Environmental Research 142 (2015) 696–702

Contents lists available at ScienceDirect

Environmental Research

journal homepage: www.elsevier.com/locate/envres

Exploration of the health risk-based definition for heatwave: A multi-city study

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ARTICLE INFO

Article history:
Received 6 January 2015
Received in revised form
7 September 2015
Accepted 8 September 2015

Keywords:
Climate changes
Heatwave definition
Mean temperature
Mortality
Time series analysis

ABSTRACT

Background: As heatwaves are expected to be more frequent, longer, and more intense in the future, it is imperative to understand how heatwaves affect health. However, it is intensely debated about how a heatwave should be defined.
Objectives: This study explored the possibility of developing a health risk-based definition for heatwave, and assessed the heat-related mortality in the three largest Australian cities.
Methods: Daily data on climatic variables and non-accidental deaths for Brisbane, Melbourne and Sydney during the period 1988–2009 were obtained from relevant government agencies. Several local heatwave definitions were tested by using percentiles (e.g., from the 75th to 99th centile) of mean temperature with duration ≥ 2 days across these cities. We examined the relative risks of mortality associated with heatwaves in each city using Poisson generalised additive model, after controlling for long-term trend, within-season variation, day of the week, and relative humidity. Then, Bayesian hierarchical model with segment–spline was used to examine the threshold for the heatwave-related impacts.
Results: A consistent and significant increase in mortality during heatwaves was observed in all three cities. The pooled data show that the relative risk of mortality started to increase around the 95th centile of temperature, increased sharply at the 97th centile and rose alarmingly at the 99th centile. Based on research findings, we proposed tiered health risk-based metrics to define a heatwave.
Conclusions: Our findings provide supportive evidence for developing health risk-based metrics to assess the impacts of heatwave. These findings may have important implications for assessing and reducing the burden of heat-related mortality.

1. Introduction

Heatwaves are associated with increased mortality and morbidity in many countries of the world, especially among vulnerable populations such as frail people, elderly and children (Anderson and Bell, 2011; Baccini et al., 2011; Basu, 2009; Guo et al., 2012; Hajat and Kosatky, 2010; Son et al., 2012; Tong et al., 2010a; Xu et al., 2014). As climate change continues, the frequency, intensity, duration and geographic extent of heatwaves are likely to increase (Koppe et al., 2004). Therefore, there is an urgent need to quantify the health impacts of heatwave.

Different heatwave definitions were used in the previous studies since there is no standard definition for heatwave to date (Robinson, 2001; Tong et al., 2010b). This is primarily because the impact of heatwave depends on many factors including the climate, socio-demographic characteristics, and acclimatisation of the population. It becomes an urgent but challenging task to reasonably define a heatwave at either a local or regional level because a suitable definition is critical for assessing its health impacts and developing effective heat warning systems across different levels (Toloo et al., 2013; Tong et al., 2014a, 2014b).

Recently, we used a consistent, health risk-based definition of a heatwave to assess its impact on mortality in Brisbane (Tong et al.,

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http://dx.doi.org/10.1016/j.envres.2015.09.009
0013-9351/

2014a). This study aimed to explore the possibility of finding a common heatwave definition across different geographic areas. We examined whether the health risk-based metrics for defining a heatwave was suitable for different cities. If the health risk-based metrics for defining a heatwave can be applied to different cities, this tool may have the potential to be used in the examination of health risks of climate variability and change and the establishment of heat warning systems in other regions.

2. Materials and methods

This study focused on the three largest Australian cities: Brisbane, Melbourne and Sydney, which are the capital cities of Queensland, Victoria and New South Wales, respectively. These cities include approximately half of the Australian population of 22.3 million (ABS, 2012). We examined the health impacts of heatwave for these cities using non-accidental mortality in the warm season (i.e., 1st November to 31st March of next year) during the period of 1 January 1988 to 31 December 2009.

2.1. Data

The data on non-accidental deaths for Brisbane, Melbourne and Sydney between 1988 and 2009 were obtained from the Australian Bureau of Statistics (ABS). Daily deaths data were acquired with categories of gender and two separate age groups (0–75 years and 75+ years). A more detailed breakdown by age groups was not possible due to data restriction based on confidentiality. Daily climate data on minimum and maximum temperatures (°C) and relative humidity (%) were obtained from the Australian Bureau of Meteorology. Daily mean temperatures were calculated by averaging maximum and minimum temperatures. If temperature records were missing ($\leq 1.3\%$) for a particular meteorological station, the daily average values were calculated using observations from other stations.

2.2. Heatwave definition

In this study, we used mean temperature as an indicator of exposure to investigate the effects of heatwaves on mortality in the three Australian cities, as our previous studies found that mean temperature was a slightly better predictor of mortality compared with maximum or minimum temperature (Vaneckova et al., 2011; Yu et al., 2010). A series of heatwaves were defined as daily mean temperature above certain percentiles of the temperature distribution for 2 or more consecutive days in the warm season between 1988 and 2009. We only used duration of 2 or more consecutive days to define a heatwave, because our previous analyses showed that regression models using heatwaves with a duration of ≥ 2 days produced the better model fit (judged by Akaike Information Criterion (AIC)) than those using duration of ≥ 3 days or ≥ 4 days (Tong et al., 2014a).

2.3. Assessment of heatwave effects

A binary heatwave variable (1 or 0) was used for each day (i.e., 1 for the heatwave days and 0 for non-heatwave days) according to the different heatwave definitions. Poisson generalised additive model (GAM) was used to examine the effects of heatwaves on mortality for each city after adjustment for the confounding effects of humidity, days of the week, long-term trend and within-season variation. We used natural cubic splines for humidity (degree of freedom (df)=3) and day of the warm season (df=4), and a dummy variable for days of the week. A linear function was used for year to control for long-term trend. Log scaled population for each city was controlled for as an offset in the model. Relative risks (RRs) and 95% confidence intervals (CIs) were calculated using GAMs. Cumulative lagged effects of 0–3 days were assessed using distributed lag models, as our previous work showed that the effects of heatwave lasted for 3 days or less (Tong et al., 2014b). Furthermore, we assessed the temporal changes in the heatwave–total mortality relationship by separating the time-series data into the early and late warm season, and two study periods (i.e., 11 years for each period). Early and late warm season was defined as 1 November–15 January (next year) and 16 January–1 March, respectively.

2.4. Exploration of a heatwave definition

To examine which percentile of temperature is suitable as a cut-off for a heatwave definition, we used a Bayesian hierarchical model with segment–spline to assess the association between different temperature percentiles (i.e., 75th, 75.5th,…99th) and log RRs of mortality for lag 0–3 days in each city and at a national level (using the 4 day-average). We assessed which knot (i.e., percentile of temperature) of the segment spline produced the best model fit as judged by AIC. Then we compared whether there was the same knot across three cities.

Poisson generalised additive models were developed using the GAM procedure implemented in the “mgcv” package of the R software (version 2.14.1), while the Bayesian hierarchical model was applied using the “INLA” package. Sensitivity analyses were conducted to check the robustness of the results. We changed *df* for humidity (3–6 *df*), and for day of the warm season (3–6 *df*), and then assessed the robustness of the modelling outcomes judged by the AIC values. We estimated heatwave effects on mortality in the three largest Australian cities using the whole year data. We also examined the relationship between percentiles of temperature and RRs of mortality using an extended time series dataset.

3. Results

In total, there were 68,113, 179,080 and 205,978 deaths in Brisbane, Melbourne and Sydney, respectively, in warm season during 1988–2009. Table 1 summarises the characteristics of population, mortality and climatic variables for these cities. The average mean temperature (range) in Brisbane, Melbourne and Sydney was 24.1 °C (16.6–33.6), 18.8 °C (9.2–35.5) and 21.7 °C (12.0–33.2), respectively. The proportion of people aged 75 and over in June 2001 was 5.0% (1.9% for male, 3.1% for female) in Brisbane, 5.6% (2.1% for male, 3.5% for female) in Sydney, and 5.7% (2.2% for male, 3.5% for female) in Melbourne. On average, the total of male deaths (51%) was slightly higher than that of female deaths (49%). The male deaths were almost equally distributed in two age groups (0–75 years) and (75+ years), while more than two thirds of female deaths occurred in those aged 75 or over (69%). There were few zero values of the daily deaths among age groups in Brisbane which were 11 (0.3%), 21 (0.6%), 78 (2.3%) and 4 (0.1%) zero values for male 0–75 and 75+ years, female 0–75 and 75+ years, respectively, in the warm season (1988–2009). Therefore, its impact on analytical outcomes is likely to be minimal.

The number of heatwave days by different heatwave definitions was shown in the Supplemental material (Table S1). Almost all cut-off percentiles of temperature for a heatwave definition in Brisbane were higher than those in the other two cities, except for the 99th centile in Melbourne. There were more heatwave days in Brisbane than Melbourne and Sydney for all heatwave definitions used.

Table S1 also reveals the RRs of total mortality during heatwaves on the current day (lag 0) after adjustment for confounding