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Heatwave and mortality in 31 major Chinese cities: Definition, vulnerability and implications

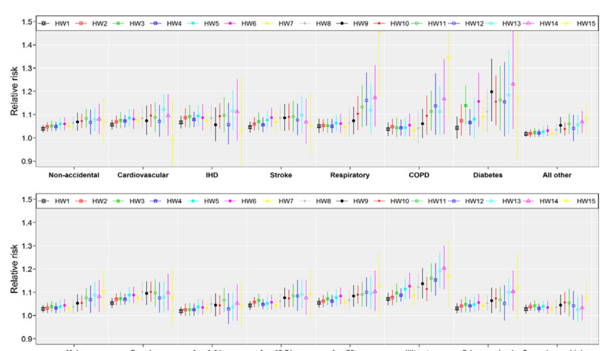
Jun Yang [a,⁎,1], Peng Yin [b,1], Jimin Sun [c,1], Boguang Wang [a], Maigeng Zhou [b], Mengmeng Li [d,j], Shilu Tong [e,f,g], Bohan Meng [h], Yuming Guo [a,i], Qiyong Liu [c,⁎⁎]

[a] Institute for Environmental and Climate Research, Jinan University, Guangzhou 511443, China
[b] National Center for Chronic and Noncommunicable Disease Control and Prevention, Beijing 100050, China
[c] State Key Laboratory of Infectious Disease Prevention and Control, Collaborative Innovation Center for Diagnosis and Treatment of Infectious Diseases, National Institute for Communicable Disease Control and Prevention, Chinese Center for Disease Control and Prevention, Beijing 102206, China
[d] Department of Epidemiology and Biostatistics, Institute of Basic Medical Sciences, Chinese Academy of Medical Sciences, Beijing 100005, China
[e] Department of Clinical Epidemiology and Biostatistics, Shanghai Children's Medical Center, Shanghai Jiao Tong University School of Medicine, Shanghai, China
[f] School of Public Health and Institute of Environment and Population Health, Anhui Medical University, Hefei, China
[g] School of Public Health and Institute of Health and Biomedical Innovation, Queensland University of Technology, Brisbane, Australia
[h] Department of Geography and Computer Science, University of Victoria, Victoria V8P5C2, Canada
[i] School of Public Health and Preventive Medicine, Monash University, Melbourne, Australia
[j] School of Basic Medicine, Peking Union Medical College, Beijing 100005, China

HIGHLIGHTS

- This is the first multicity study to comprehensively examine health-related heatwave definitions in China.
- Females, the elderly and persons with lower educational attainment were more vulnerable to heatwave.
- Cities with higher $PM_{2.5}$ and latitudes but lower numbers of hospital beds per 1,000 people had higher heat vulnerability.
- This study highlights the development of heat alert systems and protecting vulnerable subpopulations from heatwave.

GRAPHICAL ABSTRACT



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ABSTRACT

Few data are available on the health impacts of heatwaves in China, and in particular, the heatwave definition and vulnerable populations remain to be identified. We collected data on daily maximum temperature and mortality from 31 Chinese capital cities during 2007–2013. A Poisson regression model allowing for over-dispersion was applied to estimate the short-term effects of heatwaves on mortality in hot season (May–September). 15 heatwave definitions combining five heat thresholds (90.0th, 92.5th, 95th, 97.5th and 99th percentiles of daily maximum temperature) and three durations (≥2, ≥3 and ≥4 days) were compared. The pooled effects were then computed using random effect meta-analysis based on the residual maximum likelihood estimation. Effect modification of heatwave-mortality association by individual-level characteristics was tested using a stratified analysis. Potential effect modification by city-level characteristics was examined by meta-regression analysis. Totally, 259 million permanent residents were covered and 4,481,090 non-accidental deaths occurred during the

⁎ Correspondence to: J. Yang, Institute for Environmental and Climate Research, Jinan University, Guangzhou, 511443, China.
⁎⁎ Correspondence to: Q. Liu, National Institute for Communicable Disease Control and Prevention, Chinese Center for Disease Control and Prevention, Beijing 102206, China.
E-mail addresses: yangjun_eci@jnu.edu.cn (J. Yang), liuqiyong@icdc.cn (Q. Liu).
[1] Co-first authors.

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study period. Generally, the magnitude of heatwave impacts increased by intensities and durations of the heatwaves. Heatwave definition using daily maximum temperature ≥ 92.5th percentile with duration ≥3 days produced the best model fit. The pooled relative risks of heatwaves on non-accidental mortality at lag 0, lag 0–2 and lag 0–10 days were 1.06 (95%CI: 1.03–1.09), 1.09 (1.05–1.13) and 1.10 (1.05–1.15), respectively. Compared with non-accidental mortality, higher effect estimates of heatwaves were observed among deaths from ischemic heart diseases, stroke and respiratory diseases, although the differences were not statistically significant. Females, those ≥75 years old and the illiterates were more vulnerable to heatwaves. Cities with higher concentrations of $PM_{2.5}$, higher latitudes, and lower numbers of hospital beds per 10,000 populations had higher mortality risks during heatwaves. These findings may have important implications for developing heat alert systems and early response actions on protecting the vulnerable populations from adverse health effects of heatwave in China.

1. Introduction

Human is hardly completely acclimatised or adapted to the sustained extreme weather events (e.g., heatwave, drought and hurricane). In the context of on-going climate change, these adverse weather events are projected to increase dramatically in frequency, severity and duration (IPCC, 2012), which caused an astonishing number of excess deaths and hospital admissions worldwide. For instance, the 2003 European heatwave was estimated to cause nearly 70,000 excess deaths during the summer (Robine et al., 2008); and in June–August of 2010, Moscow and Western Russia underwent a historical unprecedented heatwave, causing nearly 55,000 excess deaths (Barriopedro et al., 2011). Thus, it is of great importance to assess the adverse health impact of heatwave in order to develop tailored intervention strategies on protecting the public health.

To date, the definition of heatwave is hardly conclusive around the world as population acclimatization and adaptation may differ from climates and regions (Tong et al., 2015; Xu et al., 2016; Yang et al., 2013a). In order to quantify the health risks of heatwave, previous studies mainly considered the intensity and duration of the heat days to define the heatwave (Chen et al., 2015; Guo et al., 2017; Xu et al., 2016; Zhang et al., 2017). However, heatwave-related health effects varied significantly by heatwave definitions (Chen et al., 2015; Guo et al., 2017; Zhang et al., 2017). According to China Meteorological Administration (CMA), a heatwave is officially defined as at least three consecutive days with daily maximal temperature exceeding 35 °C in China (Tan et al., 2010). However, it may be inappropriate to adopt this definition throughout the whole country because of the large temperature range, various climates and different adaptative capacities from the North to the South in China. Therefore, identification of appropriate health-based heatwave definition is needed to assess its health impact more precisely, particularly in the context of climate change and increasing global disease burden by heatwave.

Furthermore, the health risk of heatwave could be modified by individual factors, such as gender and age (Chen et al., 2015; Ma et al., 2015). Many previous studies assessed the effect estimates among the subpopulations stratified by these individual characteristics, but did not test whether the between-group difference was statistically significant (Analitis et al., 2014; Ma et al., 2015; Zhang et al., 2017). Additionally, the city-level effect modifiers of the association between heatwave and mortality remains to be well elucidated.

Thus, this study aimed to estimate the effects of heatwave on mortality under different heatwave definitions in 31 Chinese mega cities, and to detect whether the death risk of heatwave could be modified by the individual-level and city-level factors.

2. Methods

2.1. Study sites

The study population covers residents of the 31 provincial capital cities in China, including Harbin, Changchun, Urumqi, Shenyang, Hohhot, Beijing, Tianjin, Yinchuan, Shijiazhuang, Taiyuan, Xining, Jinan, Lanzhou, Zhengzhou, Xian, Shanghai, Hefei, Nanjing, Chengdu, Hangzhou, Wuhan, Chongqing, Lhasa, Nanchang, Changsha, Fuzhou, Guiyang, Kunming, Guangzhou, Nanning and Haikou (Supplementary Fig. A1). The study period is between 2007 and 2013, while the exact period of each city relied on the data availability.

2.2. Data collection

The daily death data of urban residents during 2007–2013 were derived from Chinese National Center for Chronic and Noncommunicable Disease Control and Prevention. The underlying cause of death was coded based on the 10th Revision of the International Statistical Classification of Diseases and Related Health Problems (ICD-10), containing non-accidental mortality (ICD-10: A00-R99), mortality due to cardiovascular disease (I00–I99) with its subcategories, including stroke (I60–I69) and ischemic heart disease (I20–I25), respiratory disease (J00–J99) with its subcategory of chronic obstructive pulmonary disease (J40–J47), and diabetes (E10–E14). Daily number of non-accidental death was further categorized by gender, age group (0–64, 65–74 and 75 years old or above) and educational attainments (illiterate, primary school and secondary or higher), respectively.

The daily weather data on maximum temperature, atmospheric pressure and relative humidity were collected from the China Meteorological Administration Network (http://data.cma.cn/). The meteorological data were derived from one basic weather monitoring station located in each city. There is no missing value of weather data during our study period. We obtained the daily air quality data from the Chinese Ministry of Environmental Protection, which reported daily air pollution index (API).

2.3. Statistical analysis

2.3.1. Heatwave definition

Heatwave definitions in the literatures are inconsistent around the world (Tong et al., 2015; Xu et al., 2016; Yang et al., 2013a). In general, heatwave is defined as several consecutive days (duration) with daily temperature measures exceeding specific threshold, including absolute threshold and relative threshold. In this study, we used the daily maximum temperature for heatwave indicator (Basagana et al., 2011; Diaz et al., 2015; Tan et al., 2010; Yang et al., 2013a), and limited our analyses to the warm season (1 May to 30 September) (Tian et al., 2013). To determine which heatwave definition is the best to capture the health impact of heatwave, 15 heatwave definitions were developed by combining five relative thresholds (90.0th, 92.5th, 95th, 97.5th and 99th percentiles of daily maximal temperature) with three durations of ≥2, ≥3 and ≥4 days.

2.3.2. Heatwave impacts

We used a two-stage analysis to assess the effects of heatwave on mortality in warm season (from May to September). In the first stage, we estimated the city-specific association between heatwave and