Environmental Pollution 225 (2017) 244–251

Contents lists available at ScienceDirect

Environmental Pollution

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

Impacts of cold weather on all-cause and cause-specific mortality in Texas, 1990–2011[☆]

Tsun-Hsuan Chen [a], Xiao Li [b], Jing Zhao [a], Kai Zhang [a, c, *]

[a] Department of Epidemiology, Human Genetics and Environmental Sciences, The University of Texas Health Science Center at Houston (UTHealth) School of Public Health, Houston, TX, USA
[b] Department of Biostatistics, The University of Texas Health Science Center at Houston (UTHealth) School of Public Health, Houston, TX, USA
[c] Southwest Center for Occupational and Environmental Health, The University of Texas Health Science Center at Houston (UTHealth) School of Public Health, Houston, TX, USA

ARTICLE INFO

Article history:
Received 10 October 2016
Received in revised form
1 March 2017
Accepted 9 March 2017
Available online 5 April 2017

Keywords:
Cold weather
Heart disease
Mortality
Spatial heterogeneity
Temperature

ABSTRACT

Cold weather was estimated to account for more than half of weather-related deaths in the U.S. during 2006–2010. Studies have shown that cold-related excessive mortality is especially relevant with decreasing latitude or in regions with mild winter. However, only limited studies have been conducted in the southern U.S. The purpose of our study is to examine impacts of cold weather on mortality in 12 major Texas Metropolitan Areas (MSAs) for the 22-year period, 1990–2011. Our study used a two-stage approach to examine the cold-mortality association. We first applied distributed lag non-linear models (DLNM) to 12 major MSAs to estimate cold effects for each area. A random effects meta-analysis was then used to estimate pooled effects. Age-stratified and cause-specific mortalities were modeled separately for each MSA. Most of the MSAs were associated with an increased risk in mortality ranging from 0.1% to 5.0% with a 1 °C decrease in temperature below the cold thresholds. Higher increased mortality risks were generally observed in MSAs with higher average daily mean temperatures and lower latitudes. Pooled effect estimate was 1.58% (95% Confidence Interval (CI) [0.81, 2.37]) increase in all-cause mortality risk with a 1 °C decrease in temperature. Cold wave effects in Texas were also examined, and several MSAs along the Texas Gulf Coast showed statistically significant cold wave-mortality associations. Effects of cold on all-cause mortality were highest among people over 75 years old (1.86%, 95% CI [1.09, 2.63]). Pooled estimates for cause-specific mortality were strongest in myocardial infarction (4.30%, 95% CI [1.18, 7.51]), followed by respiratory diseases (3.17%, 95% CI [0.26, 6.17]) and ischemic heart diseases (2.54%, 95% CI [1.08, 4.02]). In conclusion, cold weather generally increases mortality risk significantly in Texas, and the cold effects vary with MSAs, age groups, and cause-specific deaths.

1. Introduction

Recent events with recorded extreme low temperature and unusual snow accumulation in the U.S. and Europe have raised the public awareness of the potential health impacts of extreme cold weather. Cold weather has been linked to significant levels of mortality and morbidity (Guo et al., 2014; O'Neill and Ebi, 2009; Ye et al., 2012). In the U.S., excessive cold was the leading cause of weather-related deaths during 2006–2010, accounting for 63% of weather related deaths (Berko et al., 2014). Exposure to extreme cold can lead to direct effects such as hypothermia and result in death, moreover, extreme cold can exacerbate preexisting chronic conditions (Conlon et al., 2011). Larsen (1990) indicated that unusual cold winter temperature has strongest fatal effects on mortality, including deaths from infectious disease, heart diseases, cerebrovascular diseases, pneumonia, and influenza. In general, mortality rates are 10–20% higher in winter compared to summer (National Vital Statistics System (NVSS), 2014).

Studies worldwide have shown that the effects of cold temperature on mortality were varied by geographic location and some demographic characteristics of population (Conlon et al., 2011; Curriero et al., 2002; Huang et al., 2014; Lee et al., 2014). Cold-

---

[☆] This paper has been recommended for acceptance by Dr. Hageman Kimberly Jill.

[*] Corresponding author. Department of Epidemiology, Human Genetics and Environmental Sciences, The University of Texas Health Science Center at Houston (UTHealth) School of Public Health, Houston, TX 77030, USA.

E-mail address: kai.zhang@uth.tmc.edu (K. Zhang).

http://dx.doi.org/10.1016/j.envpol.2017.03.022
0269-7491/© 2017 Elsevier Ltd. All rights reserved.

related excessive mortality is especially relevant with decreasing latitude or in mild winter climate region (Curriero et al., 2002; Ma et al., 2014). Spatial heterogeneity in cold effects indicates cold-mortality relationships from one community may not be applicable to another (Anderson and Bell, 2009). Moreover, these findings implied how different acclimatization of the communities was associated to their local weather conditions (Curriero et al., 2002; Turner et al., 2012). Studies have observed that cold weather have a larger impact on health among the elderly compared to younger people (Yu et al., 2012; Conlon et al., 2011). The cold-related mortality had a moderate increased for persons aged 15–75, and a substantial increase for person aged 75 and over (Berko et al., 2014).

In addition to cold temperatures, higher mortality rates may be attributable to cold waves. An extended period of extreme cold temperature, cold waves, may have additional risks of mortality due to extra strains on body's thermoregulation. However, due to global climate change, attention has focused on current and future heat waves on human health rather than cold waves. Few studies have investigated cold wave-mortality association; despite climate change is expected to increase the intensity of winter storms (Conlon et al., 2011; Barnett et al., 2012). Further, the results of these studies were inconsistent (Barnett et al., 2012; Medina-Ramon and Schwartz, 2007; Montero et al., 2010; Huynen et al., 2001).

Despite cold extremes continuing to be a significant health problem, only a handful of multi-city studies have investigated the cold-mortality association in the U.S. (Ye et al., 2012). Studies investigated cold wave effects were even less common (Barnett et al., 2012). Moreover, detrimental effects of cold are especially profound in regions with mild winter climate. While temperature patterns are expected to change as a consequence of climate change, cold–mortality associations and their geographic variation are likely to be a growing concern. Texas covers an area of 267,339 square miles and is the largest of the conterminous states. Texas extends from 25°50′N to 36°30′N latitude and from 93°31′W to 106°38′W longitude; the elevation range is from sea level to 8,751 feet on Guadalupe Mountain. Because of this great variation in so many geographical features, it is ideal for studying spatial heterogeneity. In light of the spatial variation of cold effects and the lack of studies including recent cold extremes, this paper aims to examine impacts of cold weather on mortality in 12 major Texas Metropolitan Areas (MSAs) for the 22-year period, 1990–2011.

2. Material and methods

2.1. Study area

Texas is the largest of the 48 contiguous states and the second most populous state in the U.S. As of February 2013, 25 Texas Metropolitan Statistical Areas (MSAs) are delineated by the U.S. Office of Management and Budget (OMB) based on the 2010 Census Bureau data (U.S. Census, 2013). Twelve Texas MSAs were selected based on population sizes that were consistently over 200,000 throughout the 22-year study period (1990–2011) and the availability of weather and air pollution data. Selected MSAs are shown in Fig. 1. The climate of selected Texas MSAs varies widely ranging from hot-dry, mixed-dry in the west to hot-humid and mixed-humid in the east (U.S. Department of Energy, 2010).

2.2. Data collection

2.2.1. Mortality data

Mortality data were obtained from the Texas Department of State Health Services and were aggregated on a daily basis at the MSA level. The International Classification of Disease (ICD) Ninth Revision (ICD-9) and Tenth Revision (ICD-10) (World Health Organization, 1975, 1992) were used for diagnosis of primary mortality causes during the periods 1990–1998 and 1999–2011, respectively. Deaths were divided into all causes, cardiovascular disease (CVD, ICD-9 390–429; ICD-10 I01-I52), respiratory disease (RESP, ICD-9 460–519; ICD-10 J00-J99). We further classified CVDs into subtypes including ischemic heart disease (IHD, ICD-9 410–414; ICD-10 I20-I52), myocardial infarction disease (MI, ICD-9 410; ICD-10 I21, I22) and stroke (ICD-9 430–438; ICD-10 I60-I69), and categorized RESPs into chronic obstructive pulmonary disease (COPD, ICD-9 490–496 except 493; ICD-10 J40-J44, J47), and pneumonia (PNEU, ICD-9 480–486; ICD-10 J12-J18). For age stratification, we used 65 of age as the cutoff point and further categorized older population with two subgroups (0–64, 65–74 and above 75 years old).

2.2.2. Weather data

Hourly weather data at weather stations were downloaded from the National Climate Data Center (NCDC) through the Integrated Surface Database (ISD) (NCDC, 2014). For each MSA, we selected one weather station, which was considered the most representative of the population exposure at MSA-level (e.g., airport weather station and closest to the most populous city in the MSA). Daily mean, minimum, maximum temperatures and dew point temperature were then calculated. Previous studies indicated that there is no consensus in 'the best' temperature measure consistently predicting temperature-mortality association better than others (Barnett et al., 2010; Zhang et al., 2014). We used mean temperature as it represents the temperature exposure for both day and night (Guo et al., 2014). The ISD weather data have been checked for extreme values, consistency between parameters, and continuity between observations through a rigorous quality control procedure developed by NCDC (Lott, 2004).

2.3. Cold wave definition

There is no consensus on the definition of cold waves. We explored three percentile-based cutoff points with two different durations. We first identified cold waves as daily mean temperatures below the 1st, 5th, or 10th percentiles of the entire study period of each MSA with periods of 2 or more consecutive days. Then we extended each cold wave seven days beyond its last day below the threshold to capture delayed effects as described in Barnett et al, (2012).

2.4. Statistical analysis

The multi-city time-series analyses were performed in two stages: MSA-specific analysis on cold temperature-mortality association and meta-analysis. In the first stage, a Poisson regression allowing for over dispersion model was used to estimate the MSA-specific association. In the second stage, the estimated associations were then pooled at the entire state using meta-analysis. This two-stage approach is commonly used in multi-city studies (Guo et al., 2014; Gasparrini et al., 2012).

2.4.1. MSA-specific models

There are two steps in building up MSA-specific models. First, to determine whether a cold-temperature threshold exist, the association between temperature and daily count deaths was analyzed and plotted using the generalized additive model (GAM) with a spline function of temperature for each MSA separately. To account for the delayed effect of cold temperature, we used lag 0–25 (average the same day and previous 25 days temperature) as our main exposure in the GAM models. Confounding variables