



ARTICLE



Mortality burden attributable to temperature variability in China

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BACKGROUND: Several studies have investigated the associations between temperature variability (TV) and death counts. However, evidence of TV-attributable years of life lost (YLL) is scarce.

OBJECTIVES: To investigate the associations between TV and YLL rates (/100,000 population), and quantify average life loss per death (LLD) caused by TV in China.

METHODS: We calculated daily YLL rates (/100,000 population) of non-accidental causes and cardiorespiratory diseases by using death data from 364 counties of China during 2006–2017, and collected meteorological data during the same period. A distributed lag non-linear model (DLNM) and multivariate meta-analysis were used to estimate the effects of TV at national or regional levels. Then, we calculated the LLD to quantify the mortality burden of TV.

RESULTS: U-shaped curves were observed in the associations of YLL rates with TV in China. The minimum YLL TV (MYTV) was 2.5 °C nationwide. An average of 0.89 LLD was attributable to TV in total, most of which was from high TV (0.86, 95% CI: 0.56, 1.16). However, TV caused more LLD in the young (<65 years old) (1.87, 95% CI: 1.03, 2.71) than 65–74 years old (0.85, 95% CI: 0.40–1.31) and ≥75 years old (0.40, 95% CI: 0.21–0.59), cerebrovascular disease (0.74, 95% CI: 0.36, 1.11) than respiratory disease (0.54, 95% CI: 0.21, 0.87), South (1.23, 95% CI: 0.77, 1.68) than North (0.41, 95% CI: –0.7, 1.52) and Central China (0.40, 95% CI: –0.02, 0.81). TV-attributed LLD was modified by annual mean temperature, annual mean relative humidity, altitude, latitude, longitude, and education attainment.

SIGNIFICANCE: Our findings indicate that high and low TVs are both associated with increases in premature death, however the majority of LLD was attributable to high TV. TV-related LLD was modified by county level characteristics. TV should be considered in planning adaptation to climate change or variability.

IMPACT:

- (1) We estimated the associations of TV with YLL rates, and quantified the life loss per death (LLD) caused by TV.
- (2) An average of 0.89 years of LLD were attributable to TV, most of which were from high TVs.
- (3) TV caused more LLD in the young, cerebrovascular disease, and southern China.
- (4) The mortality burdens were modified by county level characteristics.

Keywords: Distributed lag non-linear model; Temperature variability; Years of life lost; Multivariate meta-analysis

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INTRODUCTION

Climate change has been regarded as the greatest threat to global public health in the twenty-first century [1]. In the context of climate change characterized with global warming, the global surface temperature has significantly increased in the past century

[2]. Numerous studies have illustrated significant associations of non-optimal temperatures with mortality and morbidity of various causes [3–5]. The associations of temperatures with mortality and morbidity are often U-, V- or J-shaped, with increases in the risks of mortality and morbidity at high or low temperatures. It has been

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estimated that more than five million deaths were associated with non-optimal temperatures per year globally [6].

Climate change not only increases the mean temperature, but also increases the variability of temperature [2]. It was suggested that people may adapt to the usual mean temperature but not well adapt to the variable temperature [7]. Previous studies have demonstrated the associations between temperature variability (TV) and adverse health outcomes [8–11]. For example, Lim et al. reported positive associations of diurnal temperature range (DTR) with hospital admissions for cardiovascular and respiratory diseases in Korea [8]. Lin et al. observed significant associations of temperature changes between neighboring days with mortality from non-accidental diseases and cardiovascular diseases [9]. These studies have provided a robust evidence on the health effects of TV.

Although the health effects of TV have been investigated in many previous studies, there are several issues that are worthy further concerns. First, many previous studies defined TV as temperature variation in intraday or interday separately. However, because temperature fluctuation is a continuous process, ignoring the temporal character of TV (without considering the intraday and interday variability together) may induce misclassifications of exposure assessment, and lead to biased health effects of TV. Several recent studies defined the TV with consideration of both intra- and interday temperature variations by calculating the standard deviation of temperatures within 2 days, and have found significant effect of TV on human health [7, 12]. However, the effects of TV on human health remain unclear particularly in developing countries which may experience more significant climate change in the future [2]. Researchers have also called for more comprehensive studies across the world to estimate the health effects of TV because it of TV may greatly vary among different countries and regions [7]. Findings of these studies have important implications for assessing TV-related disease burden and reducing the health consequences of unstable temperatures.

The second issue is related to the metrics of mortality. Most previous studies employed death count as the health outcome to estimate its association with TV [7–9, 12, 13]. The metric of death count equally weights every death at different ages, and is difficult to adequately depict the actual mortality burden attributed to TV. Although all lives are valuable, loss of young lives may lead to a greater loss of social contributions. Several studies have suggested to employ years of life lost (YLL) as the metric of mortality [5, 14–16]. Different from death counts, YLL takes not only death counts but also life expectancy and age at death into consideration, which could quantify mortality burden more precisely [17]. YLL assigned greater weights to deaths occurred at younger ages, because from a public health perspective, dying at younger ages could produce heavier burden [18]. As a key component of disability adjusted life years, YLL could be more useful to evaluate the health effects of environmental factors [19–21]. However, up to date, it is unclear of what extent does TV reduce life years. Results of such studies would help the public and policy makers to deepen the understanding of the magnitude of TV-associated health effects.

In addition, previous studies have shown modification effects of location, sociodemographic situation, and climate conditions on the TV-health impacts [13, 22, 23]. With varied terrain and great diversity of climates, climate change in China has been a crucial public health issue [24]. Considering the climate change and unstable weather patterns, it is imperative to comprehensively quantify the effect of TV on YLL nationwide, which would help evaluate the future climate change effects in China.

To fill in above research gaps, we conducted a nationwide study to examine the associations of TV with YLL in 364 counties of China, to quantify the mortality burden attributed to TV using average life loss per death (LLD) as a health outcome, and to explore potential modifications of local characteristics on the associations of TV with YLL.

MATERIAL AND METHODS

Study settings

Counties in five provinces including Jilin, Hunan, Zhejiang, Guangdong and Yunnan were selected from the mortality surveillance system in corresponding provinces [25, 26], while other counties were from China's disease surveillance points system (Section 1.1 in Supplementary Materials). One of the following criteria should be fulfilled including: (1) a population size larger than 200,000, and (2) annual mortality rates >4‰ [26]. In the end, 364 counties were included and classified into three regions [5] including, South (246 counties with latitude <30°), Central (72 counties with 40°> latitude ≥30°) and North (46 counties with latitude ≥40°) (Fig. S1). Detailed information was presented in our previous study [5].

YLL rate calculation

First, daily death record from 2013 to 2017 were obtained from Provincial Centers for Disease Control and Prevention (CDC) in Yunnan, Guangdong, Jilin, Zhejiang and Hunan, while daily mortality data were collected from Chinese CDC from 2006 to 2012 [26]. All mortality record including, total non-accidental causes (A00–R99), respiratory disease (RESP, J00–J98), cardiovascular disease (CVD, I00–I99), and cerebrovascular disease (CED, I60–I69) were classified following International Classification of Diseases, 10th revision (ICD–10).

Second, following the methods of the WHO [27], we used provincial population and mortality data to calculate provincial specific life tables for different gender. The provincial mortality and population information were extracted from the 2010 population census of China.

Then we matched the death age and gender to the life table of the corresponding province to get individual YLL. After that, we calculated daily YLL by adding up YLLs for all deaths on the specific day. Daily YLL were stratified by cause (overall non-accidental, RESP, CVD and CED), gender and age (<65, 65–74, and ≥75 years old).

Finally, YLL rate (YLL/100,000 population) adjusted for population size was chosen as the health outcome. We obtained annual average population size from statistical yearbooks during 2013–2017 for the counties in five provinces mentioned above, while for other counties it was collected from the 2010 population census of China.

Meteorological data

Daily mean temperature (TM), maximum temperature (TMax), minimum temperature (TMin), and relative humidity (RH) data of 698 weather stations across China were derived from China Meteorological Data Sharing Service System. The Australian National University Splines (ANUSPLIN) was applied to interpolate meteorological data throughout China with 0.01°×0.01° resolution (Section 1.2 in the Supplementary Materials and Fig. S2) [28]. TM, TMax, TMin and RH were extracted from the interpolated grid with 364 counties. This method has been presented in detail in previous studies [5, 19, 20, 29]. In the end, we calculated daily TV by estimating the standard deviation of the maximum and minimum temperatures (TMax_{lag0}, TMax_{lag1}, TMin_{lag0}, and TMin_{lag1}) of the preceding 2 days. [7].

Other covariates

We obtained daily average PM₁₀ from China National Environmental Monitoring Center during 2006–2017. For the reason that not all 364 counties were included by the national monitoring system of air quality, random forest model was used to assess daily PM₁₀ at 364 counties by using parameters including meteorological data (TM, RH), location (altitude, longitude and latitude), development (GDP per capita, road length, population density, land use types) (Section 1.3 in the Supplementary Materials, Figs. S3 and S4). The results of fitting performance show that the R² of TM, RH, TMax and TMin were 0.96, 0.81, 0.94 and 0.94, respectively. Detailed information was shown in our previous study [5, 29].

The GDP per capita data was derived from the Data Center for Resources and Environmental Sciences for each county in 2010. Other characteristics at city level in 2010 were accessed from Statistical Yearbooks, including urbanization rate, average education years, and central heating information.

Statistical analysis

Estimating the associations of TV with YLL rates. We employed a two-stage approach to estimate the TV-YLL rate associations. First of all, association between TV and daily YLL rates for each county were estimated by

Table 1. General characteristics of study variables in 364 locations across China.

	Mean (SD)	Minimum	25th centile	Median	75th centile	Maximum
Daily non-accidental YLL rate ^a						
Total	22.5 (23.4)	0.0	12.0	19.5	28.5	1020.4
Respiratory disease	2.2 (4.4)	0.0	0.0	1.0	3.0	620.4
Cardiovascular disease	8.0 (12.5)	0.0	2.5	5.8	10.4	799.1
Cerebrovascular disease	3.9 (6.6)	0.0	0.0	2.3	5.3	324.3
Sex						
Male	26.6 (30.3)	0.0	11.6	21.9	35.0	1826.0
Female	18.2 (24.6)	0.0	6.1	13.8	24.2	1372.5
Age (years)						
0–64	13.9 (18.0)	0.0	4.2	10.8	19.2	994.7
65–74	69.7 (100.7)	0.0	0.0	54.0	97.2	4824.5
≥75	138.2 (142.3)	0.0	66.1	119.3	182.7	5077.2
Region						
North	22.9 (15.9)	0.0	11.8	20.4	30.7	359.0
Central	24.7 (38.6)	0.0	11.9	19.2	28.0	1020.4
South	21.6 (15.3)	0.0	12.1	19.4	28.3	928.5
Meteorological variable						
Temperature variability (°C)	9.3 (3.9)	0.3	6.3	9.4	12.3	23.2
Daily maximum temperature (°C)	20.5 (10.0)	−27.2	14.1	22.3	28.1	41.2
Daily minimum temperature (°C)	11.8 (10.4)	−36.2	5.3	13.2	19.8	30.7
Daily relative humidity (%)	72.4 (15.6)	5.0	63.0	75.0	84.0	100.0
PM ₁₀ (μg/m ³)	81.6 (41.1)	8.3	51.4	76.7	103.0	767.3

^aYLL rate was the average YLL in every 100,000 population.

applying a distributed lag non-linear model (DLNM) with Gaussian distribution function [30]. The model is as following:

$$E(YLL_t) = \alpha + \beta_1 T_{1,l,t}(TV_t) + \beta_2 T_{2,l,t}(TM_t) + ns(RH_t, df) + \beta_3 PM_{10} + ns(time_t, df) + \eta DOW + e \tag{1}$$

Where *t* stands for the specific day, *YLL_t* refers to day *t*'s YLL rate; *α* represents the intercept indicative of risk at baseline; *e* denotes a Gaussian error. Applying the DLNM to TV and TM respectively could get two matrix namely *T_{1,l,t}* and *T_{2,l,t}*; *β₁* and *β₂* stand for the coefficients' vector for *T_{1,l,t}* and *T_{2,l,t}*, respectively, *l* represents lag days; *β₃* denotes the coefficient of daily PM₁₀ concentrations; *e* denotes the error term. Natural cubic B-spline (ns) (with an intercept and three internal knots with equally spaced values) and quadratic B-spline (bs) (with three internal knots and boundary knots) were applied. We employed 3 degrees of freedom (df) for RH, 7 dfs per year of ns for time, a categorical variable, and a linear model to control same day RH effects, long term trend, the day of the week, and PM₁₀ concentration on the same day, respectively [31]. In addition, as suggested in previous studies, 21 days were chosen as the maximum lag period [26, 32].

Secondly, we applied multivariate meta-analysis to combine the 0–21 day lag TV-YLL rates associations in each county [33]. We identified the MYTV (minimum YLL TV) in the pooled TV-YLL rates curve. And we classified TV into two components (low and high TV were defined as ≤MYTV and > MYTV, respectively).

Calculations of LLD attributable to TV. LLD is a part of YLL, and represent the mortality burden of YLL that was caused by TV. LLD was calculated based on the association of TV with YLL rates, which was calculated as following [34]:

$$LL_{tem} = \sum_{i=TMin}^{i=TMax} YLL' \times Freq \tag{2}$$

where *LL_{tem}* stands for the total lives lost attributable to TV in a county (per 100,000 population). *TMin* represents the minimum daily TV, and *TMax* is the maximum value of daily TV in that county. *YLL'* stands for the TV-attributable YLL rate for each specific TV value, calculated by Eq. (1), while

Freq is the frequency of the corresponding TV value:

$$LLD = LL_{tem}/N \tag{3}$$

where *LL_{tem}* could be estimated in Eq. (2), *N* represents the sum of deaths (per 100,000 population) in the county.

Subgroup analyses. Stratified analyses were separately conducted for different regions (South, Central and North China), gender, ages (<65, 65–74 and ≥75 years old), and causes (CVD, RESP, CED). Parameters were set in line with the main model.

Meta-regression analyses. We conducted a univariable meta-regression to evaluate the influence of characteristics at county level. Parameters including latitude, longitude, altitude, annual mean temperature, annual mean relative humidity, GDP per capita, urbanization rate, central heating and average years of education.

Sensitivity analyses. We conducted sensitivity analyses to examine the robustness of our analyses. (1) We switched maximum lag periods to 14 and 28 days, and also changed the time dfs from 6 to 8 per year; (2) estimated the cumulative effects of TVs on YLL rates from lag 0–1 to lag 0–21; (3) used comfortable TV to estimate the effects of TVs on YLL rates. Comfortable TV was defined as the TVs with no significant effects on YLL rates compared with MYTV. Only the effects of TVs beyond the comfortable TV were used to calculate the mortality burden; (4) changed national life tables at the 2010, 2012, 2014 and 2016 to calculate individual YLLs.

R software (version 3.5.0) was used to conduct all analyses. The results would be considered as statistical significance if it fulfilled two tailed *p* < 0.05.

RESULTS

Descriptive results

The general characteristics of meteorological variables and YLL rates (YLL/100,000 population) are presented in Table 1. The

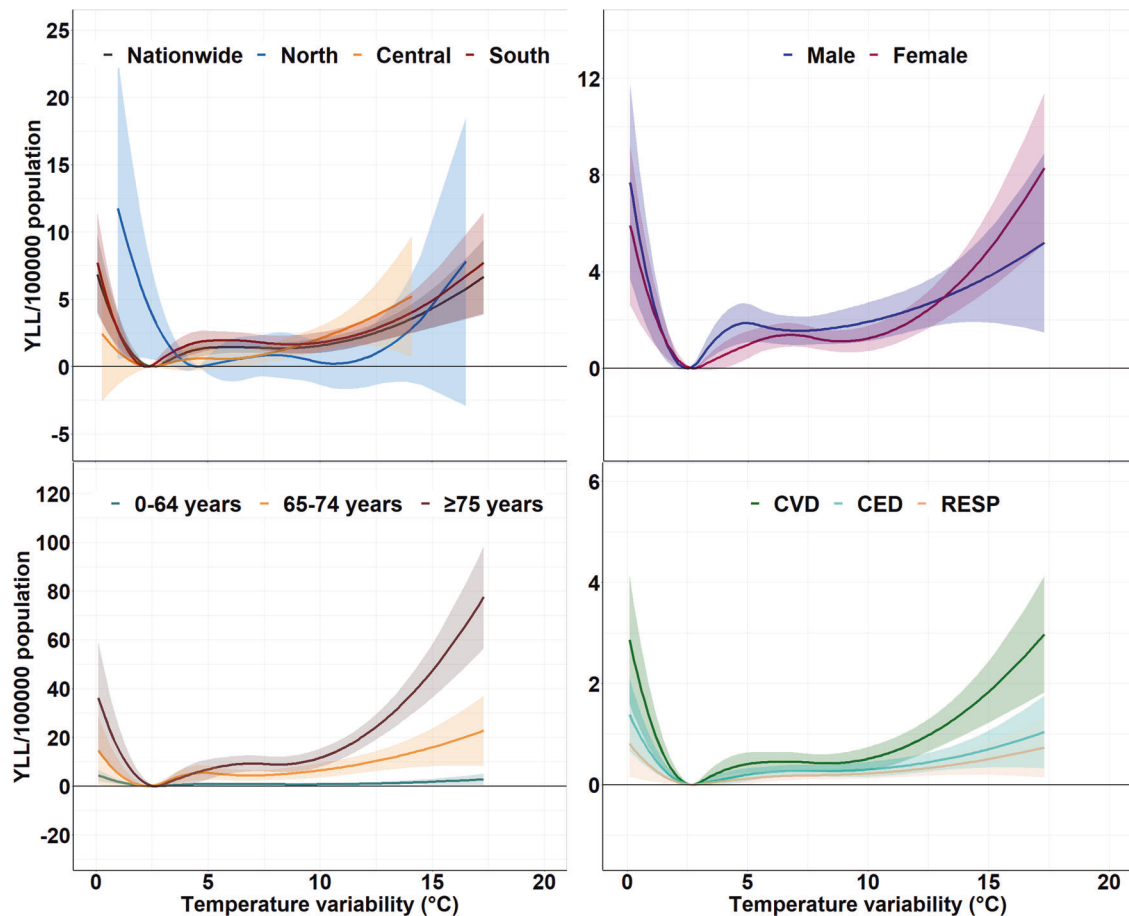


Fig. 1 The pooled cumulative exposure-response relationship between TV and YLL rate in all 364 counties and subgroups throughout China (over 0–21 days lag). RESP respiratory disease, CVD cardiovascular disease, CED cerebrovascular disease.

average daily TV, RH, and PM_{10} were 9.3 °C, 72.4%, 81.6 $\mu\text{g}/\text{m}^3$, respectively. The time series plots for TV, and YLL rates in each county are shown in Fig. S5. The average daily YLL rates of mortality, RESP, CVD and CED mortality were 22.5/100,000, 2.2/100,000, 8.0/100,000 and 3.9/100,000 respectively (Table 1). For different areas, the average daily YLL rates in Central China was highest (24.7/100,000), followed by North China (22.9/100,000), while the lowest was observed in South China (21.6/100,000).

Exposure-response relationship of TVs and YLL rates

We observed U-shaped curve of TV-YLL rates association, with a MYTV of 2.5 °C nationwide, ranging from 2.2 °C in South China to 4.6 °C in North China (Fig. S6). We found larger effects of TVs on YLL rates in old people and CVD compared with young people and RESP, respectively (Fig. 1). The effects of extremely high TV (97.5th centile) were larger and lasted longer than that of extremely low TV (2.5th centile) nationwide (Figs. S7 and S8).

Mortality burden attributable to TVs

Figure 2 shows the mortality burden attributable to TVs. An average of 0.89 (95% CI: 0.57, 1.21) years of LLD was associated with TVs nationwide, in which, 0.86 (95% CI: 0.56, 1.16) years were associated with high TVs.

In subgroup analysis, slightly higher average LLD of mortality was identified in males (1.00, 95% CI: 0.62, 1.39) than females (0.78, 95% CI: 0.41, 1.15). For the young population (<65 years old), the average LLD was 1.87 years (95% CI: 1.03, 2.71), which is higher than that of other age groups. For geographic regions, the average LLD was higher in South China (1.23, 95% CI: 0.77, 1.68) than Central China (0.40, 95% CI: -0.02, 0.81) and North China

(0.41 years, 95% CI: -0.7, 1.52). For specific disease, the average LLD attributable to TVs was highest in CED (0.74, 95% CI: 0.36, 1.11), followed by CVD (0.65, 95% CI: 0.34, 0.96) and RESP (0.54, 95% CI: 0.21, 0.87). Detailed average LLDs in subgroup analyses for TV components are shown in Table 2.

Effect modification analysis

We found modification effects of city level characteristics on average LLD caused by TV. Higher TV-attributable LLDs were found in places with high annual mean temperatures, high relative humidity, low latitude, large longitude, high altitude, and low education attainment. In addition, we observed weak modification effects of GDP per capita, the urbanization rate and heating level on the average LLD (Fig. S9).

Sensitivity analyses

In general, the associations of TV and YLL rates were robust to the changes of seasonality df. The TV-related YLL rates and MYTVs decreased with the increasing maximum lag day (Fig. S10). The cumulative effects of high TV and low TV rapidly increased between lag 0 to lag 10, and then slowly increased (Fig. S11). We did not find substantial changes of LLD by estimating LLD based on healthy temperatures (Table S1). Although LLD decreased using national level life table, we did not observe significant change of LLD using life tables estimated at different years.

DISCUSSION

In this study, significant effect of TV on YLL rates was observed after adjustment for daily mean temperatures. Throughout China,

TV was responsible for 0.89 years of LLD, the majority of which was attributed to high TV. The effects of TV on YLL were modified by city level characteristics including annual mean temperatures, relative humidity, latitude, longitude, altitude, education attainment, GDP per capita, urbanization rate, and heating level. These findings indicate that TV might contribute to mortality burden,

which should be considered when estimating the health burdens of ambient temperatures.

Similar positive association between TV and mortality was observed in several studies, which using death count as health outcome [7, 35, 36]. But studies assessing the association of TV with YLL are scarce [37, 38]. Xu et al. found YLL increased with a rise in the variability of weekly minimum temperature in Brisbane from 1996 to 2004 [37]. Similarly, large DTR was linked to YLL in Wuhan, China [38]. However, the results of different studies were difficult to compare for two reasons, first these studies did not include multi-counties at a time, and they chose varied TV index to measure the exposure and used YLL rather than YLL rate as outcome.

In terms of regional heterogeneity, TV caused higher LLD caused in South China than other parts of China. A previous study also showed higher health vulnerability to TV in warmer locations [35]. Several reasons should be taken into consideration. First of all, it may be because that numerous high TVs occurred on days with low mean temperatures in South China (Fig. S12). Second, a series of physiological, behavioral and technological adaptations contribute to the residential adaption ability to local climate [7]. Without central heating system, people live in South China may have weaker adaptive capacity to high TV than other parts of China. Last but not least, socioeconomic background and access to healthcare sources could also contribute to the spatial heterogeneity [39].

Increased TV may stress the ability of the thermoregulatory system, make it respond to sudden change inefficiently, especially when those changes happen frequently in a short time period [37, 40]. Our findings showed that TV caused a larger LLD in CVD especially CED diseases compared with RESP. The potential biological mechanisms of the association between TV and CVD/CED YLL rates are not fully understood. Kang et al. found that short-term exposures to TV significantly increased the level of high-sensitivity C reactive protein among 11,623 Chinese people, which is an important circulating biomarker of systemic inflammation, and is related to a series of adverse cardiovascular events [41]. In addition, TV may affect heart rate variability by autonomic nervous system [42, 43], which will further increase the risk of cardiovascular mortality [44].

Life lost per death caused by temperature variability

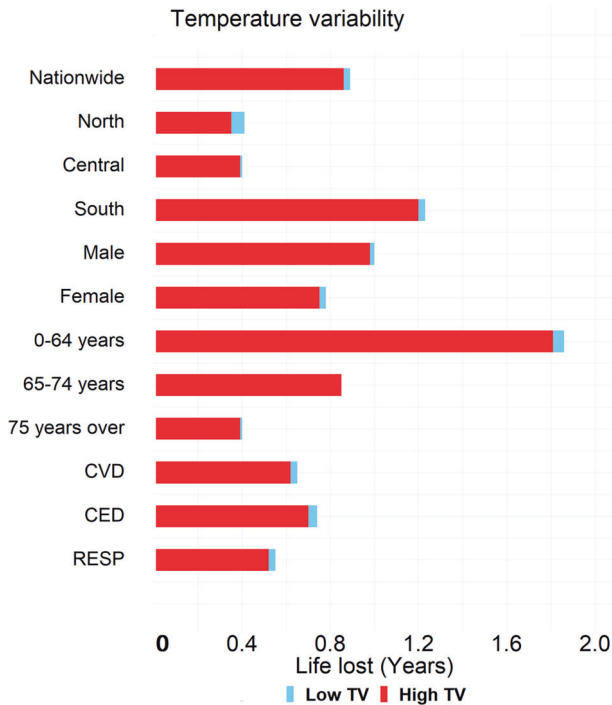


Fig. 2 Comparison of average life lost per death caused by TV in all 364 counties and subgroups across China. RESP respiratory disease, CVD cardiovascular disease, CED cerebrovascular disease.

Table 2. Average life lost per death due to TVs across 364 locations in China.

	Life lost (years, 95% CI) caused by TVs			
	MYTV (°C)	Total	Low	High
Causes of death				
Total mortality	2.5	0.89 (0.57, 1.21)	0.03 (0.01, 0.05)	0.86 (0.56, 1.16)
Cardiovascular disease	2.6	0.65 (0.34, 0.96)	0.03 (0.01, 0.05)	0.62 (0.32, 0.91)
Cerebrovascular disease	2.6	0.74 (0.36, 1.11)	0.04 (0.01, 0.06)	0.70 (0.35, 1.05)
Respiratory disease	2.6	0.54 (0.21, 0.87)	0.03 (0.00, 0.05)	0.52 (0.21, 0.83)
Geographic regions				
North	4.6	0.41 (-0.70, 1.52)	0.06 (-0.01, 0.12)	0.35 (-0.69, 1.4)
Central	2.4	0.40 (-0.02, 0.81)	0.01 (-0.02, 0.03)	0.39 (0.00, 0.78)
South	2.2	1.23 (0.77, 1.68)	0.03 (0.01, 0.05)	1.20 (0.76, 1.64)
Age of death (years)				
0-64	2.4	1.87 (1.03, 2.71)	0.05 (0.02, 0.09)	1.81 (1.01, 2.61)
65-74	2.3	0.85 (0.40, 1.31)	0.00 (0.00, 0.00)	0.85 (0.40, 1.31)
≥75	2.5	0.40 (0.21, 0.59)	0.01 (0.00, 0.02)	0.39 (0.21, 0.57)
Sex				
Male	2.4	1.00 (0.62, 1.39)	0.02 (0.00, 0.03)	0.98 (0.61, 1.35)
Female	2.6	0.78 (0.41, 1.15)	0.03 (0.01, 0.05)	0.75 (0.40, 1.10)

MYTV minimum YLL temperature variability.

Previous studies based on death count suggested greater mortality risk attributable to TV for females than males [12, 36]. In the current study, we found slightly larger LLD for males than females, however the difference may not be appreciable, which needs further investigation.

Zhang et al. found lower risk of TV-associated mortality for the young group compared with the elderly (≥ 75 years) [36]. On the contrary, we found larger LLD for the young (0–65 years old), in other words, the TV-associated mortality burden was larger for each death at young age even though the absolute number of TV-attributed deaths were smaller.

We observed significant modifiers of TV-related LLDs, including the annual mean temperatures, annual relative humidity, latitude, longitude, altitude, and low education attainment. Similarly, previous study showed socioeconomic inequality in TV and hospitalization relationship [45]. In addition, evidence showed that TV was significantly associated with the risk of cancer mortality, especially in humid days [46] or warm season [36]. The disparity suggests policy-makers should pay more attention to vulnerable areas to mitigate the adverse health impact of TV.

Overall, our study indicated that in order to decrease the mortality burden of rapid change in temperature, we should pay more attention on TV. These findings may help to develop policies from public health perspective, to minimize the adverse health effects of climate change and unstable weather conditions.

Several strengths should be mentioned in this study. First, this is the largest study focusing on TV-related mortality burden using YLL rate as outcome, in addition our study covered a long time period throughout China. Second, we estimated average LLD, which made it easier to compare the magnitude of TV-related health effects for the public. In addition, YLL rate which adjusted for population was used as outcome, which could be useful to pool and compare results in multiple locations and regions.

However, this study has some limitations. First of all, as ecological study, the results should be interpreted with caution. Secondly, because the counties are not uniformly distributed throughout China, we could access limited counties in North and West China, it is not available to explore the association at fine scale. Therefore, we divided all study counties into three regions based on the latitudes, which might underestimate the difference between province within the same region. Finally, we selected counties from two different surveillance systems (DSPS system and provincial system). Even though the provincial mortality surveillance system claimed to follow the DSPS standards, the difference between systems might lead to potential bias.

Our study showed that TV has substantial impacts on YLLs, most of which was attributed to high TV. The mortality burden of TV is heavier in South China than other part of China. Mortality effects of TV were modified by local characteristics. In planning adaptation measures to climate change, TV should be considered. These findings offer useful information to develop public health policies to reduce health burden of climate change and unstable weather conditions.

DATA AVAILABILITY

The mortality data are available upon reasonable request from the corresponding author (gztt_2002@163.com). It is not publicly available because the information that could compromise the personal privacy. Meteorological data could be downloaded from the China Meteorological Data Sharing Service System (<http://data.cma.cn/>). All related codes could be accessed in <https://github.com/gztt2002/YLL-of-Tm-and-Tv>.

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AUTHOR CONTRIBUTIONS

Conceptualization: TL and QD. Formal analysis: WG and XL. Investigation: WG, XL, MZ, CZ, YX, BH, and LL. Methodology: TL, XL, and QD. Writing-original draft: WG and XL. Writing-review and editing: WM, TL, JH, JX, WZ, GH, and CH.

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COMPETING INTERESTS

The authors declare no competing interests.

ETHICS APPROVAL

The study was approved by the Ethics Committee of Guangdong Provincial Center for Disease Control and Prevention (2019025).

ADDITIONAL INFORMATION

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