Assessing Heat-related Mortality Risks in Beijing, China[*]

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Abstract

Objective   To obtain the exposure-response relationship for temperature and mortality, and assess the risk of heat-related premature death.

Methods   A statistical model was developed using a Poisson generalized linear regression model with Beijing mortality and temperature data from October 1st, 2006 to September 30th, 2008. We calculated the exposure-response relationship for temperature and mortality in the central city, and inner suburban and outer suburban regions. Based on this relationship, a health risk model was used to assess the risk of heat-related premature death in the summer (June to August) of 2009.

Results   The population in the outer suburbs had the highest temperature-related mortality risk. People in the central city had a mid-range risk, while people in the inner suburbs had the lowest risk. Risk assessment predicted that the number of heat-related premature deaths in the summer of 2009 was 1581. The city areas of Chaoyang and Haidian districts had the highest number of premature deaths. The number of premature deaths in the southern areas of Beijing (Fangshan, Fengtai, Daxing, and Tongzhou districts) was in the mid-range.

Conclusion   Ambient temperature significantly affects human mortality in Beijing. People in the city and outer suburban area have a higher temperature-related mortality risk than people in the inner suburban area. This may be explained by a temperature-related vulnerability.

Key words: Temperature; Mortality; Premature death; Health risk; Generalized linear regression model; Climate change

INTRODUCTION

Climate change has led to increasing temperatures in urban areas in recent decades[1]. Research has shown that both high and low temperatures increase the risk of mortality[2-3]. Epidemiological research over the past two decades has clearly shown a link between elevated temperatures and mortality risk for different cities around the world[4-8]. Against the

background of climate change, the effect of temperature on human health has become an important issue of public health.

In China, there is little published literature on the relationship between temperature and human mortality. A study by Kan et al. showed a relationship between temperature and mortality in the city of Shanghai. Their results showed that when temperatures exceeded approximately 26.7 °C, total mortality increased by 0.73% for each degree Celsius increase[9]. Another study by Kan et al. showed that a 1 °C increment of the 3-day moving average of diurnal temperature range resulted in a 1.37% increase in total non-accidental mortality in Shanghai[10]. In Tianjin, a 1 °C increase in temperature increased non-accidental mortality by 2.03%[11]. A recent study of temperature and mortality in four East Asian cities showed that a mean daily apparent temperature increase of 1 °C resulted in estimated percentage increases of 9.0% for respiratory mortality and 6.4% for cardiovascular mortality in summer in Beijing[12]. Curriero et al. showed that there are large differences in the relationship between temperature and mortality in different cities and countries, because of varied geographical location and other factors[2,13]. However, research results from other countries may greatly differ from conditions in China because of a wide range of social, economic and public health differences. Therefore, it is important to study the relationship between temperature and human health outcomes in China.

The current study examined the exposure-response relationship between temperature and human mortality in Beijing, and assessed the health risks of premature death caused by high temperature in summer on the basis of the exposure-response relationship. Our result could contribute to policy making with regard to the effects of climate change on human health in China.

METHODS AND DATA

Research Design

The present study was divided into two parts. The first part of the study investigated the exposure-response relationship between temperature and mortality. The results were obtained through a statistical model calculation using historical data of temperature and mortality. The second part of the study evaluated health risk assessment. An assessment of temperature-related premature death was obtained through a health risk model calculation introducing the measured temperature value and relevant parameters in the summer of 2009, based on the results obtained from the exposure-response relationship.

Our study was conducted in the greater urban area of Beijing. Because health risk differences may exist among populations within various areas, districts or counties in Beijing, we divided the area into three regions, including urban, inner suburban, and outer suburban areas, according to the classification of Beijing Statistical Yearbook (National Bureau of Statistics of China 2008), for calculations of the exposure-response relationship. The urban area included Dongcheng, Xicheng, Chongwen, and Xuanwu districts. The inner suburban area included Chaoyang, Fengtai, Shijingshan, and Haidian districts. The outer suburban area included Fangshan, Tongzhou, Shunyi, Changping, Daxing, Mentougou, Pinggu, and Huairou districts, and Miyun county and Yanqing county. We assessed human health risk by each district or county.

Analysis of the Exposure-response Relationship

We used a generalized linear model (GLM) in logarithmic form to calculate the exposure-response relationship between temperature and mortality. We obtained the exposure-response relationship through a retrospective epidemiological analytical method, and applied it in the assessment of temperature-related premature death.

Data Sources Mortality data were provided by Beijing Municipal Center for Disease Control and Prevention, for the 2-year period from October 1st, 2006 to September 30th, 2008. As required by law, the causes of death were coded according to the International Classification of Diseases Revision 10 (ICD 10). Total non-accidental deaths (A00-R99) were selected in this study. The temperature data were from the website of the U.S. National Climatic Data Center (NCDC). We used the daily average temperature value in Beijing, for the same period of the mortality data.

Statistical Model The daily number of mortalities of residents was expressed as a Poisson distribution, while both the daily mortality numbers and temperature are time series data. Therefore, we adopted the generalized linear model (GLM) in logarithmic form to calculate the exposure-response relationship between temperature and mortality. The basic form of the model is shown in equation (1), which was processed by the R 2.10.1 statistical

software package, Bell Laboratories, USA.

$$logE(Y)=ns(temperature, df)+ns(time,df)+DOW \quad (1)$$

where, $E(Y)$--daily mortality number; *temperature*--daily mean temperature; *time*--date; *DOW*--day of the week; *ns*--natural smoothing spline function; *df*--degrees of freedom.

We determined the value of *df* by minimizing the Akaike's information criterion (AIC) parameter as discussed in the literature[2,6,8]. The number of degrees of freedom of the natural smoothing spline function for temperature was 2, and the number of degrees of freedom of the natural smoothing spline function for the date was 14 (7 for each year).

The effect of temperature on mortality has the effect of a time lag[6,8]. We carried out tests on two lag structures, including the single day lag (to match the number of mortalities of the current day with the temperature N days ago) and the moving average lag (to match the number of mortalities of the current day with the average temperature value of the current day and N days ago). We tested both the single day lag structure with a lag of 0-10 days, and the moving average lag structure with a lag of 1-10 days. Our results showed that the largest heat effect (i.e., the effect of an increase in mortality with a temperature increase) was found with a moving average lag structure with a lag of 1 day (i.e., to match the number of mortalities of the current day with the average temperature value of the current day and 1 day ago). Therefore, we used the average temperature value of the current day and 1 day ago in the *Temperature* item in equation (1) for calculations.

Health Risk Assessment

The quantitative exposure-response relationship between temperature and mortality was used to perform an assessment of the health risks of temperature-related premature death. We used the measured daily average temperature data in the summer (June 1st to August 31st) of 2009 in Beijing to calculate the number of temperature-related premature deaths during this period.

Data Sources The temperature data for calculation of health risk assessment were taken from the website of the U.S. NCDC. We selected the daily average temperature data from June 1st to August 31st (summer), 2009.

Health Risk Assessment Model The number of daily temperature-related premature deaths was calculated by the following equation:

$$\Delta \, mortality=Y_0 \times ERC \times POP \quad (2)$$

where, Δ *Mortality*--the number of daily temperature-related premature deaths; Y_0--daily baseline mortality; *POP*--total population; *ERC*--percentage change in daily mortality (The percentage change in mortality for a specified change in temperature.

The amount of the total population of Beijing city and surrounding districts was obtained from the Beijing Statistical Yearbook[14]. Our study used the household demographic population number The daily baseline mortality refers to the baseline of total mortality, excluding accidental injuries. Because the assessment period of our study was summer (June to August), we calculated the daily average baseline mortality on the basis of the mortality data in summer of 2007 and 2008 provided by the Beijing Center for Diseases Control and Prevention. A health risk map of premature death in humans was constructed using GIS software ArcGIS9.3.1, Esri, USA.

RESULTS

Descriptive Statistics

Table 1 shows the number of daily deaths (excluding accidental injuries) and temperature in Beijing from October 1st, 2006 to September 30th, 2008.

Table 1. Daily Average Mortality and Temperature in Beijing from October 1st, 2006 to September 30th, 2008

	N	$\overline{x} \pm s$	Min.	Max.
Daily average Mortality (No./d)	731	168.3±34.5	53.0	273.0
Temperature (°C)	731	13.8±10.8	-6.8	30.7

The Exposure-response Relationship between Temperature and Mortality

The exposure-response relationship between temperature and mortality of humans in Beijing during the study period is shown in Figure 1. Figure 1 shows that the curve of the exposure-response relationship between temperature and mortality has a "J" shape; therefore, the mortality risk rises with increasing temperature. The upper half of the "J"-shaped curve was of statistical significance ($P<0.001$). It has a narrow error range, and the three curves show a consistent trend, suggesting that the exposure-response relationship between temperature and mortality has a quantitative

relationship in the range of higher temperatures. The lower half of the "J"-shape curve showed no statistical significance. The range of uncertainty was large, and the trends of the three curves were not consistent. Therefore, in the following series of analyses, we only considered the range of higher temperatures in which the exposure-response was more certain, i.e., the temperature range above the annual average temperature of 13.8 °C.
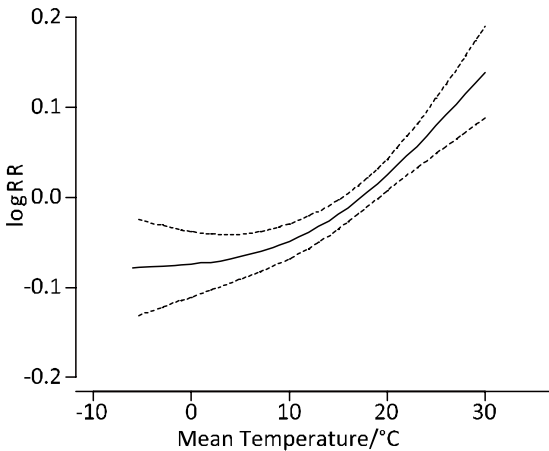

Figure 1. The exposure-response relationship between temperature and mortality in Beijing. The *Y*-axis shows the logarithm of the degree of relative risk. The black solid line indicates the exposure-response relationship curve. The two dotted lines (upper and lower) represent 95% confidence levels.

Figure 2 shows the exposure-response relationship within different areas of Beijing. To make the three curves comparable, we converted the value of relative risk into percentage change in mortality with reference to the annual average temperature (i.e., the percentage of risk difference between a certain temperature and the annual average temperature). We found that the mortality risk of humans in central urban and outer suburban areas was relatively similar, and it was higher in these areas than that in the inner suburban area. To quantify the effect of temperature change on mortality, we calculated the percentage change in mortality risk at 30 °C and 13.8 °C (annual average temperature (Table 2). People in outer suburban areas had the highest mortality risk, with up to 20.4% (95% CI: 10.4%-31.2%). People in the central urban area had a mid-range risk of 19.3% (95% CI: 6.2%-34.1%), while people in the inner suburban area had the lowest risk of 14.8% (95% CI: 5.5%-25.0%).
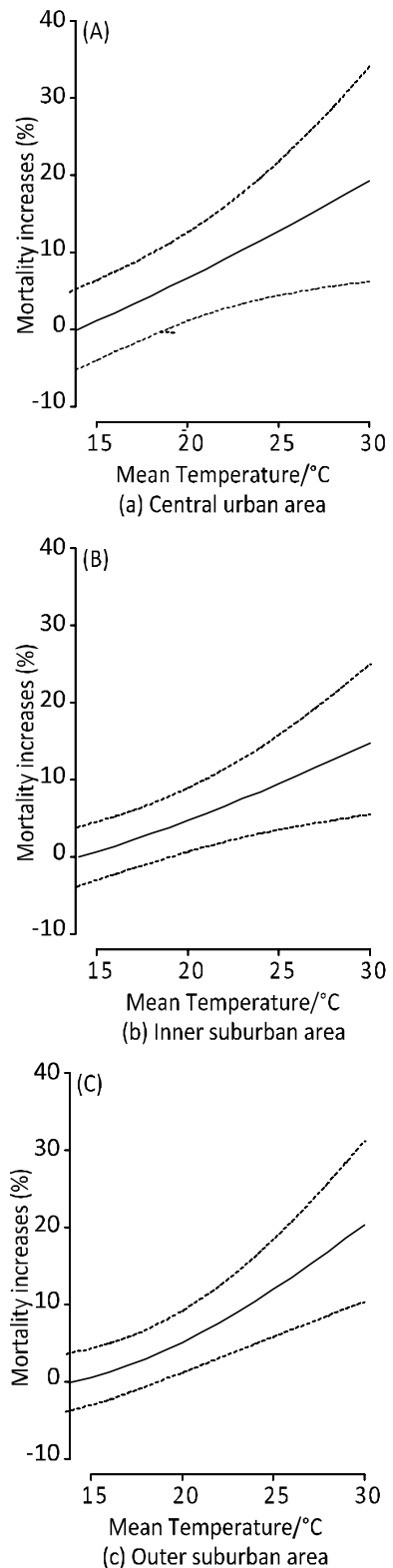

Figure 2. The exposure-response relationship between temperature and mortality in various areas in Beijing (for temperatures above the annual average of 13.8 °C).

Table 2. The Percentage Change in Mortality Risk of Humans in Various Areas in Beijing at 30 °C and 13.8 °C (Annual Average Temperature)

	Percentage Change/%	95% CI
Central urban area	19.3	6.2-34.1
Inner suburban area	14.8	5.5-25.0
Outer suburban area	20.4	10.4-31.2

Health Risk (Number of Premature Deaths) Assessment

We estimated that the number of temperature-related premature deaths in summer (June to August) in 2009 was 1581. According to statistical data, the average number of human mortalities in summer (June to August) of 2007 and 2008 in Beijing was 13 414. If we assume that there is no significant change in the average number of human mortalities in the summer of 2009 compared with that in the summers of 2007 and 2008, the number of temperature-related premature deaths in the summer of 2009 will account for 11.8% of the total human mortality in this period.

Figure 3 shows the number of temperature-related premature deaths in summer of 2008 in 18 districts and counties of Beijing. We found that the largest number of premature deaths occurred close to the city center. The city center area (Chaoyang and Haidian districts) had the maximum number of premature deaths. The southern areas of Beijing (Fangshan, Fengtai, Daxing, and Tongzhou districts) also had high numbers of premature deaths.
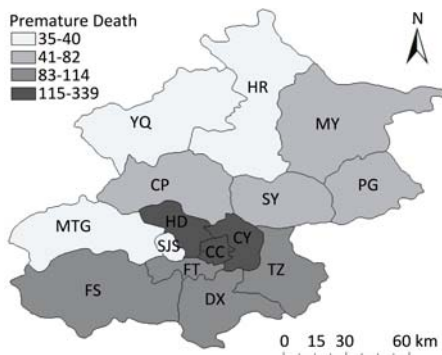

Figure 3. Estimate of the number of temperature-related premature deaths in the summer of 2009 in Beijing. Central City (CC) including Dongcheng (DC), Xicheng (XC), Chongwen (CW), and Xuanwu (XW). Chaoyang (CY), Fengtai (FT), Shijingshan (SJS), Haidian (HD), Fangshan (FS), Tongzhou (TZ), Shunyi (SY), Changping (CP), Daxing (DX), Mentougou (MTG), Pinggu (PG), Huairou (HR), Miyun (MY), and Yanqing (YQ).

DISCUSSION

Our study reports quantitative values of the health risk of temperature-related premature deaths in China. This is the first study to obtain the exposure-response relationship between temperature and mortality in Beijing using existing historical data.

We calculated the exposure-response relationship between temperature and mortality using a time serial generalized linear regression model, which has been successfully applied in a number of similar studies[2,6,13]. The exposure-response relationship between temperature and mortality has been shown to be relatively stable[6,15-18].

The exposure-response relationships between temperature and mortality reported in the literature mainly have three shapes: "J", "U" and "V". An increase in the risk of mortality is usually associated with increasing temperature. Our study statistically confirmed the association that the risk of mortality will rise with an increase in temperature through model calculation of historical data in Beijing. Our results are also consistent with results from other cities in China[9-12].

In the current study, calculation of the exposure-response relationship between temperature and mortality in various areas in Beijing showed that the effect of temperature on mortality in central urban and outer suburban areas was greater than that in the inner suburban area. This finding was caused by different vulnerabilities of the population in different areas to the effects of temperature. People in the central city area with a dense population may be more vulnerable to the effects of temperature, because there are more elderly people, children, and people with illnesses in the central city area. The economic level of various areas also determines the degree of vulnerability of people. Studies in the U.S. have shown that low-income people are often more vulnerable to heat; for example, the availability of air conditioners may vary by socio-economic level[6-7,19]. In Beijing, possible reasons for the difference between regions could be that the central area is densely populated, with more sensitive people with greater vulnerabilities. Similarly, because of their relatively low economic level, people in the outer suburban areas may also be more vulnerable. Clearly, the vulnerability of people to heat is influenced by many factors. Recent research in the U.S. showed that four

factors explained >75% of the total variance in the original 10 vulnerability variables: (1) social/environmental vulnerability (combined education/poverty/race/green space); (2) social isolation; (3) prevalence of air conditioning; and (4) the proportion of elderly and diabetic persons. In urban areas, they found that the inner cities showed the highest vulnerability to heat[20]. Although the situation in the U.S. greatly differs from that in China, the method for assessment of human vulnerability is an important reference for studies on this aspect in China, and it is also forms an important basis to further explain the differences in the exposure-response relationship between temperature and mortality in various areas.

The relationship between temperature and mortality is a nonlinear relationship[2,8,16]. However, to describe the quantitative effect of the level of temperature and mortality, some studies have performed secondary linear fitting to generate the exposure-response relationship. Although such fitting can easily obtain the slope factor of temperature and mortality, it destroys the original nonlinear relationship of the exposure-response relationship, which can lead to greater uncertainty. Therefore, the current study retained the original curve characteristics of the exposure-response relationship for the quantitative calculation of the effects of temperature on mortality, as well as follow-up assessment of the health risk. Different risk values were calculated according to different temperature values, using the "Predict" function of the R software package on the basis of the fitted curve expression of the exposure-response relationship.

We then estimated the number of temperature-related premature deaths in the summer of 2009. These values are likely only conservative estimates of the effect of temperature on the population of Beijing. We used the household demographic indicator of Beijing as population data for the city and various districts and counties. However, the permanent population of Beijing is almost 35% more than the "household" number, and therefore, the real value of the risk of temperature-related premature death in humans may be higher. From the curve of the exposure-response relationship between temperature and mortality, we observed that the effect of temperature was not restricted to summer only. In fact, the effect of temperature was also observed in spring, autumn, and even winter.

Therefore, over the entire year, the number of temperature-related premature deaths was larger than our current estimate for summer. Because only two years historical data were available for this research, we could not make an accurate judgment of the trend of the lower half of the curve of the exposure-response relationship (it was not statistically significant). To reduce uncertainty in our study, we only examined the higher-temperature part (summer) of the curve, which had greater statistical certainty.

One outcome of the health risk assessment method is that it can project future situations, to predict the effect of future climate change on human health. This can provide a relevant basis for formulation of climate change adaptation policy. Given certain scenarios of temperature estimates under climate change, the number of premature deaths can be estimated in the future. We applied the risk assessment calculation by studying the number of premature deaths in 2009 using measured temperature data in summer of 2009, to introduce and explain the method and role of health risk assessment. Our results on the effect of temperature in summer on human health in Beijing suggested that the central urban area and the Haidian and Chaoyang inner suburban areas will have a larger number of premature deaths. Although the number of premature deaths in the outer suburban districts and counties in Beijing is relatively low at present, this is mainly due to the low population base. However, as the proportional degree of effect of temperature on human mortality in the outer suburban districts and counties is relatively higher, the growth rate of temperature-related premature deaths will be higher for temperature rises in the future. Medical facilities in the central urban and inner suburban areas in Beijing are better than those in the outer suburban districts and counties. Therefore, the ability to cope with the effect of climate change on human health in the central urban and inner suburban areas will be better than those in the outer suburban districts and counties. Currently, Fangshan, Daxing, Pinggu, and Tongzhou districts in the outer suburbs have high risks, and the growth rate of risk in the future is also high. The current study only used the number of premature deaths as one indicator of health risk to carry out the risk calculation. In fact, a larger-scale effect of climate change on human health is an increase in morbidity. Research in other countries has shown that high temperature heat

waves always lead to significant increases in the number of visiting patients and hospital admissions[21]. Currently, this conclusion cannot be drawn in China, because there is no basic database for hospital visits and admission in China. It is also unknown whether the basic conditions of medical facilities in various districts and counties in Beijing, as well as in various regions in China, can cope with future possible situations. Risk assessment and policy research is an important research direction that needs to be urgently developed in the field of climate change and health research.

Because of limitations of available data, we did not consider the effects of air pollutants or other factors in the calculation of the exposure-response relationship model. This research assumes a single uniform temperature for all areas of Beijing during calculation of the exposure-response relationship. However, Beijing comprises a large area, and the temperature in different districts and counties may vary. Further study is required to confirm the effect of such a possible difference on the result of the exposure-response relationship. Similarly, because of the limitation of regional codes for the mortality data, we were not able to statistically analyze the number of deaths in each district and county to examine the different socioeconomic factors. Instead, we divided Beijing into three areas, namely the central urban area, the inner suburban area, and the outer suburban area. In follow-up studies, we intend to perform separate calculations on the exposure-response relationship in 18 districts and counties in Beijing to reduce uncertainty in the final assessment results.

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