International Journal of Disaster Risk Reduction 31 (2018) 668–678

Contents lists available at ScienceDirect

International Journal of Disaster Risk Reduction

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

Mapping hypothermia death vulnerability in Korea

Sang-Jin Park[a], Do-Woo Kim[a,*], Ravinesh C. Deo[b], Jong-Seol Lee[a]

[a] National Disaster Management Research Institute, 365, Jongga-ro, Jung-gu, Ulsan 44538, Republic of Korea
[b] School of Agricultural, Computational and Environmental Sciences, Institute of Agriculture and Environment (I Ag & E), University of Southern Queensland, Springfield, QLD 4300, Australia

ARTICLE INFO

Keywords:
Hypothermia
Generalized regression
Mapping vulnerability

ABSTRACT

Despite largely indisputable evidence of global warming, abnormally cold temperatures frequently affect regions of the Northern hemisphere. As a result of cold, several countries have sustained considerable property damage and numerous human fatalities. To reduce mortality from cold-related events, this study aims to analyze the vulnerability of people who die as a result of cold temperatures. The data used for the analysis is comprised of cold-related mortality statistics and 20 variables. We define cold-related deaths as those attributable to hypothermia during the winter and broadly classify the 20 variables, as they relate to climate, demographics, and socioeconomic factors, into three categories: exposure, sensitivity, and adaptive capacity. From the 20 variables, we enter three of them (i.e., aging rate, financial reliance, and the number of days below −10 °C) into a generalized linear regression model, accounting for statistical correlation and multicollinearity, to estimate the spatial distribution of cold-related deaths. The resulting correlation coefficient for the final model is approximately 0.82. Then, from the final model, we adopt estimated values to construct a hypothermia death vulnerability map and find that the sociodemographic distribution has a greater effect on hypothermia vulnerability than climate exposure and that residents of rural areas are more vulnerable than those of urban areas. The hypothermia death vulnerability map could be a useful scientific tool for future cold-related disaster management decisions and policies, which should ultimately reduce the number of human fatalities.

1. Introduction

Despite the trend of global warming, extreme cold has frequently penetrated the mid-latitude regions of the Northern Hemisphere in recent years. In January 2011, South Korea suffered 39 straight days of the lowest recorded daily maximum temperatures since 1973. Other abnormal cold events caused record-breaking low temperatures in 2012, 2013, and 2016, both nationwide and regionally [21–24]. In January 2014, although abnormal cold did not affect Korea, a persistent abnormal cold in Chicago (USA) caused enormous regional damage [31]. Changes in the atmospheric circulation patterns within the Arctic region, attributable to global warming, have been implicated as the major cause of abnormal cold in the mid-latitudes of the Northern Hemisphere. When abnormally high temperatures persist over the Arctic, the Arctic Oscillation decreases, which weakens the Polar jet stream that acts as a barrier blocking cold air over the North Pole. Consequently, cold air over the Arctic spreads to the mid-latitudes of the Northern Hemisphere, causing abnormally cold temperatures [18,25,26].

Although the risk of abnormally cold events has increased, demographic groups or geographic regions that are more vulnerable to cold (i.e., social vulnerability to climate change) remain unknown [17,28,7,8]. It is speculated that this is because most projections of climate change focus on future temperature elevations. Although vulnerability to heat waves, particularly in Korea, has been the focus of extensive studies (e.g., [19,20]), vulnerability to cold weather has been relatively neglected [3]. Surprisingly, the number of human fatalities caused by cold does not fall short of that attributable to heat waves. In the Netherlands, for example, the number of deaths caused by cold weather is estimated to be an average of about 6.8 higher than that of deaths caused by heat waves [15]. The number of cold-related fatalities in the United Kingdom and Australia has also been estimated to be about 58 and 31 persons per 100,000, respectively, higher than the number of heatwave fatalities [32]. In an international study analyzing over 74 million deaths from 1985 to 2012, those caused by cold (7.29%) were much more prevalent than those caused by heat (0.42%) [9]. Sudden cold amidst a warming climate system could also wreak havoc with the temperature control system of a human body that has already adapted to the warmer climate [33]. Therefore, identifying specific demographic classes and regions particularly vulnerable to cold

* Corresponding author.
E-mail address: dow1112@daum.net (D.-W. Kim).

https://doi.org/10.1016/j.ijdrr.2018.06.016
Received 28 December 2017; Received in revised form 27 June 2018; Accepted 28 June 2018

weather would enable us to implement proactive cold-related mitigation measures.

The vulnerability to climate/weather can generally be assessed based on exposure, sensitivity, and adaptive capacity [16]. To represent exposure, studies responsible for considerable advances in research on the exposure to cold frequently use the variables of daily average temperature, daily minimum temperature, and daily maximum temperature [15,2,30,4,6]. Most studies have analyzed the association between temperature and the number of deaths. One study in the Netherlands found that total mortality increased as the temperature decreased with reference to an average temperature of 16.5 °C [15]. Another study in London (UK) showed that mortality increased by about 2.52% (1900–1910), 2.34% (1927–1937), 1.64% (1954–1964), and 1.17% (1986–1996) with a drop of 1 °C with reference to an average temperature of 15 °C [4]. A rise in mortality with a decline in temperature has also been verified in New York (USA), Seoul (Korea), and Stockholm (Sweden) [10,12,2,30]. Such studies provide evidence of the impact of cold on the human population.

The exposure to similar cold events in different regions might pose a higher risk of mortality relative to the sizes of vulnerable populations. Several studies have shown that the elderly are particularly sensitive to cold weather [1,6]. Furthermore, several other researchers have found that populations with lower levels of education and income [2] and a higher prevalence of cardiovascular diseases [30,4] are more sensitive to cold weather. Despite the dearth of studies that have analyzed adaptive capacity in addition to exposure and sensitivity with regard to cold-related vulnerability, one study comparing 14 cities in Europe revealed that the number of deaths decreased as medical expenditures by the public sector and the overall socioeconomic condition increased [13], implying that these factors might reduce mortality associated with cold-related events.

Human mortality, in addition to the exposure to weather, sensitivity, and adaptive capacity, is a key variable in cold-related vulnerability studies. The extent of human mortality caused by cold can be measured using various statistical approaches. The broadest category of statistics used to measure human mortality caused by cold is excess mortality, a measure of the number of deaths that exceed the average number of deaths expected during a particular period when cold persists at the same time. One can tally the number of deaths during a particular period by screening for fatalities that fall under natural death (code: A00-R99) according to the International Classification of Diseases (ICD) [2,6]. A more specific statistic is the number of deaths caused by the exacerbation of underlying diseases resulting from cold in the winter. Cold can exacerbate a diverse range of diseases, the most typical being cardiovascular and respiratory diseases [11,12,14,15,29]. Among the statistics of human mortality caused by cold, the most salient is the number of deaths attributable to hypothermia. Because of diagnostic consistency, hypothermia death data are more reliable than overall mortality data related to weather. Thus, analyzing human vulnerability to cold-related mortality, we have limited this study to the examination of deaths caused by hypothermia.

To analyze human vulnerability to hypothermia death, we collected and processed hypothermia death statistics, as well as meteorological, demographic, and socioeconomic data used to identify exposure, sensitivity, and adaptive capacity, into consistent units and generated a spatial map of hypothermia death vulnerability in Korea. We used the processed data to analyze the correlations with hypothermia deaths based on significant variables, applied the variables in a generalized linear model (GLM), and used the GLM to create a regression model that most clearly explained the regional and class-specific vulnerabilities of hypothermia deaths. Then after computing the estimated values using the statistical model, we compared the spatial distribution of the estimated values with actual mortality to create the hypothermia death vulnerability map (HVM).

2. Materials and method

2.1. Study area

In this study, the spatial coverage of the HVM is South Korea (33–38°N, 125–131°E), located at the eastern end of the Asian continent. Winter in South Korea is generally cold and dry, a result of the cold air mass moving from the North and the continental-based high pressure belts prevalent in the West. The average temperature in January (the coldest month of the year), ranges from − 6–3 °C. In order to mitigate the impact of cold on the population, the Korea Meteorological Administration (KMA) issues cold weather watches when the daily minimum temperature is forecasted to be below − 12 °C for two or more days, and it issues cold weather alerts when the temperature is expected to be below − 15 °C.

Korea's administrative district consists of nine provinces, six metropolitan cities, and Seoul (the capital of South Korea). Each of the 16 regional administrative districts is composed of several administrative counties. The six metropolitan cities and Seoul are home to 68 administrative counties, known as *gu*, 26 of which are concentrated in the vicinity of Seoul. The 164 administrative counties, which constitute nine provinces, are divided into 76 urban areas, known as *si,* and 88 rural areas, known as *gun,* according to the population and infrastructure. Fig. 1 shows the 232 administrative counties in Korea (68 metropolitan counties (*gu*), 76 urban counties (*si*), 88 rural counties (*gun*)), and the locations of 68 weather observatories.

2.2. Data

2.2.1. Mortality data

This study analyzed cases in which a cold event was the direct cause of deaths, that is, deaths resulting from hypothermia or exposure to natural cold. Despite the possibility that cold weather may have induced frostbite in parts of the body (ICD code: T34- or T35-) or vascular chilblains (ICD code: T691) that eventually led to death, this study did not include these factors in the analysis because deaths from hypothermia account for more than 99% of all cold-induced mortality (see Table 1).

To develop the HVM, we collated the data on hypothermia deaths by extracting cases linked to the ICD cause-of-death code T68 (hypothermia) primarily from the cause-of-death statistics compiled by Statistics Korea. Fig. 2 shows the number of deaths attributable to hypothermia from 1991 to 2014. Between 1991 and 2002, an average of 37 people died annually from hypothermia (T68); this number, however, surged to about 214.8 during between 2003 and 2014. This finding raises the following question: Was the dramatic increase the result of a rapid decline in the temperature or a sudden increase in the number of people dying from hypothermia after 2003. In a comparison of cases of death caused by the “effect of reduced temperature, unspecified (code: T699)” during the same period, it can be surmised that some cases of hypothermia deaths before 2003 were classified as T699.

In light of the above factors, this study excluded mortality data prior to 2003 in order to increase the accuracy of the data used for an analysis of the impact of cold. Of the monthly deaths resulting from hypothermia in Korea from 2003 to 2014, shown in Fig. 3, about 87.3% of all hypothermia deaths in Korea occurred from November to March. Thus, this study used the data on hypothermia deaths that occurred between November and March from the 12-year study period (2003–2015). We further divided the data according to the size of the population in each region and computed the annual averages for these regions of study.

2.2.2. Climate data

In addition to the daily average temperature, daily minimum temperature, and daily maximum temperature, this study used the sensible temperature incorporating the wind chill factor by taking the daily