Preplanned Studies

High Temperature and Risk of Cause-Specific Mortality in China, 2013–2018

Yu Zhong[1]; Chen Chen[1]; Qing Wang[1]; Tiantian Li[1,#]

Summary

What is already known about this topic?

High temperature is a well-recognized public health threat and may increase mortality risks, especially mortality risks involving diseases of the circulatory system.

What is added by this report?

Using a six-year time series analysis, the differences of daily mean, maximum, minimum temperature were explored in assessing the health effects of high temperatures in nationwide and at climatic-zone level, and population groups susceptible to high temperatures were identified.

What are the implications for public health practice?

This study suggests that the daily mean temperature is the optimal indicator for high temperature exposure in heat-related health risk assessments and early warnings. The policy measures of heat-related public health protection should be made considering regional distribution, sensitive diseases, and vulnerable populations.

There is no nationally representative conclusion on associations between high temperature and cause-specific mortality, and it is unclear which indicator is applicable for evaluating health risks for high temperature. This study intends to estimate associations between high temperature and cause-specific mortality and to identify suitable indicators for heat-related risk assessment. We applied a time-series study with generalized linear model in 130 Chinese counties to estimate the national and climatic-zone associations between 3 high temperature indicators and cause-specific mortality for summer months of 2013–2018. We also considered estimation for sex and age groups. We found that all 3 high temperature indicators had positive associations with cause-specific mortality, and associations between daily mean temperature and cause-specific mortality were relatively higher than daily maximum and minimum temperature. Female and the elderly aged 75 years old or more were the population groups more susceptible to heat-related mortality. This study provides key information for future heat-related health risk assessments and early warning systems and suggests that public health action plans on high temperatures should be tailored to vulnerable population and climatic zones.

The influence of high temperature on human health has been a worldwide major public concern during the past few decades (*1–4*). During the 2003 heat wave in France, the number of deaths related to high temperature was 3,306, including 3,004 deaths from heat-related circulatory system diseases (*5*). Many studies have found that the mortality rates of ischemic heart disease (IHD) and cerebrovascular disease were associated with high temperature (*4*). The Intergovernmental Panel on Climate Change (IPCC) has predicted that global temperature is likely to increase 1.5 ℃ between the 2030s and 2050s, and global extreme heat events will increase in frequency, duration, and intensity (*6*). Previous studies have predicted that heat-related mortality may increase by 66%, 257%, and 535% by the 2020s, 2050s, and 2080s, respectively (*7*). Along with rising temperature levels under climate change, the effects of high temperature on human health will likely become more serious in the future.

However, as the association between high temperature and mortality may vary by study area, there is no consistent conclusion on the quantitative effect of high-temperature to mortality (*8*). Furthermore, there is currently no agreement on which indicator should be used for high temperature measurements to evaluate health risks (*8–9*). Under the conditions of different climatic zones, it is especially necessary to identify the appropriate indicator to conduct the high temperature related health risk assessment and establish the early warning system in China.

The main purpose of this study is to evaluate the effect of high temperature indicators (daily mean, maximum, and minimum temperature) on mortality and determine the optimal high temperature indicator. Moreover, this study also sought to estimate the mortality effects of high temperature on different population groups and different climatic zones.

We linked three indicators (mean, maximum, and minimum) on daily temperature with daily mortality counts for the summer months (June, July, August, and September) of 2013 to 2018 in 130 Chinese counties. A map of climatic zones was provided by the China Meteorological Administration (*10*) (Supplementary Figure S1 available in http://weekly.chinacdc.cn/). These 130 counties were distributed in different climatic zones with 42 counties in subtropics, 71 counties in warm temperature zone, 15 counties in middle temperate zone, and 2 counties in plateau climatic zone.

Meteorological data were collected from the European Centre for Medium-Range Weather Forecasts. The daily mortality data were obtained from the Disease Surveillance Point System (DSPS) of China CDC. Based on this dataset, the daily counts of non-accidental mortality and circulatory system disease mortality were calculated. The causes of circulatory system mortality, including cerebrovascular disease, ischemic heart disease, myocardial infarction, and stroke, were also analyzed in this study. The International Statistical Classification of Disease Version 10 (ICD-10) of the included diseases was provided in supplementary material (available in http://weekly.chinacdc.cn/). We classified the deaths by age (0–64, 65–74, and ≥75) and sex (female and male). To adjust for the confounding effects of air pollutants, we collected air pollution data, including the concentrations of fine particulate matter ($PM_{2.5}$) and ozone (O_3), and the data sources and cleaning principles of air pollutants had been described in previous study (*11*) .

The associations between high temperature and mortality were investigated in a two-stage analysis. First, we analyzed associations of high temperature and cause-specific mortality in each county by using a generalized liner model (GLM) with quasi-Poisson regression. Second, we pooled estimates nationwide and at climatic-zone scales by a random effects meta-analysis. Considering the lagged effect of high temperature, the moving average exposure of previous 1 day and current day (lag 01) was the largest and used in the core model to assess heat effects (Supplementary Figure S2 available in http://weekly.chinacdc.cn/). We also examined the effects at other lags of high temperature. Furthermore, in order to identify vulnerable populations for heat-related mortality, we performed the subgroup analysis by sex (female and male) and age (0–64, 65–74, and ≥75) groups. We conducted sensitivity analysis to validate the robustness of the core model. The temperature-mortality association was estimated by percent increase in mortality risk and its 95% confidence interval (CI) with 1 ℃ increase of daily high temperature indicators. Detailed information on the statistical model and sensitivity analysis were available in the supplementary materials. All analyses were performed by R statistical software (version 4.0.0; The R Foundation for Statistical Computing).

During the study period, the 24-hour average value of daily mean, maximum, and minimum temperature of all the studying counties was 24 ℃, 29 ℃, and 20 ℃, respectively; the daily mean deaths of non-accidental were 9 ± 6 and circulatory system disease were 4 ± 3 per day (Table 1). For each climatic zone, the descriptive results were shown in supplementary Table S1 (available in http://weekly.chinacdc.cn/).

At the national level, daily mean, maximum temperature, and minimum temperature were all significantly associated with the six causes of mortality. Using Z test, we found that associations between daily mean temperature and the 6 causes of mortality were more significant (Figure 1 and Supplementary Table S2 available in http://weekly.chinacdc.cn/). The 1 ℃ increase of daily mean temperature was estimated to have a 2.71% (95% CI: 2.25%–3.19%) increase of heat effect on IHD mortality, while the heat effect on stroke mortality showed a lower level increase (1.67% with 95% CI: 1.28%–2.07%).

For the climatic zones, the associations between daily mean temperature and the six causes of mortality in all climate zones were consistent with nationwide results, especially in warm temperature zones with 1 ℃ increase in daily mean temperature, the mortality risk for IHD was estimated to increase by 2.95%, (95% CI: 2.31%–3.60%), and the stroke has the lowest mortality risk increase 1.52%, (95% CI: 0.99%–2.05%) (Figure 1).

For subgroup analysis, females and people older than 75 years were more vulnerable to high temperatures. For females, mortality risk of circulatory system disease was estimated to increase by 3.12% (95% CI: 2.67%–3.57%). For the group aged over 75 years old, the mortality risk of circulatory system disease was estimated to increase by 3.00% (95% CI: 2.59%–3.42%) (Table 2).

TABLE 1. Summary statistics of mortality, meteorology, and air pollution of summer months in 2013 to 2018 nationwide

Variable	Mean ± SD	Median (P_{25}, P_{75})
Cause of mortality		
Non-accidental mortality	9 ± 6	7 (4, 12)
Circulatory system disease	4 ± 3	3 (2, 6)
Cerebrovascular disease	2 ± 2	1 (0, 3)
Ischemic heart disease	2 ± 2	1 (0, 3)
Myocardial infarction	1 ± 1	1 (0, 1)
Stroke	1 ± 2	1 (0, 2)
Meteorology		
Temperature (℃)		
Daily mean temperature	24 ± 5	25 (21, 27)
Daily maximum temperature	29 ± 5	29 (26, 32)
Daily minimum temperature	20 ± 5	21 (17, 24)
Relative humidity (%)		
Daily mean relative humidity	72 ± 16	75 (63, 83)
Air pollution		
$PM_{2.5}$ concentration (24-hour average, μg/m^3)	39 ± 28	32 (20, 50)
O_3 concentration (24-hour average, μg/m^3)	73 ± 35	70 (48, 95)

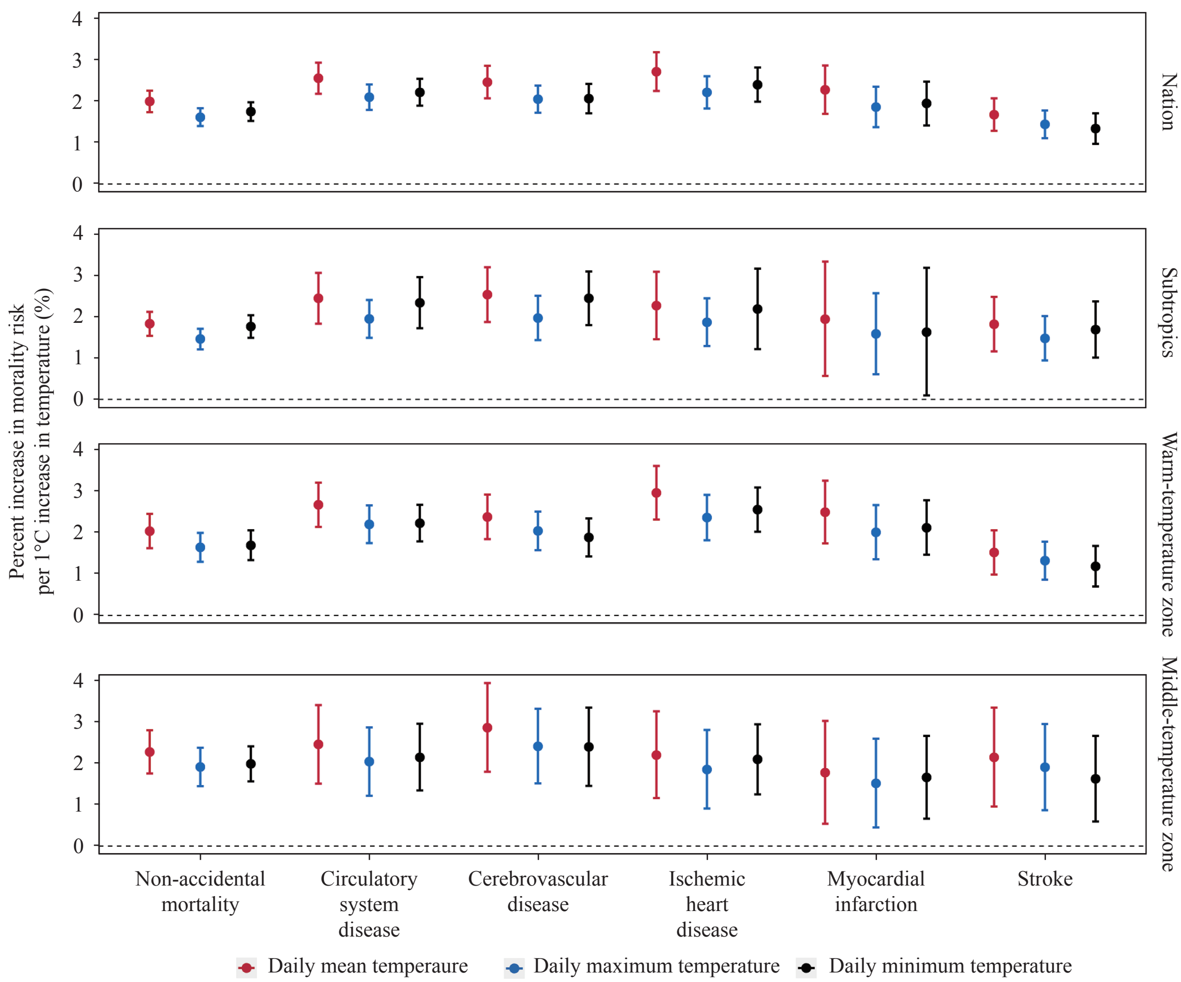

FIGURE 1. Percent increase in mortality risk due to high temperature during summer months of 2013 to 2018 in nation and climate zones.

TABLE 2. Subgroups estimates of high temperature and mortality risk for the summer months in 2013 to 2018 nationwide.

Cause of death	Exposure	Percent increase in mortality risk (%)(95%CI)				
		Female	Male	Age 0–64	Age 65–74	Age ≥75
Non-accidental mortality	Daily mean temperature	2.54 (2.20–2.88)	1.62 (1.39–1.85)	1.06 (0.77–1.34)	1.82 (1.50–2.15)	2.53 (2.21–2.85)
	Daily maximum temperature	2.05 (1.77–2.33)	1.30 (1.10–1.50)	0.86 (0.62–1.10)	1.46 (1.19–1.73)	2.04 (1.78–2.31)
	Daily minimum temperature	2.24 (1.94–2.54)	1.42 (1.22–1.62)	0.90 (0.63–1.17)	1.54 (1.26–1.83)	2.26 (1.97–2.56)
Circulatory system diseases	Daily mean temperature	3.12 (2.67–3.57)	2.08 (1.71–2.46)	1.16 (0.66–1.65)	2.51 (2.06–2.96)	3.00 (2.59, 3.42)
	Daily maximum temperature	2.57 (2.19–2.94)	1.70 (1.38–2.01)	0.94 (0.52–1.37)	2.03 (1.64–2.43)	2.47 (2.13–2.80)
	Daily minimum temperature	2.72 (2.32–3.12)	1.80 (1.46–2.13)	1.00 (0.58–1.42)	2.08 (1.67–2.48)	2.65 (2.26–3.03)

DISCUSSION

In this study, we assessed associations between high temperature indicators and six causes of mortality. We found that high temperature indicators had positive associations with six causes of mortality, and the daily mean temperature was estimated to have higher mortality-effect than daily maximum and minimum temperature. The elderly group (aged 75 years old or more) and female were more vulnerable to heat-related mortality risks.

A study in US showed that a 5 ℃ increase in mean, maximum, and minimum temperature was accompanied by a non-accidental mortality increase of 3.58%, 2.27%, and 3.14%, respectively (*1*). The association between mean temperature and non-accidental mortality was higher than that of the maximum and minimum temperature (*1*), which was consistent with our study. However, a study of nine counties in California found that the daily minimum temperature had a higher association with mortality than daily mean and maximum temperature (*2*). The inconsistency may be due to the differences in geographical characteristics and demographic structure (*8*), as well as the difference in the sensitivity of the population to night temperature changes (*2*). In many countries, daily mean temperature was widely used as the exposure indicator for high temperature monitoring and health risk assessments (*9*). The daily mean temperature represents the average level of exposure and had a good representativeness when applied to estimating health risks due to high temperature. This suggested that we could give priority to daily mean temperature as the exposure measurement indicator when conducting heat-health early warning research.

Previous studies had found that high temperature was associated with deaths due to circulatory system disease (*4*). A worldwide meta-analysis reported that high temperature increased 1 ℃, the mortality risks of circulatory increased by 1.3% (95% CI: 1.1%–1.5%) (*4*), which was consistent with our findings at the national-level and climatic-zone level.

Some previous studies had not found any differences of high-temperature-related mortality risk between genders (*3*). Through subgroup analysis, we observed that females were a high-risk group for high temperature and that the elderly aged over 75 years old were more vulnerable to high temperature. The elderly may be more likely to be in poorer physical health than those in younger groups and may more likely to have basic diseases. In addition, the elderly had a more limited ability to perceive changes in the temperature of the external environment, so their adaptability to high temperatures was reduced (*3*).

This study was subject to at least one limitation. In addition to the single temperature indicator, some studies have constructed composite indicators that included both temperature and humidity variables (*8*–*9*). Since this model controlled the confounding effects of humidity factors, in order to avoid the variable collinearity, the health impact of the composite indicator had not been estimated in this study and therefore further analysis is needed.

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Corresponding author: Tiantian Li, litiantian@nieh.chinacdc.cn.

[1] China CDC Key Laboratory of Environment and Population Health, National Institute of Environmental Health, Chinese Center for Disease Control and Prevention, Beijing, China.

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Supplementary Material

Mortality data

This study includes six causes of mortalities: Non-accidental mortality (ICD-10:A00-R99), Circulatory system disease (ICD-10:I00-I99), Cerebrovascular disease (ICD-10:I60-I69), Ischemic Heart Disease (ICD-10:I20-I25), Myocardial infarction (ICD-10:I21-I23), and Stroke (ICD-10:I60-I64). They are classified by the International Statistical Classification of 10th Revision (ICD-10; World Health Organization 2007).

Meteorological data

Temperature and dewpoint temperature during summer of 2013 to 2018 in 130 counties were collected from the European Centre for Medium-Range Weather Forecasts (https://cds.climate.copernicus.eu/cdsapp#!/dataset/reanalysis-era5-land?tab=form). First, we calculated the daily temperature and dewpoint temperature in each county by using R software (version 4.0.0; The R Foundation for Statistical Computing); then, according to the equation, we calculated daily relative humidity by temperature and dewpoint temperature for each county.

$$e = 6.11 * 10^{\left(\frac{7.5*T_d}{237.3+T_d}\right)}$$

$$e_s = 6.11 * 10^{\left(\frac{7.5*T}{237.3+T}\right)}$$

$$rh = \frac{e}{e_s} * 100$$

In the formula, T was temperature (℃), T_d was dewpoint temperature (℃), e was the actual vapor pressure, e_s was saturated vapor pressure, rh was the relative humidity (%).

Statistical model

$$LogE(Y_t) = Intercep_t + \beta_1 Var_t + \beta_2 RHmean_t + ns(time, df) + dow$$

In the formula, t was the day of observation; Y_t was the observed daily death counts on day t; β_1 was the regression coefficient of Var_t; β_2 represented regression coefficient of daily mean relatively humidity; Var_t was the observed variable of daily mean temperature, daily maximum temperature, daily minimum temperature on day t; $RHmean_t$ represented mean relative humidity at day t; ns ($time$, df) represented the natural-spline function of time trend and was used a natural cubic regression spline with 3 degrees of freedom (df) in summer of per year to control the long-term and seasonal trends; dow was a dummy variable to control the week effect.

Lagged effect of high temperature

In this study, we studied the lag structures for high temperature and cause-specific mortality. The association between the current day (lag0) of high temperature and cause-specific mortality was tested. What is more, the moving average lag of 1 day to the moving average lag of 7 days of high temperature were also examined in this study. The mortality effect of moving average exposure of previous 1 day and current day (lag 01) was highest among all the lagged exposures (Supplementary Figure S2).

Z test

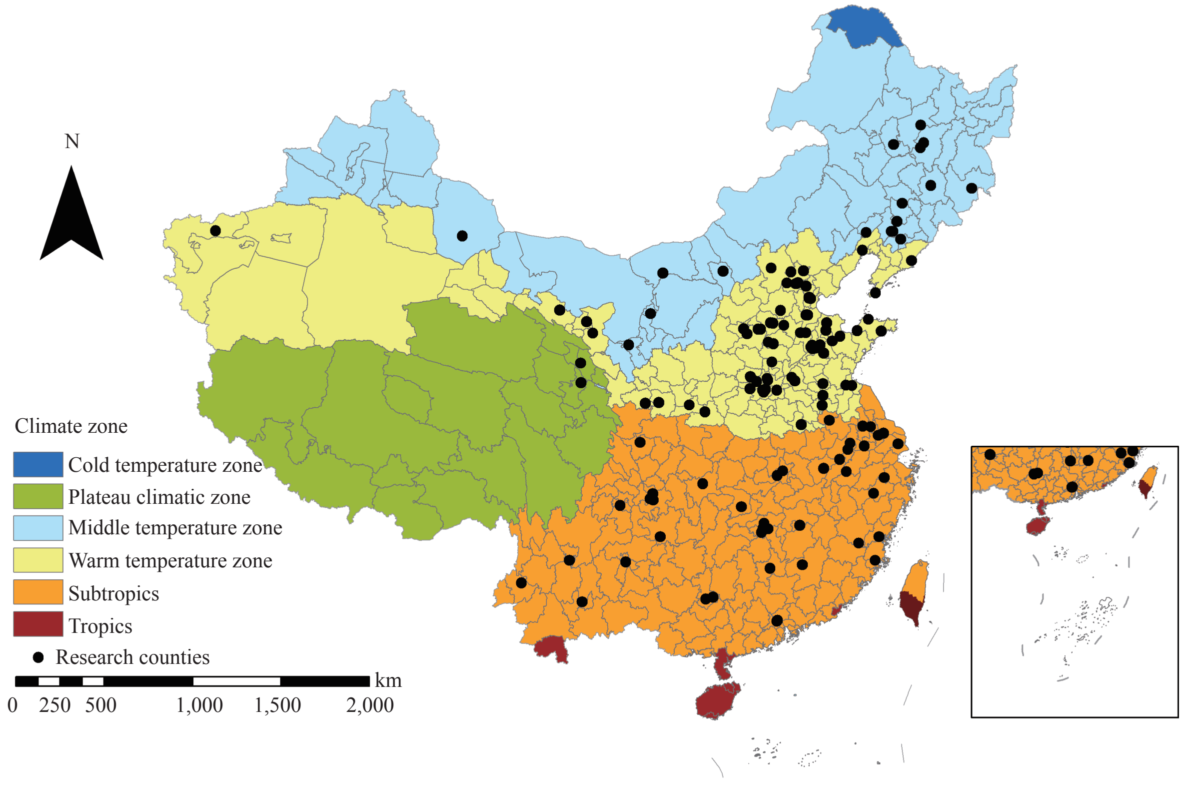
To determine if the risk estimates of high temperature indicators were statistically different, we used the daily mean temperature as a reference and compared it with the daily maximum and minimum temperature respectively (Supplementary Table S2).

$$z = \frac{\beta_1 - \beta_2}{\sqrt{se_1(\beta_1)^2 + se_2(\beta_2)^2}}$$

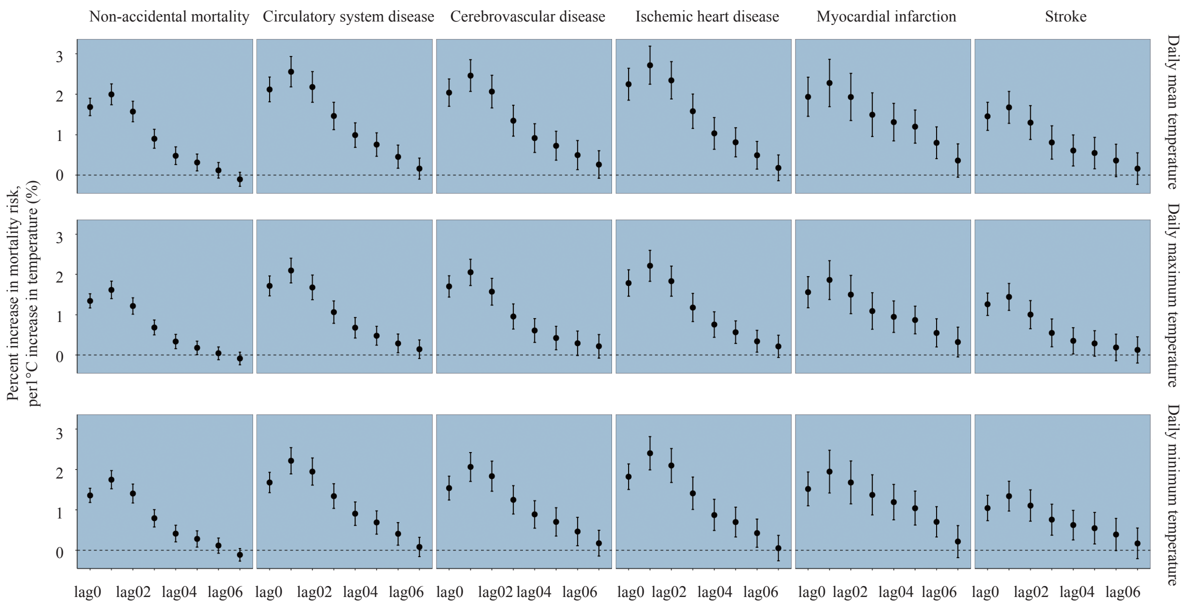
The formula z value was the Z test score for pairwise comparison; the β_1 was the regression coefficient of the daily mean temperature; β_2 was the regression coefficient of the daily maximum temperature or daily minimum temperature; se_1 represented the standard error of daily mean temperature; se_2 represented the standard error of daily maximum temperature or daily minimum temperature.

Sensitivity analysis

Table S3 showed the sensitivity analysis results of daily mean temperature and non-accidental mortality: first, specification of degrees of freedom in the smooth functions of time (df_{time}=2, 4) to observe whether the effect estimation changed; second, inclusion of $PM_{2.5}$ and O_3 as potential confounders on the relationship between high temperature and health, respectively. Sensitivity analysis showed that the core model was robust (Table S3).



SUPPLEMENTARY FIGURE S1. The map of climatic-zones and the distribution of the surveyed 130 counties in China.



SUPPLEMENTARY FIGURE S2. Percent increase in mortality risk due to lagged effect of heat exposure for summer months in 2013 to 2018 nationwide.

SUPPLEMENTARY TABLE S1. Descriptive analysis of daily cause-specific mortality and meteorological data for the summer months in 2013 to 2018 at four climatic zones.

Item	Subtropics	Warm-temperature zone	Middle-temperature zone	Plateau climatic zone
Number of counties	42	71	15	2
Causes of death (Mean ± SD)				
Non-accidental mortality	9 ± 6	9 ± 7	8 ±6	1 ± 1
Circulatory system disease	4 ± 3	4 ± 4	4 ± 3	1 ± 1
Cerebrovascular disease	2 ± 2	2 ± 2	2 ± 2	0 ± 1
Ischemic heart disease	1 ± 1	2 ± 2	2 ± 2	0 ± 0
Myocardial infarction	1 ± 1	1 ± 1	1 ± 1	0 ± 0
Stroke	1± 1	1±2	1 ± 1	0 ± 1
Meteorological factors (Mean ± SD)				
Daily mean temperature (℃)	26 ± 4	24 ± 4	21 ± 5	11 ± 4
Daily maximum temperature (℃)	29 ± 4	29 ± 4	26 ± 5	16 ± 5
Daily minimum temperature (℃)	22 ± 4	20 ± 4	16 ± 5	6 ± 5
Daily mean relative humidity (%)	80 ± 10	68 ± 15	64 ± 20	69 ± 16

SUPPLEMENTARY TABLE S2. Z test of different heat temperature indicators on cause-specific mortality risk for the summer months in 2013 to 2018 nationwide.

Item	Percent increase in mortality risk (%)(95%CI)					
	Non-accidental mortality	Circulatory system disease	Cerebrovascular disease	Ischemic heart disease	Myocardial infarction	Stroke
Indicator						
Daily mean temperature*	2.00 (1.74–2.25)	2.56 (2.18–2.93)	2.46 (2.07–2.85)	2.71 (2.25–3.19)	2.28 (1.70–2.86)	1.67 (1.28–2.07)
Daily maximum temperature	1.61 (1.40–1.83) †	2.10 (1.79–2.41) †	2.05 (1.72–2.38) †	2.21 (1.82–2.60) †	1.86 (1.37–2.35) †	1.44 (1.11–1.77) †
Daily minimum temperature	1.75 (1.52–1.97) †	2.21 (1.89–2.54) †	2.06 (1.71–2.42) †	2.40 (1.99–2.81)	1.94 (1.42–2.47) †	1.34 (0.97–1.71) †

* Daily mean temperature as a reference.
† Z test: p value<0.05.

SUPPLEMENTARY TABLE S3. Summary estimates of sensitivity analysis for daily mean temperature and non-accidental mortality.

Item	No. of Counties	Percent increase in mortality risk (%)(95%CI)
The main analysis		
df_{time}=3	130	2.00 (1.74–2.25)
Alternative degrees of freedom		
df_{time}=2	130	1.51 (1.29–1.74)
df_{time}=4	130	1.94 (1.70–2.18)
Adjusted by adding air pollutants		
$PM_{2.5}$	130	2.19 (1.89–2.49)
O_3	130	2.08 (1.79–2.38)