mortality relationships in urban areas, while more J-shaped curves were observed in rural areas. At national scale, we found that the cold effect was stronger in rural areas (RR: rural 1.69 vs. urban 1.51), while heat effect was stronger in urban areas (RR: rural 1.01 vs. urban 1.12). Moreover, the modifying influence of air pollution on temperature-mortality relationship was found to be very limited.

Conclusion: The difference in response of MoET between rural and urban areas was noticeable, cold effect is more significant in China both in rural and urban areas. Additionally, urban areas in southern China and rural areas in northern China suffered more from extreme temperature events. Our findings suggest that differences in rural-urban responses to MoET should be taken seriously when intervention measures for reducing the risks to residents' health were adopted.

1. Introduction

Investigating the association between temperature and non-accidental mortality is not only a challenge, but also a significant scientific topic, since climate change is being considered as the biggest global health threat in the 21st century (Costello et al. 2009; IPCC 2013). Given the temporal and spatial complexity, specialists in different countries have been dedicated to investigating the impact of ambient temperature on public health, so as to have a comprehensive understanding of the temperature-mortality relationship. Researchers have not only attempted to explore the influence of different natural (Bentayeb et al., 2015; Kan et al., 2012; Sousa et al., 2012; Xie et al., 2013) and socio-economic factors (Kalkstein and Sheridan, 2007) on temperature-mortality relationship, but also to describe the relationship quantitatively across different spatial scales (Guo et al., 2013; Medina-Ramon and Schwartz, 2007; Wang et al., 2017). In recent years, it is encouraging to find researches in the field of epidemiology and public health involving many advanced mathematic models (Gasparrini et al., 2010, 2012; Wood and Augustin, 2002), which has contributed to deepening our understanding of the impact of environment on the public. Among these, some geo-statistical methods (Christakos and Vyas, 1998; Li et al., 2008; Wang et al., 2010) have also been applied to diagnose the spatial features of the association between ambient temperature and human health more accurately.

* Correspondence to: State Key Laboratory of Earth Surface Processes and Resource Ecology, Beijing Normal University, 19 Xinjiekou Street, Haidian District, Beijing 100875, China.
E-mail addresses: chenzhiwang@mail.bnu.edu.cn (C. Wang), zhangzhao@bnu.edu.cn (Z. Zhang), maigengzhou@126.com (M. Zhou), wangpin@hznu.edu.cn (P. Wang), yinpengcdc@163.com (P. Yin), yewan@mail.bnu.edu.cn (W. Ye), zhanglingyan@mail.bnu.edu.cn (L. Zhang).

https://doi.org/10.1016/j.healthplace.2018.01.011
Received 29 August 2017; Received in revised form 19 January 2018; Accepted 30 January 2018
Available online 09 February 2018
1353-8292/

A series of IPCC reports have emphasized that the impact of increasingly extreme temperature events on public health would become more severe (IPCC, 2007, 2013), particularly in China, the largest developing country in the world. With the 1.4 billion population base, the health impacts of climate change in China should receive adequate attention, considering the unprecedented population growth of China (Chan and Yao, 1999; Lin, 2007). Some studies summarized vulnerable population to extreme temperature in China (Ma et al., 2015b; Wang et al., 2016). Ma et al. (2015b) found a significant effect of heat waves on the people who suffered from cardiovascular disease and respiratory disease. Additionally, he also found there was a higher mortality risk of heat waves for those dying outside hospital compared with those dying in hospital and he ascribed this to the difference of air filtration and air conditioning between indoors and outdoors. Wang et al. (2016) demonstrated that there is a great effect of cold spell on the people who suffered from cardiovascular diseases and the low-educated. Both Ma and Wang pointed that the elder, the female are more vulnerable in China. They argued that vulnerability of the Chinese to extreme temperature was associated with both individual health condition and social-economic condition. Meanwhile, we found previous studies described the temperature-mortality relationship in China based on only one or several metropolitan communities (Gao et al., 2015; Guo et al., 2011; Kan et al., 2007; Liu et al., 2013a; Wang et al., 2014a; Zeng et al., 2014). Given the large area and the variety of environmental conditions of China into consideration, more systematic studies based on the numerous communities are crucial.

As mentioned above, both, natural factors and social-economic factors, can modify the temperature-mortality relationship (Burkart et al., 2013; Goggins et al., 2012; Kalkstein and Sheridan, 2007; Ren et al., 2008b). The difference between the urban and rural areas can be considered to be a combination of the abovementioned factors. However, environmental data monitoring sites are usually located in cities or the outskirts, both in developed and developing countries, resulting in the lack of environmental data: substantial in time but scarce in space (Madrigano et al., 2015). Therefore, compared with the number of studies on urban temperature-mortality relationship, only a few focus on the difference in mortality responses between rural and urban areas. In Europe, some studies discussed the difference in urban and rural mortality responses to temperature in Germany (Gabriel and Endlicher, 2011) and the Czech Republic (Urban et al., 2014). In North America, Madrigano et al. (2015) used the observed and interpolated data to investigate temperature, ozone, and mortality in 91 urban and non-urban counties. Fuhrmann et al. assessed the effect of three heat events on public health in North Carolina (Fuhrmann et al., 2016). Sheridan et al. presented an analysis of heat vulnerability across the Ohio and found there is no significantly difference of vulnerability to heat between rural and urban areas (Sheridan and Dolney, 2003). In China, Li et al. estimated the heat vulnerability of urban and rural populations in Tibet (Li et al., 2016), while Zhang et al. compared the impact of temperature variation on mortality between rural and urban areas of the Hubei Province (Zhang et al., 2017). Hence, more attention should be paid to the difference in mortality response to temperature between rural and urban regions to deepen our knowledge of the impact of environment on public health.

Since the 1990s, China has been experiencing rapid urbanization. Many previous studies have emphasized (Jones et al., 2008; Patz et al., 2004; Sheridan and Dolney, 2003; Weiss and McMichael, 2004) the influence of urbanization on public health due to population density, urban heat island effect, unmatched and outmoded infrastructure. However, according to the National Bureau of Statistics of China, more than 40% Chinese continue to reside in rural areas. Thus, the effect of population distribution on public health should be considered seriously. Experts have reported (Anderson and Bell, 2009; Epstein, 2005; Ma et al., 2015a; McGeehin and Mirabelli, 2001) that targeted intervention for specific subpopulations is necessary to reduce the overall health risk from extreme temperature events. Although some research compared the impact of temperature on urban and rural areas at a regional level (Li et al., 2016; Zhang et al., 2017), the lack of studies based on data from the numerous communities would hamper a comprehensive understanding of the temperature-mortality relationship and its difference from rural to urban regions. Therefore, a comparative study with copious community-specific data is warranted to provide a better understanding of the difference in mortality to extreme temperatures (MoET) between rural and urban areas.

In the present study, based on valid data from more than 70 sites from 2007 to 2012 across China, we estimated the difference in responses of MoET between urban and rural areas across China on different spatial scales. Compared with previous study focusing on one or few communities and underlined the effect of individual factors on temperature-mortality relationship, the aims of this study were: (1) to offer a quite comprehensive analysis on the differences in temperature-mortality relationship between rural and urban areas across China at different spatial scales; (2) to judge whether the modified effect of the air pollution on our estimated temperature-mortality relationship is significant.

2. Data and methods

2.1. Study sites

Given the large area of China, with complex topography and diverse climatic conditions, we selected 75 communities from China's Disease Surveillance Points system (DSPs) (Fig. 1). The communities in this research included 29 communities from urban regions, which are common administrative districts in cities, and 45 communities from rural areas. Moreover, the sites we selected were distributed across mainland China, with varying climatic conditions, ranging from temperate to subtropical. The comparison of temperature-mortality relationship between rural and urban regions should be carried out within the same temperature zone. Therefore, in this study, we compared the regional difference between rural and urban areas in the same temperature zone. The criterion of climate regionalization conformed to the standard by China Meteorological Administration (China National Institute of Standardization, 1998) and details of indictors of temperature zones in climate regionalization were shown in Table 1.

2.2. Data source

We collected continuous daily mortality data for each community, ranging from 1st January 2007 to 31st December 2012, from the DSPs. The system is supervised by the Center for Disease Control and Prevention (CDC) of China, which ensures the inclusion of the cause of death according to the International Classification of Diseases (10th Revision; ICD-10) as a crucial component of the death record. In addition, the mortality data we utilized were for “total mortality”, which includes all the causes of death, barring external causes like injury and poisoning. In this study, the mortality data of the 75 communities that we collected covers 5 million people, which accounts for 5% of China's population.

We obtained continuous meteorological data, matched with mortality data, from 2007 to 2012. A new, superior meteorological variables dataset (Yuan et al., 2015) was applied in our research to ensure both, temporal and spatial continuity, to ensure a fine scale view of the communities. This daily gridded meteorological dataset (Yuan et al., 2015) was generated using the thin-plate spline method, based on measurements from 600 climate stations of the China National Weather Data Sharing System (http://cdc.cma.gov.cn/home.do), the accuracy of which is widely accepted and has been used in previous study (Wang et al., 2017). The meteorological data in this study included daily mean temperature (Tm) and relative humidity (Rh).

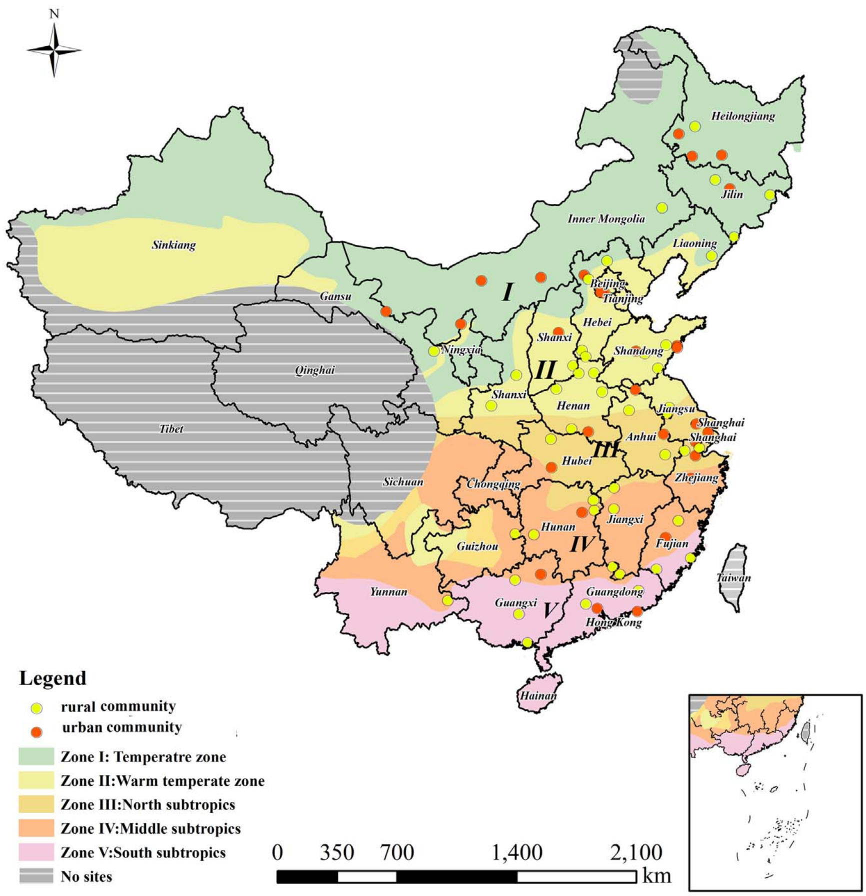

Fig. 1. The spatial distribution of all communities covered in present study.

Additionally, we collected the air pollution data for the same period from the China National Environmental Monitoring Center (http://113.108.142.147:20035/emcpublish) and the Ministry of Environmental Protection of China (http://datacenter.mep.gov.cn/index). This dataset has been used in many previous studies (Hu et al., 2014, 2015; Wang et al., 2014b). Air Pollution Index (API) was used to represent the air pollution condition in China. API depicts the air quality and air pollution level by using SO_2, NO_2, CO, O_3, and PM_{10} concentrations. All these measurements are conducted at the standard air quality monitoring sites located in each city. According to China Environmental Protection Standards HJ 193–2013 (http://bz.mep.gov.cn/bzwb/dqhjbh/jcgfffbz/201308/W020130802493970989627.pdf), and HJ 655–2013(http://bz.mep.gov.cn/bzwb/dqhjbh/201308/W020130802492823718666.pdf), values of air pollutant concentration are validated based on Technical Guideline on According to Environmental Monitoring Quality Management HJ 630–2011 (http://kjs.mep.gov.cn/hjbhbz/bzwb/other/qt/201109/W020120130585014685198.pdf) and then reported to the China National Environmental Monitoring Center. In our study, API data of 19 cities was collected. The API data was published by China National Environmental Monitoring Center. Supplementary Table 1 shows the association between the level of API and its health impact, as well as the corresponding air pollutant concentrations. Notably, due to the limitation of infrastructure, there is no monitoring sites in rural area in China and this situation is also common in developed countries (Madrigano et al., 2015)

Community level basic information was collected from the statistical yearbook of the National Bureau of Statistics of China and abovementioned datasets (Please see details in Supplementary Table 2). In addition to statistical information, based on the National Standard of Climatic Regionalization for Architecture (GB 50178-93),

Table 1
The classification indicators of the temperature zones (Wang et al., 2017).

Temperature zone	*Days of* $T_{\geq 10}$[a] (day)	*AT of* $T_{\geq 10}$[b] (°C)		January Tmean[c] (°C)		July Tmean[c] (°C)	
		Lower bound	Upper bound	Lower bound	Upper bound	Lower bound	Upper bound
Temperate	100–171	1600–3200	3400	−30 to −12	−6	18	24–26
Warm temperate	171–218	3200–3400	4500–4800	−12	−6 to −1	24	28
North subtropical	218–239	4500–4800	5100–5300	1	4	28	30
Middle subtropical	239–285	5100–5300	6400–6500	4	10	28	30
South subtropical	285–365	6400–6500	8000	10	15	28	29

[a] Days of $T_{\geq 10}$: The number of days with mean temperature ≥ 10 degree over a year.
[b] AT of $T_{\geq 10}$: Accumulated temperature with the daily mean temperature≥ 10 degree centigrade over a year.
[c] Tmean: monthly mean temperature.

we obtained the central heating mapping of China (Supplementary Figure 1)

2.3. Analysis methods

To investigate the difference in mortality response to extreme temperatures between urban and rural areas in China, the analysis was carried out at three scales: community level, regional level and national level. Firstly, we quantified the temperature-mortality relationship at the community level, calculating the mortality risk related with extreme temperatures for each community. Secondly, based on the result of each community, we characterized different temperature-mortality relationships between urban and rural areas across the five main temperature zones of China. Thirdly, we applied the geo-statistic and meta-analysis methods to analyze the urban-rural difference at a national level. Finally, we analyzed the influence of air pollution on the temperature-mortality relationship.

Firstly, a time-series quasi Poisson generalized linear model (GLM) was applied to estimate community-specific mortality effects of daily mean temperature at the community level. Subsequently, the distributed lag non-linear model (DLNM) was incorporated into the GLM regression, so as to assess the lagging effect (Gasparrini et al., 2010; Gasparrini, 2011; Gasparrini and Armstrong, 2013). In accordance with previous studies, DLNM also included the following covariates: relative humidity, public holiday and day of the week. The statistical model used in the analysis was as follows:

$$LogE[Y_t] = \alpha + cb(T_{mean}, lag) + NS(RH_t, 3) + NS(Time_t, 9) + \beta DOW_t + \gamma Holiday_t,$$

where E[$\boldsymbol{Y_t}$] refers to the expected number of deaths on day t; α is the intercept; ***cb*** indicates the "cross-basis" function, defined by a B-spline with 5 degrees of freedom (*df*) for the space occupied by temperature and 4 ***df*** for lag spaces (Gasparrini et al., 2010; Gasparrini and Armstrong, 2013; Ma et al., 2015a; Wang et al., 2017). NS represents the natural spline function. According to previous studies, we selected 0–21 days as the maximum lag, which estimated the effect of temperature accurately. Additionally, we placed 3 knots at 10th percentile, 50th percentile and 90th percentile of the mean temperature distribution of each community to ensure that the model can cover the tails of the distribution. $\boldsymbol{T_{mean}}$ indicates daily mean temperature; $\boldsymbol{RH_t}$ refers to humidity on day t, with the degrees of freedom (*df*) being 3; $\boldsymbol{Time_t}$ denotes the time variable, whose *df* was identified as 9/year; ***DOWt*** is the day of the week on day t and $\boldsymbol{\beta}$ is the coefficient; $\boldsymbol{Holiday_t}$ is the categorical variable to illustrate whether a particular day is a public holiday; while $\boldsymbol{\gamma}$ is the coefficient. All the degrees of freedom in the model were chosen by the Akaike Information Criterion (AIC).

Minimum-mortality temperature (MMT) is an important indicator which represents the temperature with the low relative risk of mortality. According to previous research (Gasparrini et al., 2010; Gasparrini and Armstrong, 2013; Ma et al., 2015a; Wang et al., 2017), we defined the heat mortality effect due to extremely high temperature as the relative risk at the 99th percentile of local mean temperature, compared with the MMT, while the cold mortality due to extremely low temperature was defined as that at the 1st percentile of mean temperature, compared with MMT.

In the second stage, based on the community-specific result, we applied a meta-analysis to pool the community-specific estimates to obtain the temperature-mortality curves at a regional level. Compared with the previous studies (Ma et al., 2015a, 2015b), we pooled the estimates at community level according to temperature zones, instead of administrative/geographical region. Based on the regional temperature-mortality curves, we calculated the cold- and heat-effect by temperature zone, as well as by rural and urban.

In the third stage, in order to determine the total effect of extreme temperature at the national level quantitatively, a similar meta-analysis was also applied to all the rural and urban sites. It is worth noting that we standardized the daily temperature at each site (the range of temperature from 0 to 1) to overcome the non-negligible gap of daily temperature in such a vast country.

Many studies stated that a modification effect from air pollution will show on temperature-mortality relationship (Burkart et al., 2013; Meng et al., 2012; Ren et al., 2008b; Roberts, 2004; Samet et al., 1998; Williams and Tong, 2006), although some others in China have indicated that the impact from air pollution is negligible (Chen et al., 2015; Xie et al., 2013). Therefore, to quantify how much of air pollution impact the temperature-mortality relationship, finally, API (Air Pollution Index) was introduced into the DLNM models of 19 cities as the following. We reconstructed the original model with adding a natural cubic smooth function of API with 3 *df*.

$$LogE[Y_t] = \alpha + cb(T_{mean}, lag) + NS(RH_t, 3) + NS(API_t, 3) + NS(Time_t, 9) + \beta DOW_t + \gamma Holiday_t$$

As we mentioned above, there is no observational air pollution data in rural areas. Additionally, we hardly obtained the air pollution condition from remotely sensed data at such fine spatial and temporal resolution. Previous study proved that there no significant difference observed in air pollutants between rural and urban areas in northern China (Li et al., 2014). Thus, to explore whether the difference of temperature-mortality relationship between urban and rural could be affected by air pollution, an urban community and an adjacent rural community in northern region were selected and assumed the API of them the same.

We used the "dlnm" package in R software version 3.3.2 to model the temperature-mortality relationship at the community level. The meta-analysis was performed using the "mvmeta" package. We used ArcGIS 10.1 software for the spatial trend analysis, and we defined statistical significance at the 5% level.

3. Results

3.1. The characteristics of communities and temperature-mortality curves at community level

Supplementary Table 2 (ST2) summarizes the characteristics of all the communities, including information on meteorology, mortality and social environmental factors. In our research, a total of 1,357,959 deaths were included in the analysis. The daily mean temperature ranged from 6.3 °C to 21.0 °C, while the daily relative humidity ranged from 58.69% to 74.87%. Moreover, we found the urban economic condition in the southern region (zone IV, zone V and part of zone III) is better than southern region (zone I and zone II) and this means southern urban areas is richer than northern regions.

Some representative community-specific curves from the five temperature zones were selected to be listed in Supplemental Table 3 (ST3). The temperature-mortality curves were found to be different for rural and urban areas, even though the sites were located in the same temperature zone. The temperature-mortality curves, which were consistent with many previous studies, were presented by U-, J-, V-, and W-shaped curves, suggesting a higher mortality risk from both, hot and cold temperature. Although more shapes of community-specific curves (U-, V-, W-shaped) were found in the temperate and warm temperate zones, while only J-shaped curve was observed in the middle subtropical and south subtropical zones. The U-, V-, and W-shaped curves generally indicated that temperate and warm temperate zones were vulnerable to both, cold- and heat- related risks, while only cold-related risk was present in the subtropical zone.

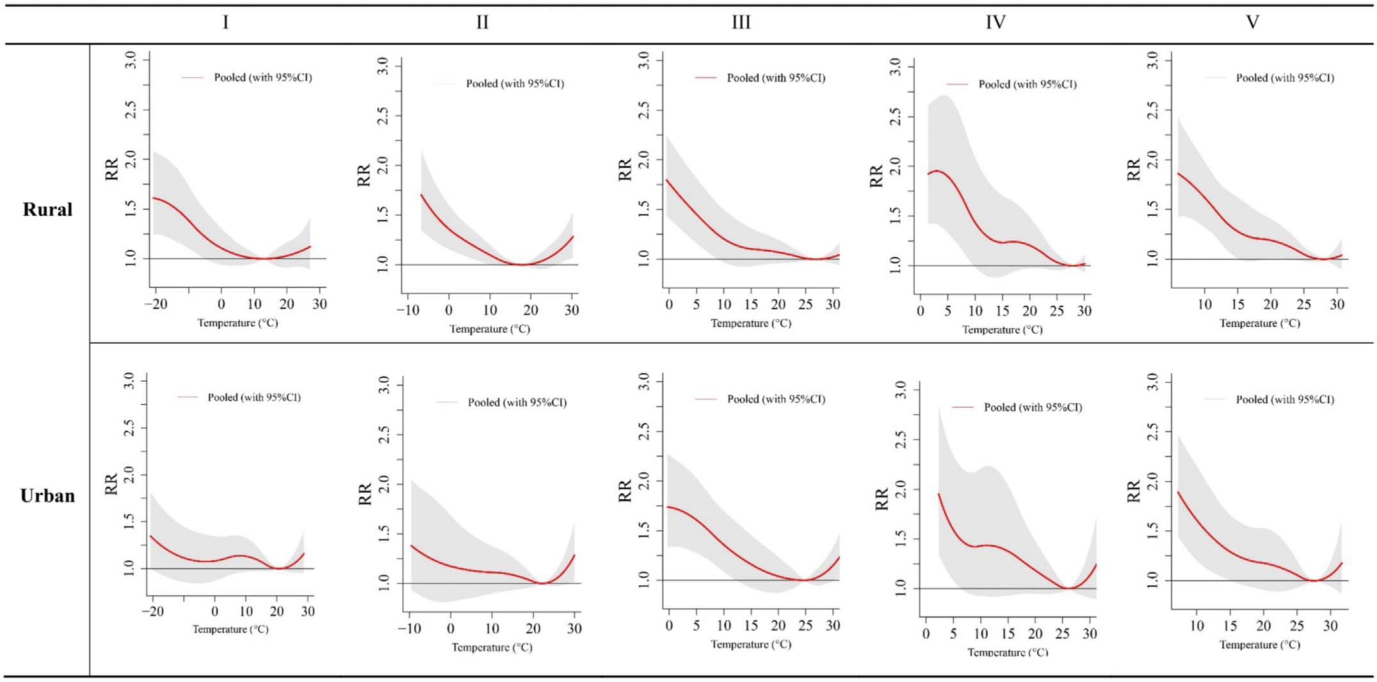

Fig. 2. Temperature-mortality curves in rural and urban areas across different temperature zones.

3.2. Results of the meta-analysis on temperature-mortality curves at the regional scale

The temperature-mortality curves for rural and urban areas were plotted for each temperate zone in Fig. 2. In the temperate zone (zone I), the relationship presented a U-shaped curve with a longer left side in rural areas and a W-shaped curve in urban areas. The minimum mortality temperature (MMT) in rural areas was lower (12.9 °C) than that in urban areas (20.3 °C). In addition, the relative risk (RR) increased more sharply with decreasing temperature in rural areas than it did in urban areas, and vice-versa in urban-rural areas. The findings consequently suggest higher cold-related risk in rural areas, with higher heat risk in urban areas.

In warm temperate zones (zone II), U-shaped curves with a longer left side were found in both, rural and urban areas, suggesting higher cold and heat risk with decreasing and increasing temperature, respectively, in zone II. Moreover, a smaller confidence interval (95% CI of cold risk: 1.34–2.12) in rural areas, compared to urban areas (95% CI of cold risk: 0.91–2.02) highlights a higher confidence level for temperature-mortality relationship in rural areas. A higher cold risk and lower MMT in rural areas relative to those in urban were further substantiated in zone II.

In the north subtropical zone (zone III), which is in the central areas of China, there were large differences in the shapes of the two temperature-mortality curves. In rural areas, the curve was approximately J-shaped. The flat line in the right part of the curve for rural areas indicated minimal change in heat risk with increasing temperature. The overall heat-related risk in rural areas is much lower than that in urban areas. However, the pooled results in the urban areas presented a typical U-shaped curve with a longer left side, suggesting both, low and high temperatures, would increase mortality risk.

In the two southern regions (middle subtropical zone IV and south subtropical zone V), temperature-mortality curves in rural and urban areas were J-shaped curves, with an obviously longer right side and a shorter left side. Moreover, relatively higher confidence levels for temperature-mortality relationships were observed in zone IV than IV. Compared with other zones, the difference in MMT was less (< 2 °C) in the middle and southern zones than that (> 5 °C) in the two north zones (zone I, zone II). Finally, a sharper increase in RR was observed with increasing temperature in urban areas than in rural areas, implying a more significant heat effect in urban areas.

Overall, the temperature-mortality relationships varied from one zone to the other, and from urban areas to rural. The longer left sides for all curves, together with the sharper increase in RR with decreasing temperature, substantiated a higher cold risk than heat risk in both rural and urban areas in each zone. Moreover, consistently higher MMT were observed for urban areas, as compared to rural areas, with an MMT difference of more than 4 °C in the two zones (zone I, zone II).

Table 2
Relative risk of extreme temperatures and MMT at regional level based on the meta-analysis.

		Rural region			Urban region		
		Heat	Cold	MMT	Heat	Cold	MMT
Region	I	1.14(0.89,1.39)	1.60(1.25,2.07)	12.9	1.12(0.95,1.37)	1.31(1.00,1.78)	20.3
	II	1.27(1.07,1.50)	1.69(1.34,2.10)	17.8	1.21(0.98,1.55)	1.37(0.91,2.03)	22.1
	III	1.06(0.93,1.19)	1.77(1.42,2.21)	25.3	1.32(1.05,1.65)	1.73(1.34,2.26)	24.7
	IV	1.03(0.96,1.10)	1.87(1.41,1.94)	26.9	1.18(0.90,1.56)	1.95(1.34,2.84)	26.1
	V	1.02(0.92,1.13)	1.83(1.42,2.43)	28.0	1.15(0.90,1.42)	1.88(1.42,2.45)	27.5

I: Temperate zone; II: Warm temperate zone; III: North subtropics; IV: Middle subtropics; V: South subtropics.

3.3. Mortality risk due to extreme temperatures based on the meta-analysis in temperate zones

The mortality risk due to extreme temperatures and MMT in both, urban and rural areas, in different zones have been summarized in Table 2. MMT is a crucial indicator of the characteristics of the temperature-mortality relationship. It was evident that MMT in both, rural and urban areas, increased with increasing ambient temperature from north to south. In the two northern zones (zones I, II), it was observed that MMT in urban areas was significantly higher than in rural areas. However, in the middle (zone III) and southern zones (zone IV, V), gaps of MMT between urban and rural areas were not so oblivious.

With regard to the risk of extremely low temperature on mortality, it can be seen from Table 1 that the most significant cold effect was observed in zone IV, with a RR of 1.87 (95% CI: 1.41–1.94), while the lowest was in zone I, with a RR of 1.60 (95% CI: 1.25–2.07). In urban areas, cold-related risk increased as the temperature increased, with the highest risk being in zone IV and the lowest risk being in zone I. In addition, we found the cold risk in urban areas of the northern region (zones I and II) was lower than in rural areas, while the result was reversed in the southern regions (zones IV, and V).

With regard to heat-related risk, the risk in rural areas presented a downward trend with decreasing latitude, with the highest RR being 1.27 (95% CI: 1.07–1.50) in zone II, and the lowest RR being 1.02 (95% CI: 0.92–1.13) in zone V. However, the trend of risk associated with extremely high temperatures was observed to be different for urban areas. With increasing temperature (or decreasing altitude) across the five temperature zones, the RR ascends initially, descending subsequently. Moreover, the difference in heat-related risk between urban and rural areas followed a similar pattern with that for cold risk. This indicates that the heat-related risk in urban areas of northern regions was lower than rural areas, and vice-versa for the central and southern areas.

3.4. Meta-analysis results on temperature-mortality curves and relative risk of MoET at a national scale

Fig. 3 and Table 3 show the pooled temperature-mortality response curves based on overall urban and rural results across China. At national level, curves of the temperature-mortality relationship for both rural and urban areas are like"J" shape. However, we found the left of the rural curve is higher than urban curve, which means there was a higher cold risk in rural areas (1.69) than in urban areas (1.51). Meanwhile, it was observed that the right tail of the urban curves is much higher than rural curves and this reflect that the heat risk in urban area was more obvious (urban 1.12 vs. rural 1.01)., Additionally, from Fig. 3 we found MMT was approximately 75% of the average air temperature for both, rural and urban areas, and only a relative lower percentage of temperature was observed for rural areas. Overall, even though shapes of temperature-mortality curves are similar in rural and urban areas at national level, the cold effect was more obvious in rural areas while the heat effect was more obvious in urban areas.

Table 3
Relative risk of extreme temperatures at national level based on the meta-analysis.

	Rural region		Urban region	
	Heat	Cold	Heat	Cold
National	1.01(0.96,1.07)	1.69(1.52,1.88)	1.12(1.04,1.20)	1.51(1.28,1.78)

3.5. Quantifying the impact of air pollution on the temperature-mortality relationship

3.5.1. Seasonal patterns of API in 19 selected cities

Fig. 4 shows the seasonal averages of both air pollution and temperature condition in 19 urban communities. In northern China (zone I and zone II), it was apparent that the air pollution is much more severe in winter months (November, December, January, and February) than in summer season (June, July, and August). However, in the median (northern subtropics) and southern (middle and southern subtropics) China, the API is relatively higher in spring and winter than those in summer. Such seasonal characteristics and regional differences in air pollution are consistent with previous studies (Wang et al., 2011; Zhang et al., 2011; Zhu et al., 2013). Therefore, the consistently lower API in summer had highlighted that there are very weak association between high temperature and air pollution in cities of China

3.5.2. Influence of air pollution on the temperature-mortality relationships of 19 selected cities

The effects of extreme temperature on mortality were calculated among 19 urban communities under two circumstances: with or without API in DLNM (Fig. 5). From the box chart, it can be seen that the upper (75th percentage) and lower quartiles (25th percentage) of both cold and heat effect increased very slightly with API, and the mean/median values were the same with API and without API. This suggests that the modified effect of air pollution on the temperature-mortality relationships was very weak in urban communities.

3.5.3. The response of air pollution to the temperature-mortality relationship between urban and rural areas

The two communities were selected to compare the different responses of air pollution to the temperature-mortality relationships between urban and rural areas (Fig. 6). It was found that the shapes of the DLNM curves, with or without API, are generally similar for urban

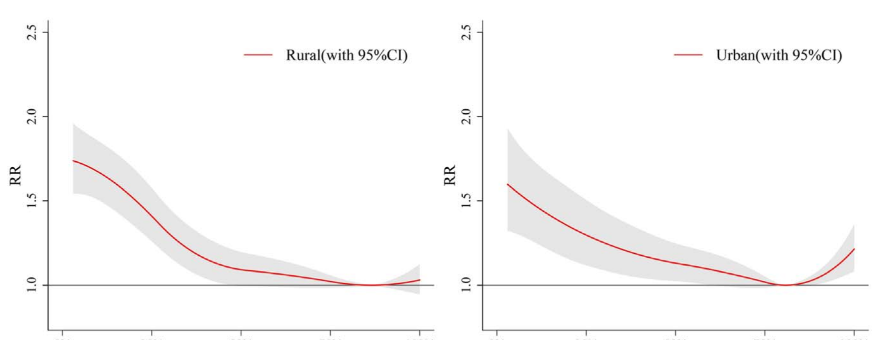

Fig. 3. Meta-analysis on temperature-mortality curves at a national scale. (1) The temperature-mortality relationship of rural areas; (2) The temperature-mortality relationship of urban areas.

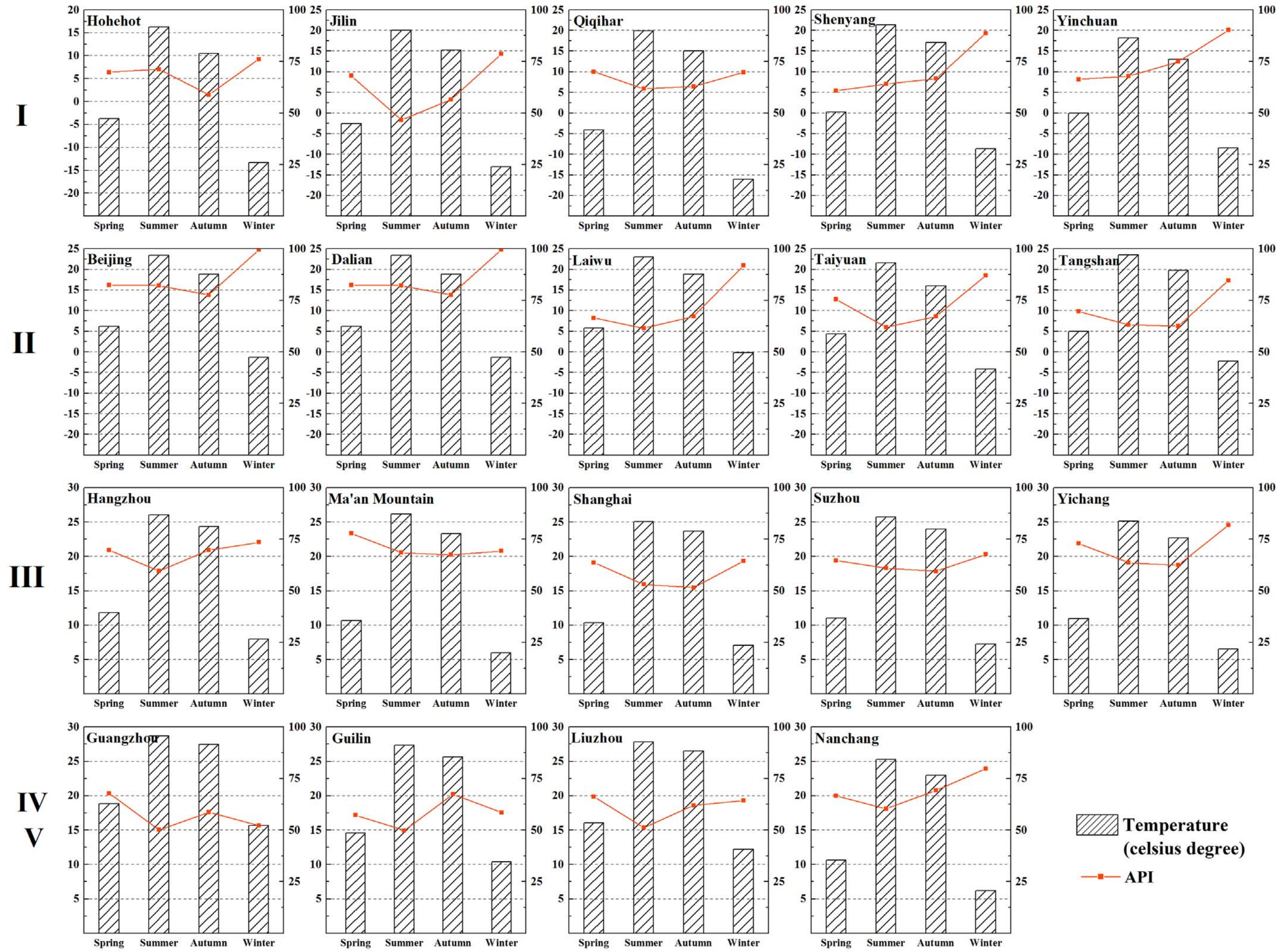

Fig. 4. Seasonal patterns of both API and temperature in 19 urban communities. I: Temperate zone; II: Warm temperate zone; III: North subtropics; IV: Middle subtropics; V: South subtropics.

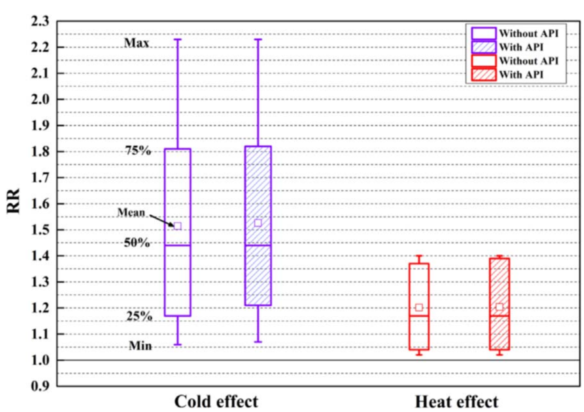

Fig. 5. Comparison of cold and heat effect with and without API. The upper and lower hinges of the box indicate the 75th percentile and 25th percentile, respectively. The line in the box indicates the median value, and the open square represents the mean of the data.

and rural areas. With the ambient temperature ascending, however, the curve of Laiwu city rises more steeply with API than without API, suggesting a high heat risk in urban areas from API. Overall, the change in these two curves was not noticeable when API values were introduced into the related DLNM models.

4. Discussion

In our research, based on the community-specific result of 75 communities in five temperature zones across mainland China, we explored the urban-rural difference in temperature-mortality relationship, and then analyzed the difference in responses of urban-rural mortality to extreme temperature across three spatial scales. To the best of our knowledge, this is the largest study comparing the difference in the temperature-mortality relationship between rural and urban areas in China. Generally speaking, we found people living in the rural areas of northern China and urban areas of southern China suffered more from extreme temperature. Moreover, based on the API data of 19 cities, we found even though there was an effect of API on the temperature-mortality relationship of urban areas, its modification seemed limited. Our findings will provide a deeper and more extensive understanding of the temperature-mortality relationship, with the potential implications providing a paradigm for designing scientific and detailed measures to improve public health in rural and urban areas, especially for the developing countries with large differences in urban and rural areas.

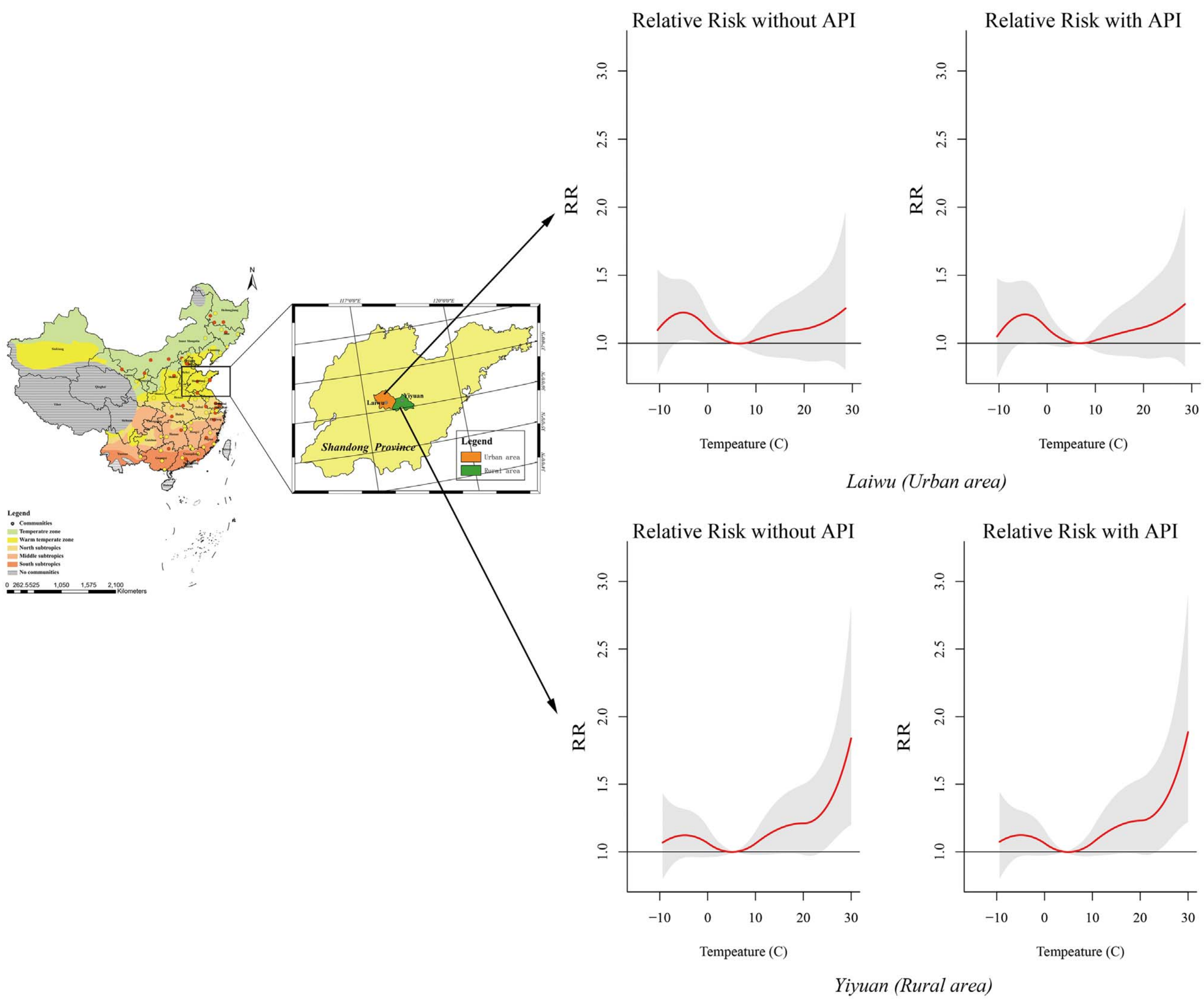

Fig. 6. Effect of API on the temperature-mortality curves of an urban community and its adjacent rural community.

4.1. Characteristics of the difference of temperature-mortality relationship between rural and urban areas and their potential explanations

Based on the meta-analysis at the national level, we found mortality risk related with extremely high temperature was higher in urban region. But both urban and rural people suffered more from extremely low temperature, especially those rural residents. Several previous studies have also pointed out (Guo et al., 2011, 2013; Ma et al., 2015a; Wang et al., 2017; Yang et al., 2012)that extremely low temperatures had a stronger effect on mortality risk than extremely high temperatures in China while our findings further indicated that the cold effect is more serious in rural areas. Even though urbanization of China is very rapid, there is still 40–60% people living in rural areas of China (Liu and Li, 2017). Recent study (Liu and Li, 2017) have pointed that the urban-rural divide is widening. Considering the low level of medical condition in Chinese countryside, government should pay more attention to the prolonged and adverse cold effect on public health, especially in the rural areas.

Previous studies (Analitis et al., 2008; Anderson and Bell, 2009; Curriero et al., 2002) argued that the association of temperature and mortality varied hugely by research sites. However, in our study, even though shapes of temperature-mortality curves were distinct in different temperature zones, some tendency could be observed: more U-shaped curves were found in cold zones while more J-shaped curves were found in heat zones. This tendency was more evident in rural areas, which suggests that, in these areas, the higher the temperature, the lower mortality risk of extreme heat event local residents suffered. Studies (Anderson and Bell, 2009; Guo et al., 2013; Medina-Ramón and Schwartz, 2007) have pointed out acclimatization of people to their local weather conditions would result in the above features of temperature-mortality relationship: people living in hot areas are generally more resilient to heat stress, while being more vulnerable to cold stress due to their physiological resilience ability to ambient air temperature after living in a certain environment for a long period. This spatial diversity suggested that different adaption strategies should be taken in different regions to low the detrimental effect of extreme temperature effect on public.

But we found this spatial tendency is not so obvious in the urban

Table 4
Comparison of the mortality risk of extreme temperature between rural and urban in different regions.

Region	Heat effect	Cold effect
Northern Region	R > U	R > U
Central Region	U > R	R > U
Southern Region	U > R	U > R

* : R: Rural areas; U: Urban areas; northern region included zone I and zone II, central region was the zone III and southern region included zone IV and zone V.

areas, in other words, even in the hotter region, the urban residents may also suffer from local extreme heat events. To draw a more clear comparison to the difference of temperature-mortality relationship between rural and urban areas at regional scale, we summarized the information from Table 1 and Fig. 2 and got a comparison of the mortality risk of extreme temperature between rural and urban in different regions (Table 4). Totally, northern rural areas as well as southern urban areas were at relative higher risk of extreme temperature. Moreover, we could find a clear spatial change of extreme temperature effect on rural and urban areas: with the temperature increasing, risk of extreme temperature became higher in urban areas. Another crucial indicator, MMT (Gasparrini and Armstrong, 2013; Gasparrini et al., 2015a, 2015 b; Ma et al., 2015a), which could also reflect the difference in temperature-mortality relationship between rural and urban areas, show similar spatial tendency: in northern China, the MMTs in rural areas are lower than those in urban areas, while the situation was reversed in the southern regions of China (Table 2 and Fig. 2).

The difference of temperature-mortality relationship between rural and urban areas can be partly ascribed to the change of microclimate resulting from urbanization. Previous studies proved that urbanization can alter underlying surface (Alberti, 2008; Carlson and Arthur, 2000) and result in the UHI (Urban Heat Island)effect (Mohan and Kandya, 2015). UHI effect can heat the ambient temperature in urban regions, especially in some temperate zone (Roth, 2007) and this can mitigate the adverse effect of extremely low temperatures on public health in areas with low ambient temperature: in the northern region, there were a lower cold-related risk and higher MMT of urban areas. Additionally, because of the slow thermal diffusion of urban areas, the effects of UHI would also exacerbate the negative heat effect on residents living in hot regions, such as the southern region. This adverse influence could be observed from the higher heat risk and lower MMT of urban areas in southern China, which is consistent with previous studies (Goggins et al., 2012; Ma et al., 2015b; Tan et al., 2010). Moreover, as we mentioned above (ST2), the urban areas in southern is richer than that in northern. This means more metropolitan areas located in the southern China which means the UHI is more serious in the southern China. Therefore, in southern region, relatively higher air temperature in urban areas due to UHI might cause urban residents to be more vulnerable to cold stress (RR from 1.88 to 1.95) than rural areas (RR from 1.83 to 1.87) in the same zone because of residents' acclimatization to the microclimate. Faced with the rapid urbanization, appropriate strategic plans should be taken to mitigate the potential adverse effect of the UHI on public health in southern region.

Apart from the UHI effect, studies also pointed that social economic factors (Case et al., 2002; Case and Deaton, 2005) can have a modification on the temperature-mortality relationship. Social-economic condition can affect temperature-related public health from various aspects (Gosling et al., 2009). First and foremost, distribution of medical resources as well as infrastructure situation are highly related with the local economic condition, both of which together determined the access to health care (O'Neill et al., 2003). In China, the social-economic status of urban areas is common superior to rural areas. In other words, there is an urban-rural inequality in accessing to health care due to the inequality in economic developing. Previous studies (Liu et al., 2007) also argued that evident disparities in utilization of health care between rural and urban areas exists in China. Another important social-economic factor is the use of heating system and air-conditioning. Compared Fig. S1 to Fig. 1, it was clear that the northern region (zone I and zone II) was central heating area while southern region (zone IV, zone V) was excluded. Central heating in China is a public policy, which has been implemented in urban areas of northern China many years ago. Consequently, from Table 2, a significantly lower cold risk has been observed in urban areas than in rural areas in the two northern temperature zones (zones I and II). Thus, our study also sustained the point (Gasparrini et al., 2015a; Ma et al., 2015b) that social factors have modification effect on the association with the temperature-mortality relationship. Previous studies (O'Neill et al., 2005; J Tan et al., 2007a) have proved that lack of air-conditioning might be related with the excess-heat deaths (Medina-Ramon and Schwartz, 2007). Some rural residents in China still have no air conditioning due to poverty. Moreover, even though most family in urban areas are equipped with air conditioning, Liu et al. (2013b) found some vulnerable populations, such as the elderly, were often reluctant to use them because of the high electricity cost, which will pose them at a higher risk of extreme high temperature.

Previous studies (Gasparrini et al., 2015a; Patz et al., 2005) have stressed that extreme temperature have significant influence on several disease. Extreme heat event has a greater effect on respiratory disease (Ai et al., 2008; Le et al., 2006), such as pneumonia and influenza (Fuhrmann et al., 2016), and it can serve as stressors in individuals with pre-existing cardiovascular and cerebrovascular disease as well as can directly precipitate exacerbations. Compared with the heat event, extreme low temperature is often associated with cardiovascular disease (Kysely et al., 2009), such as stroke, chest pain, dysrhythmias and so on. Thus, the governments and policy-makers in China should take corresponding measures to mitigate the adverse effect of extreme temperature on public health. As we mentioned above, it is very necessary to develop regional specific response plans. For northern region, it is very necessary for government to help rural residents improve their indoor temperature condition to mitigate adverse effect of extreme weather condition in summer and winter, including providing home heater and air-conditioning, cutting down the power fare for the poverty. Moreover, as we mentioned above, extreme cold can exacerbate cardiovascular diseases. Thus, promoting the local health system in rural areas and increasing the emergency ambulances both in rural and urban areas during the winter were also helpful to low the cold effect on public health in the north. For southern region, government can take alternative measures to improve the adaption capacity of the public, especially those vulnerable population, such as promoting air conditioning use(Tan et al., 2007b), setting up heat early warning systems (Matthies and Menne, 2012), cooperating with commercial insurance company to promote health insurance (Mills, 2007) and so on. Another considerable point is adverse effect of on public health. Given the rapid urbanization in China, it is very essential for government to make scientific urban planning to mitigate the effect of UHI.

4.2. Modified effect of the air pollution on the temperature-mortality relationship in China

Both environmentalists and epidemiologists, are concerned with the interactions between ambient temperature and air pollution, along with its adverse effects on human health (Gordon, 2003; Ren et al., 2008a, 2008b; Roberts, 2004; Samet et al., 1998; Williams and Tong, 2006). Many previous researchers (Chen et al., 2015; Guo et al., 2011; Xie et al., 2013) have pointed out that the combined effects of air pollution and ambient temperature could exacerbate the adverse impact on public health, while some recent studies on the temperature-mortality relationship in China found no significant influence when air pollution was taken into consideration. According to the API data of 19 urban communities in our research, the reason behind the disagreement between studies in China and other developed countries was the difference in temporal distribution of air pollution between China and Europe (Katsouyanni et al., 1993) or North America (Ren and Williams, 2007). Fig. 4 shows that the level of air pollution is high in winter and low in summer. Our result was consistent with the seasonal distribution of air pollutants in China (YG Wang et al., 2014b; Zhang et al., 2011; Zhu et al., 2013) and some study further points out there is a synergistic effect of the air pollution and low temperature in China (Cheng and Kan, 2012). Furthermore, in the present study, we assumed that the air pollution situation in rural regions was the same as the adjacent urban regions. However, the result shows no significant change when we introduced API into the model, even though the overall trend of the relative risk appeared to ascend slightly. Similarly, a recent nationwide investigation (Chen et al., 2017) on the fine particulate air pollution and daily mortality in China also demonstrated that the adverse effect of PM2.5 on public health in China was lower than those reported in Europe and North America. These differences between China and other developed countries can be ascribed to the difference in seasonal distribution of air pollutants between China and those developed countries. Therefore, considering the high level of air pollution in winter, more study should pay attention to the negative effect of the interaction between the cold environment and air pollution on public health in China.

4.3. Limitations

We concede that some limitations continue to exist in our research, although we determined the distinct responses of MoET between rural and urban areas. Firstly, even though we considered the air pollution, the only available data, API, cannot adequately represent the concert air pollutants such as sulfur dioxide, ox nitride completely. Secondly, some uncertainty also exists in the limited meteorological dataset obtained from an interpolated method, with some gap existing between observed data and interpolated data. Lastly, what we stress or the main focus of this research was to provide a comprehensive perspective to compare the different temperature-mortality relationship and investigate different response of resident mortality to extreme temperatures between urban and rural areas across the whole China. Therefore assessing the modification of individual factors or social-economic factors, such as gender, age and cause of death in detail, have not been taken into the model, which would be taken into consideration in the future study.

5. Conclusion

Our research utilized valid data from more than 70 communities to explore the temperature-mortality relationship of rural and urban areas across different temperature zones in China at different spatial scales, comparing the difference in responses of MoET. Overall, cold effect is more significant in China both in rural and urban areas and urban areas in southern China and rural areas in northern China suffered more from extreme temperature events. Moreover, we found the modification of air pollution on the urban temperature-mortality relationship is not significant in China because the air pollution is often at high-level in the cold season instead of the warm season. Our findings suggested that developing countries should not only adopt efficient measures to improve infrastructure systems to prevent extreme temperature events, but also make scientific urban planning during rapid urbanization to avoid exacerbating the effects of UHI. Furthermore, more studies should pay attention to the interactive relationship between air pollution and low temperature in China.

Acknowledgement

This study was supported by the fund for Creative Research Groups of the National Natural Science Foundation of China (No. 41621061) and National Natural Science Foundation of China (41571493; 41571088).

Conflict of interest

None declared.

Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at https://doi.org//10.1016/j.healthplace.2018.01.011.

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