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Impact of extreme high temperature on mortality and regional level definition of heat wave: A multi-city study in China

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HIGHLIGHTS

- High quality datasets were used in the present study.
- Regional characteristics of the five studied cities in China were considered.
- A general U-shaped temperature–mortality relationship with location-specific threshold temperatures was observed.
- Positive and short-term association between extreme high temperature and mortality was found.
- Regional level definition of heat wave for five cities in China was conducted.

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ABSTRACT

Background: Few multi-city studies have been conducted to explore the regional level definition of heat wave and examine the association between extreme high temperature and mortality in developing countries.
Objectives: The purpose of the present study was to investigate the impact of extreme high temperature on mortality and to explore the local definition of heat wave in five Chinese cities.
Methods: We first used a distributed lag non-linear model to characterize the effects of daily mean temperature on non-accidental mortality. We then employed a generalized additive model to explore the city-specific definition of heat wave. Finally, we performed a comparative analysis to evaluate the effectiveness of the definition.
Results: For each city, we found a positive non-linear association between extreme high temperature and mortality, with the highest effects appearing within 3 days of extreme heat event onset. Specifically, we defined individual heat waves of Beijing and Tianjin as being two or more consecutive days with daily mean temperatures exceeding 30.2 °C and 29.5 °C, respectively, and Nanjing, Shanghai and Changsha heat waves as ≥3 consecutive days with daily mean temperatures higher than 32.9 °C, 32.3 °C and 34.5 °C, respectively. Comparative analysis generally supported the definition.
Conclusions: We found extreme high temperatures were associated with increased mortality, after a short lag period, when temperatures exceeded obvious threshold levels. The city-specific definition of heat wave developed in our study may provide guidance for the establishment and implementation of early heat-health response systems for local government to deal with the projected negative health outcomes due to heat waves.

1. Introduction

"Warming of the climate system is unequivocal", according to the fourth report of the Intergovernmental Panel on Climate Change (IPCC), the average temperature of the earth has increased by 0.74 °C since 1906 and is projected to rise by 1.1 to 6.4 °C during the next hundred years (IPCC, 2007; Medina-Ramón and Schwartz, 2007). As global warming continues, there is increasing evidence that extreme heat events are becoming more frequent, more intense and longer lasting.

Abbreviations: DLNM, distributed lag non-linear model; GAM, Poisson generalized additive model; AIC, Akaike's information criterion; RH, relative humidity; BP, barometric pressure; PM_{10}, particulate matter with aerodynamic diameter ≤10 μm; DOW, day of the week; df, the degrees of freedom; RR/RR(s), relative risk(s); CI, confidence interval.

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Consequently, the incidence of heat-associated adverse health outcomes will escalate among vulnerable subpopulations, such as the elderly, young children, and people with preexisting medical conditions (Balbus and Malina, 2009; Peng et al., 2011; Smith et al., 2013). Unsurprisingly, in recent years, heat-related health disorders have become a major public health concern associated with global warming.

In 2003, western Europe experienced a record-breaking heat wave, resulting in an excess of over 70,000 heat-related deaths (Robine et al., 2008). In a severe heat wave in California in 2006, approximately 16,166 additional emergency department visits and 1182 additional hospitalizations occurred (Knowlton et al., 2009). These well-documented increases in heat wave-associated morbidity and mortality demonstrate the stunning lethality of extreme heat exposure. However, most of these studies focus on cities in high-income countries (e.g. Europe and USA), and relatively few studies have been conducted in developing countries, especially in Asia, where characteristics of climate, socioeconomic status and demographic pattern differ greatly from those in developed countries (Anderson and Bell, 2011; Baccini et al., 2011; Gasparrini and Armstrong, 2011; Ishigami et al., 2008; Peng et al., 2011).

As in other areas of the world, China has experienced noticeable changes in climate during the past 100 years (Development and Commission, 2007). The annual average temperature has risen by 0.5–0.8 °C, and this trend of climate warming is projected to intensify in the future (Kan, 2011). Heat waves are silent killers that are becoming a significant public health problem in China, and will be exacerbated by the synergistic effects of global warming, urbanization and a large aging population. To date, the few studies that have examined the temperature–mortality relationship in large Chinese cities (e.g. Beijing and Guangzhou) have generally observed that extreme high temperature is associated with increased risk of death, especially among the elderly (Liu et al., 2011; Wu et al., 2013; Yang et al., 2013). In light of the expected increase in frequency and severity of extreme heat events and the large aging population, it is crucial and essential to estimate the health consequences of extreme high temperature, and to explore how to best define heat waves properly in different regions in China.

In meteorological terms, extreme heat events are defined as extended periods of unusual warmth with high minimum temperatures (D'Ippoliti et al., 2010; Luber and McGeehin, 2008). However, to date, there is no uniform definition of heat wave for most countries, because it is generally accepted that geographical location, regional variability, and acclimatization of the local population play a significant role in determining the heat-related impact (Hajat et al., 2006; Hajat and Kosatky, 2010). Although no universal definition exists, numerous studies have used a combination of temperature (intensity) and duration to define heat waves (Huang et al., 2012; Smith et al., 2013; Son et al., 2012; Yang et al., 2013). Additionally, some researchers also suggest that the definition of a heat wave should be based on knowledge of cause–effect relationships between temperature and the health of a given population, and that regional differences and local characteristics should be taken into account (Kim et al., 2006; Montero et al., 2012, 2010).

Common epidemiologic approaches, used to investigate the health effects of temperature, are of 2 types — the distributed lag non-linear model (DLNM) and the Poisson generalized additive model (GAM). The DLNM was developed to simultaneously examine non-linear and delayed effects of temperature on morbidity or mortality, and describes a bi-dimensional exposure–response relationship along the dimensions of temperature and lag (Armstrong, 2006; Gasparrini et al., 2010; Goldberg et al., 2011). The GAM has been widely used in environmental epidemiology to adjust for air pollution, day of the week, and long-term trends when performing time-series analysis, and characterizes temperature–mortality associations (Kim et al., 2006; Tong et al., 2012; Wood, 2006).

In the present study, we first used the DLNM to quantify and characterize the effects of daily mean temperature on non-accidental mortality in five Chinese cities from 2006 through 2011. Then we used the GAM to explore the city-specific definition of heat wave by analyzing the temperature–mortality relationship and evaluating the Akaike's information criterion (AIC) values. Finally, we performed a preliminary comparative analysis to evaluate the suitability of the definition. To our knowledge, this is the first multi-city study to explore the definition of heat wave on a local basis in China. Results from this study will improve our understanding about the heat-related health effects in different latitudes and climate zones of China, and contribute to the development and implementation of regional early heat-warning systems and heat-health prevention plans in the future.

2. Materials and methods

2.1. Study settings

We conducted the study in the urban districts of five cities (Beijing, Tianjin, Nanjing, Shanghai and Changsha) with different characteristics in China (Fig. 1). Beijing and Tianjin are located on the North China Plain, along the coast of the Bohai Gulf, and typically have a warm, temperate, semi-humid continental monsoon climate. Nanjing and Shanghai are located on the Yangtze River Delta and along China's eastern coastal areas and have a subtropical, humid monsoon climate, while Changsha is located in the south-central China and has a subtropical, continental monsoon climate.

All of the selected settings are the densely populated cities in China. According to the *China City Statistical Yearbook 2012*, at the end of 2011, the population in the urban districts of Beijing, Tianjin, Nanjing, Shanghai and Changsha were 12.07 million, 8.16 million, 5.52 million, 13.51 million and 2.97 million, respectively. Our study areas included all of the urban districts of each city, and the target population included all permanent residents living in the areas. We chose the study settings on the following basis: first, taking into account the data availability and completeness, the suburban districts of the five cities were excluded from our analysis due to the poor quality of mortality data and inadequate weather monitoring stations in those areas. Second, the five cities were selected as the study areas because they are representative of the different climatic characteristics and latitudes in China.

2.2. Data sources

Daily mortality data from January 1st, 2006 to December 31st, 2011 was obtained from the Chinese Center for Disease Control and Prevention for the five cities. The causes of death were coded according to the 10th International Classification of Diseases (ICD-10). Only the non-accidental mortality data (ICD-10: A00-R99) were analyzed, while deaths resulting from external causes, such as poisoning and injury, were excluded (World Health Organization, 2011).

Daily meteorological data of all the chosen cities was obtained from the China Meteorological Data Sharing Service System (http://cdc.cma.gov.cn) for the same period. City-specific variables included daily maximum, minimum, and mean temperatures (°C), relative humidity (RH, %) and barometric pressure (BP, kPa). Daily city-specific concentrations of respirable particulate matter with aerodynamic diameter ≤10 μm (PM_{10}) covering the study period was collected from the local Environmental Monitoring and Protection Bureaus.

2.3. Statistical analysis

Studies suggested that the counts of daily mortality typically followed a Poisson distribution, and the relationship between temperature and mortality might be non-linear with a lag effect (Son et al., 2012; Xie et al., 2013). Thus, in the present study, we made use of the DLNM to simultaneously investigate non-linear and delayed dependencies in the association between daily mean temperature and mortality for each city. This methodology is based on a “cross-basis” function that describes a bi-dimensional association along the dimensions of temperature and lag days, which not only allows for examination of the relationships between temperature and mortality at each lag period,