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Projecting future climate change impacts on heat-related mortality in large urban areas in China

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ABSTRACT

Global climate change is anticipated to raise overall temperatures and has the potential to increase future mortality attributable to heat. Urban areas are particularly vulnerable to heat because of high concentrations of susceptible people. As the world's largest developing country, China has experienced noticeable changes in climate, partially evidenced by frequent occurrence of extreme heat in urban areas, which could expose millions of residents to summer heat stress that may result in increased health risk, including mortality. While there is a growing literature on future impacts of extreme temperatures on public health, projecting changes in future health outcomes associated with climate warming remains challenging and underexplored, particularly in developing countries. This is an exploratory study aimed at projecting future heat-related mortality risk in major urban areas in China. We focus on the 51 largest Chinese cities that include about one third of the total population in China, and project the potential changes in heat-related mortality based on 19 different global-scale climate models and three Representative Concentration Pathways (RCPs). City-specific risk estimates for high temperature and all-cause mortality were used to estimate annual heat-related mortality over two future twenty-year time periods. We estimated that for the 20-year period in Mid-21st century (2041–2060) relative to 1970–2000, incidence of excess heat-related mortality in the 51 cities to be approximately 37,800 (95% CI: 31,300–43,500), 31,700 (95% CI: 26,200–36,600) and 25,800 (95% CI: 21,300–29,800) deaths per year under RCP8.5, RCP4.5 and RCP2.6, respectively. Slowing climate change through the most stringent emission control scenario RCP2.6, relative to RCP8.5, was estimated to avoid 12,900 (95% CI: 10,800–14,800) deaths per year in the 51 cities in the 2050s, and 35,100 (95% CI: 29,200–40,100) deaths per year in the 2070s. The highest mortality risk is primarily in cities located in the North, East and Central regions of China. Population adaptation to heat is likely to reduce excess heat mortality, but the extent of adaptation is still unclear. Future heat mortality risk attributable to exposure to elevated warm season temperature is likely to be considerable in China's urban centers, with substantial geographic variations. Climate mitigation and heat risk management are needed to reduce such risk and produce substantial public health benefits.

1. Introduction

Climate change is anticipated to raise overall temperatures in the 21st century. Exposure to higher temperature in the warm season has been associated with both increased mortality and morbidity across the globe (Gasparrini et al., 2017; Guo et al., 2014; Huang et al., 2011; Zanobetti and Schwartz, 2008; Kinney et al., 2008;). Urban areas are particularly vulnerable to heat because of high concentrations of susceptible people as well as greater exposures associated with the urban heat island (Estrada et al., 2017; Li et al., 2015; Rosenzweig et al., 2010). As the world's largest developing country, China surpassed the U.S. and became the largest emitter of the primary greenhouse gas (GHG) carbon dioxide in 2007. Over the past 50 years, China has experienced noticeable changes in climate, with average air temperature rising by 0.5–0.8 °C (Kan, 2011). The nation is experiencing frequent occurrence of extreme heat in urban areas, which is likely to expose millions of residents to summer heat stress that could result in increased health risk, including mortality (Li et al., 2015). The trend of climate warming in China is projected to intensify in the future, which is likely to further increase the health risk associated with heat, particularly in large urban areas.

Future impacts of high temperatures on public health have been a

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topic of focused research in recent years (Gasparrini et al., 2017; Petkova et al., 2017, 2013; Weinberger et al., 2017; Schwartz et al., 2015; Mills et al., 2015; Wu et al., 2014; Voorhees et al., 2011; Knowlton et al., 2007; Also see a review by Sanderson et al. (2017)). Studies have consistently projected that a warmer future will lead to increase in future mortality on the order of thousands to tens of thousands of additional premature deaths per year in large countries such as the United States (US) (Sarofim et al., 2016), and over a hundred thousand per year globally (WHO, 2014). Although the decrease in cold season temperature is expected to result in decreases in deaths in winter months, recent studies have reported that increases in heat-related mortality could outweigh reductions in cold-related mortality, even in regions with colder climate (Gasparrini et al., 2017; Hajat et al., 2014; Li et al., 2013). Still, projecting changes in future health outcomes associated with climate warming remains challenging and subject to large uncertainties, and little is known about the future impacts of climate change in less developed countries, which are likely to be most vulnerable to climate change due to their reduced capacity to adapt and are also more vulnerable to climate-related damages (McCarthy, 2001).

The increase in future heat-related mortality is considered as one of the most likely impacts of climate change due to human activities. While climate-related health impacts are critical information in the economic assessments of climate change, to date they have been mostly overlooked by governments at all levels in energy and climate decision making. Therefore, projections of future heat mortality would provide valuable information to support climate policy decision making and heat-related risk management. Here we quantify excess heat-related mortality in the 51 largest urban areas in China in the 2050s and 2070s resulting from potential increases in future temperatures under three of the latest Representative Concentration Pathways emission scenarios developed for the Intergovernmental Panel on Climate Change Fifth Assessment Report (IPCC AR5, IPCC, 2014). The heat mortality projections are based on an integrated assessment framework that combines downscaled, very high resolution climate projections, city-specific temperature-mortality relationships, population projections and baseline mortality rates. We examine the future heat mortality impacts relative to the present situation, and also the differences of heat mortality between different future scenarios, which help to understand the potential benefits of reducing heat mortality risk through climate mitigation. We investigate sources of uncertainty including the temperature-mortality relationship, population projection, and human adaptation.

It is our goal to improve our understanding of possible impacts of elevated temperatures on public health in rapidly developing urban areas with high population density, where people may be especially vulnerable to global climate change, and also compare our findings with earlier projections in western developed countries. In addition to providing evidence of future heat-related mortality in the world's most populous developing county, this study improves earlier heat mortality projections by applying the latest RCP emission scenarios and the latest projections on China's population growth over the 21st Century, incorporating the newly developed city-specific temperature-mortality risk estimates, and using city-specific baseline mortality rates rather than national rates. Furthermore, given that population acclimatization and adaptation, such as improved human tolerance to heat and improvements in infrastructure and health care systems, has rarely been taken into account in existing projections, we use an "analogue city" approach to investigate the potential effects of adaptation on future temperature-related mortality estimates.

2. Materials and methods

2.1. Study areas and population

Based on the latest China census 2010 survey (National Bureau of Statistics of China, 2011), we selected 51 metropolitan areas in China to develop heat-related mortality projections for future climates (See Figs. 1 and 2 for the locations of the 51 cities). We included the four municipalities (Beijing, Tianjin, Shanghai and Chongqing),[1] the Hong Kong Special Administrative Region, and all province capital cities to ensure at least one city is selected in each province (generally in China, the capital is the major city in a province in terms of population and economic development). We also included non-capital cities that are among the top-30 cities by population. All together, these 51 cities encompass 0.458 billion, or roughly one third of the total 2010 Chinese population.

2.2. Climate models, emission scenarios, and future temperature projections

Using global climate model (GCM) outputs developed for IPCC AR5 (IPCC, 2014), we estimated future temperature changes in the mid (2050s) and late (2070s) 21st century in the 51 selected Chinese cities. We used downscaled, very high resolution climate data from the Coupled Model Intercomparison Project Phase 5 (CMIP5), which were developed for IPCC AR5. Data were obtained from WorldClim (http://worldclim.org/). The finest available spatial resolution of the data (30 arc-seconds, about 1 square kilometer) was used. Data for baseline conditions covered the time period of 1970–2000, and data for future conditions covered twenty-year time periods in the 2050s (2041–2060) and the 2070s (2061–2080). Future temperature projections for the 51 selected cities were developed by combining (averaging) the 30 arc-second down-scaled outputs from 19 GCMs from different modeling centers developed for IPCC AR5.[2]

IPCC AR5 uses four RCPs to describe different 21st century pathways of GHG emissions and atmospheric concentrations, air pollutant emissions and land use (IPCC, 2014). The RCPs include a stringent mitigation scenario (RCP2.6), two intermediate scenarios (RCP4.5 and RCP6.0) and one scenario with very high GHG emissions (RCP8.5). We conduct heat-related mortality projections under three emission scenarios: RCP8.5, RCP4.5 and RCP2.6. RCP8.5 can be considered as the business as usual scenario - an emissions scenario of high population and high energy demand in absence of climate change policies over this century, yielding the RCP with the highest GHG emissions (Riahi et al., 2011). RCP4.5 is a stabilization scenario in which the total radiative forcing is stabilized shortly after 2100 (Thomson et al., 2011). RCP2.6 is representative of a scenario that leads to very low GHG concentration levels and aims to keep global warming likely below 2 °C above pre-industrial temperatures (Vuuren et al., 2011).

Annual heat-related mortality in the future were estimated using the modeled mean temperature of the warmest quarter (variable "BIO10" in the WorldClim dataset). Although different temperature metrics have been used to measure heat exposure, such as maximum, mean and minimum daily temperature, and apparent temperature (a metric that combines the effects of ambient temperature and relative humidity), earlier studies found no temperature measure was superior to the others (Barnett et al., 2010), and suggested that for the projection research of heat-related mortality, the temperature measure can be chosen based on practical concerns, such as using the measure that is commonly available from the climate models (Huang et al., 2011). Based on this, we selected the modeled mean temperature of the warmest quarter as the indicator of average human exposure to heat during the warm season, and linked it to heat-related mortality using temperature-mortality relationships reported in epidemiological studies. For each city, we averaged the model-simulated mean temperature of the warmest

[1] In China, municipalities are directly under the administration of central government. Despite their city-level areas and populations, a municipality has the same political, economic and jurisdictional rights as a province.

[2] These 19 GCMs include: ACCESS1-0, BCC-CSM1-1, CCSM4, CESM1-CAM5-1-FV2, CNRM-CM5, GFDL-CM3, GFDL-ESM2G, GISS-E2-R, HadGEM2-AO, HadGEM2-CC, HadGEM2-ES, INMCM4, IPSL-CM5A-LR, MIROC-ESM-CHEM, MIROC-ESM, MIROC5, MPI-ESM-LR, MRI-CGCM3, and NorESM1-M.