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Projection of temperature-related mortality due to cardiovascular disease in beijing under different climate change, population, and adaptation scenarios[☆]

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ABSTRACT

Human health faces unprecedented challenges caused by climate change. Thus, studies of the effect of temperature change on total mortality have been conducted in numerous countries. However, few of those studies focused on temperature-related mortality due to cardiovascular disease (CVD) or considered future population changes and adaptation to climate change. We present herein a projection of temperature-related mortality due to CVD under different climate change, population, and adaptation scenarios in Beijing, a megacity in China. To this end, 19 global circulation models (GCMs), 3 representative concentration pathways (RCPs), 3 socioeconomic pathways, together with generalized linear models and distributed lag non-linear models, were used to project future temperature-related CVD mortality during periods centered around the years 2050 and 2070. The number of temperature-related CVD deaths in Beijing is projected to increase by 3.5–10.2% under different RCP scenarios compared with that during the baseline period. Using the same GCM, the future daily maximum temperatures projected using the RCP2.6, RCP4.5, and RCP8.5 scenarios showed a gradually increasing trend. When population change is considered, the annual rate of increase in temperature-related CVD deaths was up to fivefold greater than that under no-population-change scenarios. The decrease in the number of cold-related deaths did not compensate for the increase in that of heat-related deaths, leading to a general increase in the number of temperature-related deaths due to CVD in Beijing. In addition, adaptation to climate change may enhance rather than ameliorate the effect of climate change, as the increase in cold-related CVD mortality greater than the decrease in heat-related CVD mortality in the adaptation scenarios will result in an increase in the total number of temperature-related CVD mortalities.

1. Introduction

Due to the concern over globally increasing temperatures, numerous studies (Zander et al., 2015, 2017; Basu, 2009; Gosling et al., 2009; Bi et al., 2011; Medina-Ramon et al., 2006; Conti et al., 2005; Lee and Kim, 2016) have focused on the public health problems, including temperature-related mortality and morbidity, and other social and economic issues (*e.g.*, labor productivity loss) caused by extreme climate events.

The Intergovernmental Panel on Climate Change (IPCC) has projected that the frequency, intensity, and duration of heat waves will increase, and unstable weather patterns are likely to occur in the coming decade (Stocker et al., 2014). Therefore, detailed projection of future temperature-related mortality is important for formulating public health policies to minimize the deleterious effects of climate change.

In the past decade, an increasing number of projections of temperature-related mortality have been performed in developed countries,

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Abbreviations: GLM, generalized linear models; DLNM, distributed lag no-linear models; GCM, global circulation models; RCPs, representative concentration pathways; SSPs, socioeconomic pathways; CVD, cardiovascular disease

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but few in developing countries (Li et al., 2016; Sanchez et al., 2016). Some studies projected heat-related or cold-related deaths for a whole year or for a particular season under future climate scenarios (Petkova et al., 2014; Honda et al., 2014). Others estimated future temperature-related mortality for the total population (Guo et al., 2015; Morabito et al., 2012). However, few studies considered population change (Knowlton et al., 2007; Ballester et al., 2011; Huynen and Martens, 2015), which restricts our understanding of the emerging risks to human health caused by climate change.

In addition, previous studies (Li et al., 2016; Morabito et al., 2012) have indicated that particular populations, including the elderly, the very young, and those with existing illnesses, are more susceptible to extreme temperatures than are normal adults. Nevertheless, few data on temperature-related cause-specific mortality are available. Cardiovascular disease (CVD) (I00–I99) is now the major cause of death for both males and females in China. Thus, projection of the impact of climate change may reduce the incidence of CVD.

This study used historical data from Beijing during 2007–2009 as the baseline and combined generalized linear models (GLMs) and distributed-lag non-linear models (DLNMs) to estimate the relative risk of CVD mortality in association with the daily maximum temperature. To project future temperature-related CVD deaths, we used two global circulation models (GCMs), three representative concentration pathway (RCP) scenarios, and three socioeconomic pathways (SSPs) and developed models for two 20-year periods centered around the years 2050 and 2070. By examining a range of climate- and population-change scenarios, we aimed to assess the magnitude of future temperature-related CVD deaths in Beijing.

2. Methods

We collected historical data and downscaled future daily temperatures from 19 climate models and 3 RCPs and population projection scenarios. Then, we estimated the baseline temperature–CVD mortality relationship in Beijing, which we combined with the future daily temperature data to estimate future daily temperature-related CVD mortality under different greenhouse gas emission and population change scenarios. We also analyzed the seasonal variation in temperature-related CVD mortality.

2.1. Historical data collection

We collected historical data on daily CVD mortalities (I00-I99) in the entire population of Beijing from 2007 to 2009 from the Chinese Center for Disease Control and Prevention. Daily data on maximum temperature and relative humidity were obtained from the China Meteorological Administration. Air pollution data, including the daily concentration of PM_{10}, which was transformed based on the air pollution index (Table S1), were obtained from the Beijing Municipal Environmental Monitoring Center.

2.2. Future temperature projection

Future temperature projections were performed by exporting downscaled outputs from 19 GCMs used in the fifth IPCC reports under the RCP2.6, RCP4.5, and RCP8.5 scenarios, which are a new series of greenhouse gas emission scenarios defined by the IPCC. Among these RCP scenarios, RCP2.6 projects the lowest radiative forcing. RCP4.5 projects a stabilization scenario, with the total radiative forcing rising until 2070. RCP8.5 represents a continuously rising radiative forcing, which projects a larger increase in temperature than do RCP2.6 and RCP4.5.

We downloaded the GCM outputs from the WorldClim Database and selected climate models that are reportedly reliable for simulating climate change in China (Ying, 2012). Details of the 3 RCP scenarios and the 19 GCMs are shown in Tables S2 and S3.

2.3. Baseline temperature–mortality relationship

To assess the impact of variables other than temperature on CVD mortality, a GLM with a logarithm link and a DLNM were used to estimate the effects of several covariates on daily CVD mortality. GLM is an extension of traditional linear models and is widely used for estimating the relative rates of mortality or morbidity associated with exposure to air pollution or meteorological parameters; however, sometimes the effect of a specific exposure event is not limited to the period when it is observed but can also be delayed (Zanobetti and Schwartz, 2001). Thus, a specific statistical model should be introduced to describe the additional time dimension of the exposure–response relationship. DLNM can simultaneously represent non-linear exposure–response dependencies and delayed effects. Therefore, to describe the relationship between ambient temperature and CVD mortality more precisely, we combined DLNM with GLM to fit the exposure–response curve. The basic model is as follows:

$$\begin{aligned}\log[\mathrm{E}(\mathrm{Y_t})] = \mathbf{f}(\mathbf{x_t}) + \mathbf{NS}(\mathbf{time}, \mathbf{df.\ Time}) + \mathbf{NS}(\mathbf{rHumi_t}, \mathbf{df.\ rHumi}) \\ + \mathbf{NS}(\mathbf{PM10_t}, \mathbf{df.\ PM10}) + \mathbf{DOW_t} \qquad \text{(Model1)}\end{aligned}$$

where Y_t is the observed daily CVD deaths on day t; f(x) is the DLNM model with 14 lag days; NS(time, df. Time) is the natural cubic spline of time, and df.Time is the degree of freedom per year for time, which is used to control for long-term trend and seasonality; NS(rHumi_t,df.rHumi) is the natural cubic spline of relative humidity, and df.rHumi is its degrees of freedom; and DOW_t is a categorical variable for day of the week. We also used a natural cubic spline to add the daily air pollution concentration to the model.

Similar to previous studies (Knowlton et al., 2007; Guo et al., 2012), time was modeled with 7 degrees of freedom (df) per year. PM_{10} and rHumi were each modeled using 3 degrees of freedom.

Taking the potentially non-linear and lagged relationship between ambient temperature and CVD mortality into consideration, we applied a distributed-lag nonlinear model to examine the effect of temperature on mortality. We applied a natural cubic spline with 5 degrees of freedom to daily maximum temperature. As in previous studies (Gasparrini et al., 2015; Lin et al., 2011), a natural cubic spline with 5 degrees of freedom was also used for lags of up to 14 days, which is sufficient to capture the lagging effects of temperature and would not lead to over-fitting. Previous studies (Goldberg et al., 2011; Dang et al., 2016) have summarized the relatively longer period over which cold effects take place compared with the relatively shorter period over which heat effects take place. Therefore, we selected the cumulative effects of lag0–lag3 and lag0–lag12 for hot and cold temperatures, respectively, in our main analysis.

2.4. Population

The population of Beijing during the baseline period (2007–2009) was obtained from the Beijing Municipal Bureau of Statistics. Projections of future population changes in Beijing based on SSP scenarios were obtained from Hoornwag and Pope (2014). The main assumption for population growth in the three SSP scenarios is dependent on fertility, mortality, migration, and education rates.

These assumptions describe fast, medium, and slow urbanization rates for SSP1, SSP2, and SSP3, respectively (Lutz et al., 2014). Details of the three SSP scenarios are shown in Table S4. In the three SSP scenarios, countries are categorized based on their current fertility rate, high ($>$ 2.9 children per woman) or low ($\leq$ 2.9 children per woman), for low- and medium-income nations. The third category consists of OECD and high-income nations; these follow the World Bank definition. The education rates are based on projections in IIASA/VID, in which a high rate represents global expansion of school systems at the fastest possible rate, which is based on recent examples such as Singapore and South Korea. A medium rate represents a scenario in which countries