Environment International 121 (2018) 41–50

Contents lists available at ScienceDirect

Environment International

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

Mortality burden attributable to heatwaves in Thailand: A systematic assessment incorporating evidence-based lag structure

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ARTICLE INFO

Handling Editor: Yong Guan Zhu

Keywords:
Cause-specific mortality
Heatwave
Thailand

ABSTRACT

Background: Available information on the acute and cumulative effects of heatwaves on cause-specific mortality in Thailand is scarce.
Objectives: To quantify the acute and cumulative effects of heatwaves on mortality in Thailand, and assess heatwave-related mortality burden.
Methods: Thirty heatwave definitions were used and categorized into three groups: low intensity heatwaves (HW_{low}), middle intensity heatwaves (HW_{middle}), and high intensity heatwaves (HW_{high}). Time-series analyses were conducted to examine the acute and cumulative effects of HW_{low}, HW_{middle}, and HW_{high} on total and cause-specific mortality in 60 provinces of Thailand, incorporating an optimal lag for each cause and each province. Random-effects meta-analyses were performed to pool provincial estimates to national estimates for both acute and cumulative effects. Meta-regressions were conducted to identify the possible factors contributing to the spatial heterogeneity of heatwave vulnerability.
Results: The cumulative effects of HW_{low} and HW_{middle} on total and cause-specific mortality were greater than HW_{high}. Both acute and cumulative effects of HW_{low}, HW_{middle} and HW_{high} on neoplasms and certain infectious and parasitic diseases were among the highest across all death causes. Effects of heatwaves on deaths from endocrine, nutritional and metabolic diseases appeared to be longer-lasting, and effects of heatwaves on deaths from ischaemic heart diseases and pneumonia occurred more rapidly. Northern and Central Thailand were the regions vulnerable to heatwaves, and proportion of elderly population was the major driver behind the spatial heterogeneity of heatwave vulnerability.
Conclusions: More attention needs to be paid to mild heatwaves. Future heatwave-related mortality burden due to neoplasms and infectious diseases in Thailand may increase as climate change continues.

1. Introduction

Climate change has been considered as the biggest global health threat in the 21st century (Watts et al., 2018), and properly tackling its adverse impacts can be the greatest opportunity to improve public health (Wang and Horton, 2015). Increasing global surface temperature is the most symbolic parameter of climate change (IPCC, 2014) and ambient high temperature, especially prolonged extreme high temperature (i.e., heatwave) (Anderson and Bell, 2011; Basagaña et al., 2011; Ma et al., 2015), has caused substantial health burden globally (Gasparrini et al., 2015). There is no universal consensus on how to well define heatwaves so far (Xu et al., 2016) and a slight change in heatwave definition may have a considerable impact on the estimated health effect (Tong et al., 2010). A recent multicountry study which used four temperature thresholds to define heatwaves have observed that the association between heatwaves and total mortality increased with increasing temperature thresholds (Guo et al., 2017). To better facilitate the development of tailored and cost-effective heatwave-prevention strategies (e.g., heatwave early warning system), it is judicious to categorize heatwaves of various intensities into several groups while

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https://doi.org/10.1016/j.envint.2018.08.058
Received 16 April 2018; Received in revised form 24 August 2018; Accepted 24 August 2018
0160-4120/

evaluating the health effects of heatwaves (Tong et al., 2014; Xu et al., 2016).

The effect of heatwaves on mortality appeared not just on the same day of exposure, but also lasted for few days (i.e., lag effect) (Guo et al., 2017). Further, mortality increase during heatwaves in some regions may be followed by a mortality decrease after heatwaves due to the decrease in the population of susceptible pool (i.e., harvesting effect) (Hajat et al., 2005). The widely-observed harvesting effects could, to some extent, affect or bias the assessment of the overall heatwave-related health burden (Baccini et al., 2013). It is possible that spatially variable population vulnerability to heatwaves due to different contexts, such as demographic characteristics (Schifano et al., 2009) and adaptation capacities (Huang et al., 2013), results in the heterogeneity of heatwave effects across different regions, mainly in terms of lag structure and effect size. Also, the lag structure of health effects of different-intensity heatwaves on the same city may also be different as more intense heatwaves may trigger deaths more promptly and have a longer-lasting harvesting effect (Guo et al., 2017). Therefore, it is desirable to scientifically consider evidence-based lag structure so as to accurately assess heatwave-related health burden. For example, Hertel et al. have used generalized cross validation to determine the optimal lag period when looking at heatwave effect on cause-specific mortality in Essen, Germany (Hertel et al., 2009).

A population/community's heatwave vulnerability is mainly determined by three factors: exposure, sensitivity, and adaptive capacity. Thus, heatwave vulnerability varies considerably across different communities due to their various exposure levels, as well as different demographic and adaptation characteristics (Guo et al., 2017). It is crucial to identify those communities/populations which are more vulnerable to heatwave impacts for wisely allocating limited health resources to help those who are most in need (Benmarhnia et al., 2015).

The heatwave definition of World Meteorological Organization is "when the daily maximum temperature of more than five consecutive days exceeds the maximum normal temperature by 5 °C, the "normal" period being defined as 1961–1990". This definition has been adopted by Thai Meteorological Department and thus Thailand has been considered as rarely experiencing heatwaves. However, heatwaves should not be assessed without reference to its human health impacts although it is generally considered as a meteorological event (Robinson, 2001), and prior studies have observed considerable adverse effects of heat and heatwaves (using a few widely used definitions) on mortality in Thailand (Guo et al., 2017; Guo et al., 2012). However, to the best of our knowledge, no study has characterized the effects of heatwaves on cause-specific mortality in Thailand.

This study aimed to quantify the effects of heatwaves on total and cause-specific mortality in 60 provinces of Thailand, a country where health effects of heatwaves have not been adequately evaluated. Specifically, this study attempted to answer four research questions: 1). How did different-intensity heatwaves affect total and cause-specific mortality in Thailand? 2). What were the total and cause-specific mortality burdens attributable to different-intensity heatwaves after incorporating evidence-based lag structure? 3). What was the spatial distribution of the heatwave effects on mortality in Thailand? And 4). What were the possible factors contributing to the heterogeneity of heatwave effects across different provinces of Thailand?

2. Methods

2.1. Study site

Thailand is located in the tropical area, with latitudes ranging from 5° 37′ N to 20° 27′ N and longitudes ranging from 97° 22′ E to 105° 37′ E. Upper part of Thailand, e.g., Northern Thailand and Northeastern Thailand, usually experiences a long period of warm weather, and maximum temperatures can reach 40 °C or more. As a developing country, public health resources in Thailand, especially those used for preventing and controlling heat impact, are limited. The great exposure to heat and the relatively low adaptive capacity may make Thailand residents vulnerable to the adverse impact of heatwaves.

2.2. Data collection

Daily data on non-external cause-specific deaths (International Statistical Classification of Diseases and Related Health Problems 10th Revision (ICD-10): A00-R99) from 1st January 1999 to 31st December 2008 in 60 provinces of Thailand were obtained from Ministry of Public Health, Thailand. To specifically analyze the relationship between heatwaves and cause-specific deaths, we extracted the daily number of deaths due to the following diseases: certain infectious and parasitic diseases (A00-B99), neoplasms (C00-D48), malignant neoplasms (C00-97), endocrine, nutritional and metabolic diseases (E00-90), diabetes mellitus (E10-14), diseases of the circulatory system (I00-99), ischaemic heart diseases (I20-25), diseases of the respiratory system (J00-99), pneumonia (J12-18), diseases of the digestive system (K00-93), diseases of the genitourinary system (N00-99), and renal failure (N17-19). Daily climatic data for each province which covered the same period of time, including maximum temperature, minimum temperature, mean temperature and relative humidity, were provided by Meteorological Department, Ministry of Digital Economy and Society, Thailand.

Data on the possible factors contributing to the heterogeneity of heatwave effects on deaths across provinces (population heatwave sensitivity modifiers), including population density, average years of education attainment of population aged 15 years and over, proportion of people aged ≥ 60 years, proportion of people aged ≥ 65 years, proportion of people aged ≥ 70 years, proportion of people aged ≥ 75 years, and proportion of one-person households, were obtained from the results of Thailand 2000 Population and Housing Census (National Statistical Office, 2000). There were three censuses in Thailand (year 1990, year 2000 and year 2010) from year 1990 until now, and we chose the information from year 2000 Census because our study period covered this year and also because this census results included the most relevant/thorough information on possible factors associated with heatwave effect. No information on gross provincial product per capita (GPPPC) (heatwave adaptive capacity modifier) was found in this census results and thus we used the GPPPC in 2013 as a proxy (NESDB, 2015). We also used the average values of mean temperature as well as relative humidity in each province as the indicators for heatwave exposure level modifiers. The details of these factors were presented in Table S1 (supplementary material). Ethics approval was granted by the Ethics Committee of Sun Yat-sen University prior to the data collection.

2.3. Heatwave definitions

The four hottest months (March to June) from 1999 to 2008 were chosen as the study period in this study. Heatwave was defined by incorporating duration and intensity (Xu et al., 2016). To comprehensively explore how different heatwaves affect mortality in Thailand, we adopted the most-commonly used 10 intensities (90th, 91st, 92nd, …, or 99th percentile of the mean temperature across the study period) and three durations (i.e., ≥2, 3 or 4 consecutive days) in the existing literature to define a heatwave. Thus, we used a total of 30 heatwaves definitions. For the development of cost-effective heatwave early warning system, it is desirable to categorize heatwaves into different groups according to its intensity. Our prior work has observed that grouping heatwaves into three categories seemed reasonable (Tong et al., 2014), and Nairn has also proposed to group heatwaves into three categories (Nairn and Fawcett, 2015; Wang et al., 2018). We categorized these 30 heatwave definitions into three groups: low intensity heatwaves (HW_{low}), middle intensity heatwaves (HW_{middle}), and high intensity heatwaves (HW_{high}). This classification may provide practical