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The short-term effect of heat waves on mortality and its modifiers in China: An analysis from 66 communities

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Background: Many studies have reported increased mortality risk associated with heat waves. However, few have assessed the health impacts at a nation scale in a developing country. This study examines the mortality effects of heat waves in China and explores whether the effects are modified by individual-level and community-level characteristics.

Methods: Daily mortality and meteorological variables from 66 Chinese communities were collected for the period 2006–2011. Heat waves were defined as ≥2 consecutive days with mean temperature ≥95th percentile of the year-round community-specific distribution. The community-specific mortality effects of heat waves were first estimated using a Distributed Lag Non-linear Model (DLNM), adjusting for potential confounders. To investigate effect modification by individual characteristics (age, gender, cause of death, education level or place of death), separate DLNM models were further fitted. Potential effect modification by community characteristics was examined using a meta-regression analysis.

Results: A total of 5.0% (95% confidence intervals (CI): 2.9%–7.2%) excess deaths were associated with heat waves in 66 Chinese communities, with the highest excess deaths in north China (6.0%, 95% CI: 1%–11.3%), followed by east China (5.2%, 95% CI: 0.4%–10.2%) and south China (4.5%, 95% CI: 1.4%–7.6%). Our results indicate that individual characteristics significantly modified heat waves effects in China, with greater effects on cardiovascular mortality, cerebrovascular mortality, respiratory mortality, the elderly, females, the population dying outside of a hospital and those with a higher education attainment. Heat wave mortality effects were also more pronounced for those living in urban cities or densely populated communities.

Conclusion: Heat waves significantly increased mortality risk in China with apparent spatial heterogeneity, which was modified by some individual-level and community-level factors. Our findings suggest adaptation plans that target vulnerable populations in susceptible communities during heat wave events should be developed to reduce health risks.

1. Introduction

Numerous studies have demonstrated that heat waves are associated with increased mortality (Anderson and Bell, 2011; Huynen et al., 2001; Le Tertre et al., 2006; Ostro et al., 2009; Son et al., 2012). Some of these studies also reported that individual characteristics modified the association between heat waves and mortality (Lin et al., 2011; Medina-Ramón et al., 2006; Son et al., 2012). For instance, a study conducted in seven U.S. cities found that age, gender and cause of death significantly modified the heat effects on mortality (O'Neill et al., 2003); and studies from Guangdong province and Shanghai city of China showed that heat wave effects were higher for respiratory mortality and the elderly ≥75 years old (Ma et al., 2012; Zeng et al., 2014).

Some multi-city studies have also reported that the mortality effects of heat-wave were spatially heterogeneous, which may be partially explained by city-level modifiers such as socio-economic status and adaptive capacity (Curriero et al., 2002; Reid et al., 2009). For example, in the United States, one study revealed a greater increase in heat-related

Abbreviations: AIC, Akaike information criterion; AC, air conditioning; CI, confidence interval; CBD, cerebrovascular disease; CER, cumulative excess risk; CVD, cardiovascular disease; GDP, Gross Domestic Product; HW, heat wave; IQR, inter-quartile range; PM_{10}, particulate matter with aerodynamic diameters less than 10 μm; RESP, respiratory disease.

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mortality for a low socio-economic population compared with a high socio-economic population (O'Neill et al., 2003). Another study showed people living in urban areas were more vulnerable possibly due to the urban heat island effect and greater social isolation (Laaidi et al., 2012; Tan et al., 2009). O'Neill and colleagues found that central air-conditioning (AC) prevalence could explain some of the differences in heat effects by race (O'Neill et al., 2005).

Although many previous studies have investigated the mortality risk of heat waves, most studies focused on a single city or a small number of cities because of limited data availability, and these studies used different methods and parameter specifications making it difficult to compare the results from different studies (Guo et al., 2011; Sun et al., 2014; Tan et al., 2006; Wang et al., 2014). Furthermore, few previous studies considered the potential modifiers of heat wave effects on mortality (Ma et al., 2012), which are helpful to identify those populations and regions more vulnerable to heat waves. A more comprehensive understanding of the relationship between heat waves and mortality is important in developing policies and strategies that specifically target the most vulnerable populations and regions during heat wave events.

In the past five decades, especially in the first decade of the 21st century, the frequency and intensity of heat waves increased significantly in China (IPCC, 2013; Kan et al., 2012). Though some studies have examined mortality risk associated with high temperature (Lin et al., 2011; Ma et al., 2012; Wang et al., 2014), no research has comprehensively assessed the mortality effects of heat waves across the diverse climatic regions of China.

In the present study, we estimated the mortality effects of heat waves during summer in the years 2006–2011 using data from 66 Chinese communities, and further identified individual-level and community-level factors that confer susceptibility to heat waves. Our study aims to provide information for policy makers and the public to better understand the health effects of heat waves in China.

2. Methods

2.1. Study sites

China, located in East Asia and with a large coastline on the Pacific Ocean, covers an area of 9.6 million square kilometers. China's Disease Surveillance Points system (DSPs) is a set of 161 communities (each community is a county or a district of a city), chosen to be nationally representative. The system is administrated by the Chinese Center for Disease Control and Prevention (China CDC) (Zhou et al., 2010). The DSPs record all deaths and population counts at the sites and yields a nationally representative annual sample of deaths (Yang et al., 2005; Zhou et al., 2010). In order to assure enough daily death counts for every surveillance point in model fitting for time series analysis, the current study only included 66 DSPs where the population size is over 200 000. The Huai River-Qin Mountains Line was used as the geographical dividing line between north and south China. East and west China were defined according to the Chinese Government official classification. The selected 66 communities are distributed across four geographical regions: East China (16 communities in Jiangsu, Zhejiang, Anhui and Shanghai), South China (17 communities in Hubei, Hunan, Jiangxi, Fujian, Guangdong and Guangxi), West China (15 communities in Shanxi, Gansu, Ningxia, Xinjiang, Qinghai, Sichuan, Guizhou, Yunnan and Chongqing) and North China (18 communities in Heilongjiang, Liaoning, Jilin, Beijing, Tianjin, Hebei, Shanxi, Inner Mongolia and Henan) (Supplementary Fig. A1). The 66 DSPs are home to 44.3 million inhabitants (Supplementary Fig. A1, Table A1).

2.2. Data collection

2.2.1. Mortality data

For each community, mortality data during the warm season (May 1–September 30) from 2006 to 2011 were obtained from China CDC (Gasparrini and Armstrong, 2011). In China, the CDC is the government agency responsible for health data collection and a death must be reported to the local CDC. The hospital or community/village doctors filled in a standard Death Certificate and the information was then reported to a higher administrative level of CDC through a network reporting system. The standard information collected individual-level information, such as cause of death, date of death, age, gender and education attainment. In this study, we classified the deaths according to the International Classification of Diseases (ICD-10) for external causes (A00-R99), cardiovascular diseases (CVD: I00-I99), cerebrovascular diseases (CBD: I60-I69) and respiratory diseases (RESP: J00-J99). We also divided daily deaths into several strata by gender, place of death (in hospital or outside hospital), age groups (0–64 years, 65–74 years and 75 years or older) and education attainment (low: <6 years of education, medium: 6–9 years of education and high: >9 years of education). The place of death was defined as "in hospital", which included a hospital, clinic, or medical center, as well as outpatients admitted to the emergency room; and "outside hospital", including all other deaths, such as deaths at home.

2.2.2. Meteorological data

Daily meteorological data from all communities were collected from the China Meteorological Administration Network, a compilation of quality-controlled global surface observations, including daily mean temperature, daily maximum temperature, daily minimum temperature and daily relative humidity. Diurnal temperature range was calculated as the difference between maximum and minimum temperatures within 1 day for the community during the study period.

2.2.3. Community level data

Community level data were collected from the sixth national census, including marital status, percentage of unemployed population, per capita GDP, latitude, population size, ownership of air-conditioning per 100 households and urbanization, which have been commonly used as indicators of socio-economic status (Curriero et al., 2002; Zeng et al., 2014). We collected air pollution data (PM_{10}) from 55 communities: 26 community data sets were obtained from the local environmental protection agency website; 12 community data sets were collected from literature reviews and government reports, and for another 17 communities without specific data, we used data from the nearby communities. All the community level variables were shown in Table 1.

2.3. Statistical analysis

2.3.1. The definition of heat wave

To date, there has been no consistent definition of heat wave. In China, heat wave is defined as a period of at least 3 days where daily maximum temperature exceeds 35 °C (Tan et al., 2006). However, several studies have indicated that it may not be appropriate to use a unique temperature as a threshold in a spatially large country (Anderson and Bell, 2009; Kent et al., 2014). In the present study, we defined a heat wave as ≥ 2 consecutive days with daily mean temperature at or above the 95th percentile of the year-round community-specific distribution (Gasparrini and Armstrong, 2011) (Supplementary Table A1). Heat wave was classified as a dichotomous variable with 1 for heat wave days and 0 for non-heat wave days.

2.3.2. Analysis of heat wave effects on mortality

The statistical analysis followed an approach already proposed for several multicity studies (Lin et al., 2011; Wu et al., 2013). We first applied a Distributed Lag Non-linear Model (DLNM) to each community and then combined the estimates using a meta-analysis (Gasparrini et al., 2010; Lin et al., 2011). We also explored whether effect estimates differ by region to understand spatial distribution of heat wave effects on mortality. To examine the cumulative excess mortality risks (CERs, %) with heat wave at a 0–1 day lag, we fitted the following Poisson