Ambient Temperature and Health in China

Hualiang Lin
Wenjun Ma
Qiyong Liu
Editors

Springer

Ambient Temperature and Health in China

Hualiang Lin • Wenjun Ma • Qiyong Liu
Editors

Ambient Temperature and Health in China

Springer

Editors
Hualiang Lin
School of Public Health
Sun Yat-sen University
Guangzhou
Guangdong
China

Wenjun Ma
Guangdong Provincial Institute of
Public Health
Guangzhou
Guangdong
China

Qiyong Liu
National Institute for Communicable
Disease Control and Prevention
Chinese Center for Disease Control and
Prevention
Beijing
Beijing
China

ISBN 978-981-13-2582-3 ISBN 978-981-13-2583-0 (eBook)
https://doi.org/10.1007/978-981-13-2583-0

This Springer imprint is published by the registered company Springer Nature Singapore Pte Ltd.
The registered company address is: 152 Beach Road, #21-01/04 Gateway East, Singapore 189721, Singapore

Foreword

Climate change is a global threat: its effects are felt everywhere, although not always in the same form or to the same extent. But the impacts in China, and measures taken in that country to cope, have special significance. This is partly a matter of scale, given that roughly 20% of the world's population lives in China. Losses (and gains) dwarf, in absolute terms, those experienced in almost any other country. However, the Chinese story stands out in other ways also.

With its fast-rising economy, China is challenged to simultaneously protect the environment, sustain public health and meet social expectations for better quality of life. These pressures exist in many developing countries, but the Chinese response to climate change is of particular interest, given the country's capacity to plan long-term and nationwide. Examples include decisive, wide-ranging policies to curb air pollution, expand forests and promote low-carbon forms of power generation.

As a summary of climate and health impacts in China, this is an important book, for all the reasons above. It aims to describe the climate trends now observed in China, the health impacts of these changes, projections for the future and adaptations to protect public health. The focus is mainly on rising temperatures, but attention is paid also to related changes such as rainfall intensity, storm frequency and occurrence of droughts. The health outcomes include some that have been closely researched in other countries, such as cardiovascular mortality and incidence of water-borne infectious diseases. But there are chapters also on less well-understood effects, such as those of high temperatures on reproductive health outcomes.

We know that the health effects of a given environmental change, such as increased frequency and severity of heatwaves, may differ from one location to another and from one time period to the next. Vulnerability to adverse effects of climate variability and climate change is partly a function of individuals (e.g. their age or baseline health status). But vulnerability is determined also by qualities of the group (social connectedness, for instance) and the services that sustain the population (e.g. health care). However, relatively few studies have examined the multilevel causes of vulnerability in a country like China that is transitioning rapidly to high-income/high-life status.

This book includes several chapters that pursue these questions. In what ways do the health risks of rising temperatures differ between China and other countries and why? What are the most robust and informative indicators of personal vulnerability to climate-related health loss? And what is the role of joint exposures, such as the combination of particulate air pollution and heatwaves? This last issue is particularly important in China, since poor air quality is still common in many cities and urban environments are especially prone to damaging heat.

A distinctive feature of the book is the diverse authorship. A large number of scholars from across China have worked together to summarise the present state of the science, review the implications for public health and identify the most important knowledge gaps requiring further research. It will be a valuable resource, both in China and internationally, for scientists and also those engaged in one way or another in climate policy.

Auckland, New Zealand Alistair Woodward

Foreword

Scientific evidence regarding the relationship between climate change and human health has been intensified in recent decades, based on the historical and current exposure-health outcome associations in different regions of the world, together with the modelling of future scenarios. In 2005, the WHO Millennium Ecosystem Assessment found that these health effects were mediated by various causal pathways including heatwaves and other extreme weather events, changes in the spread of pathogens and pollution of air and water. A decade later, the Lancet Commission published its report on Health and Climate Change, which concluded that climate change threatens to undermine public health gains in the past 50 years, and suggested that a comprehensive response to climate change could be "the greatest global health opportunity of the 21st century". Indeed, given that even at the current 1 degree global warming, it has demonstrated the impact on our health and wellbeing. Over the next 20 years, we are likely, as the most recent IPCC report presented, to exceed the 1.5 degree threshold agreed to as an aspirational limit, and thus it is important that we take a timely systematic approach to understand the health risks from climate change and plan for future human health impacts.

As the largest developing country, climate change has and will continue to have negative impacts on population health in China. Given its vast geographic coverage, large population, varying climatic zones, in-balanced socioeconomic developments and underdeveloped health services, it is important to undertake comprehensive health risk assessments and risk characterisation in the context of climate change, especially considering the extreme heat and other extreme weather events. This will also allow relevant policies and practical guidelines to be developed and refined.

Edited by Professors Hualiang Lin, Wenjun Ma and Qiyong Liu, a group of distinguished Chinese scientists in the climate change and population health area are working together to complete this book. It is, for the first time, a comprehensive summary of the impacts of extreme heat and other extreme weather events on population health in China, including the risk assessments on both infectious diseases and chronic diseases, as well as reproductive health outcomes. In addition, the authors have examined health impacts from the interactions between air pollution and weather variables, assessed the health vulnerability to climate change, compared the health outcomes due to extreme heat with these in other countries and projected future health outcomes due to climate change. Furthermore, they have explored the public health adaptation strategies and proposed further research directions in climate change and population health in China.

This comprehensive book provides updated information to readers in the areas of health and medical services, climate change adaptation, community resilience, emergency service and environmental protection, both in China and international research and adaptation communities. It will not only help readers fully understand climate change and population health in China but also assist research and adaptation capacity building, especially for postgraduate students, early career researchers and practitioners alike.

Adelaide, SA, Australia Peng Bi

Acknowledgements

I would like to thank all the scholars, teachers, and staff, who have contributed to this book. They have made great efforts while writing and revising each of the chapters.

I am grateful to Professor Alistair Woodward from the University of Auckland and Professor Peng Bi from the University of Adelaide for their prefaces about this book, which provided a brief overview of the whole book and current state of research on climate change and human health.

I would like to express our special thanks of gratitude to Mr. Rakesh Kumar Jotheeswaran, Ms. Rajalakshmi Jayakumar, Dr. Xuewen Li, Ms. Ellen Seo, and Dr. Peng Zhang for their valuable suggestions and patient feedback during the entire process of book revision and editing.

I would also like to thank all the experts and friends, who have provided help and suggestions during the whole process; this book would not have been possible without their support and encouragement. Special thanks to Mr. Siqi Ai for the coordination and finalization of this book within the limited time frame.

My sincere thanks go to the National Key R&D Program (Grant No: 2018YFA0606200) for the financial support.

Contents

1 Overview of Climate Change in China

Changke Wang and Lin Zhao

Abstract

It is at the rate of 0.32 °C/decade that the annual average surface air temperature over China rose from 1961 to 2017. And the warming rate of the annual mean minimum temperature, 0.42 °C/decade, was much higher than that of the maximum temperature (0.27 °C/decade). The annual precipitation over China showed no linear trend. During 1961–2017, China is characterized by a rise in high temperature days, heavy rainfall days, and the number of typhoons. Annual mean sea level around China increased at an average rate of 3.3 mm/a from 1980 to 2017, which was higher than that of the world. Temperature in China will keep rising in the future and go up 1.3–5.0 °C by the end of the twenty-first century. The number of high temperature days and heat wave will also increase in the twenty-first century over China. And the annual precipitation, extreme precipitation, and extreme drought events in China will increase. The sea level in China will also continue to rise in the future.

C. Wang (✉) · L. Zhao
National Climate Center, China Meteorological Administration, Beijing, China
e-mail: wangck@cma.cn; Zhaolin@cma.gov.cn

Keywords

Climate change · Climate-related extreme event · China

1.1 Introduction

Severe changes in local climate and weather caused by climate change can have multiple effects on human health. Due to various adaptation capacities, the impacts of climate change on human health will be different among regions [1].

Climate change impacts human health adversely by increasing human populations' exposure and vulnerability to climate-related stresses [2]. The human health is sensitive to shifts in weather patterns and other aspects of climate change [3]. Shifts in the seasonality, geographic range, and intensity of transmission of climate-sensitive infectious diseases are associated with changing weather patterns [4, 5].

Climate change produced a series of harmful effects on human health in China [6, 7]. For example, the cardiovascular mortalities in Wuhan City increased year by year during 1998–2008, which has been associated with climate change [8]. In the Yangtze River Basin, snails has expanded from the south to the north under climate warming [9]. In eastern Sichuan Province and eastern Yunnan Province, the number of respiratory diseases patients has risen resulting

H. Lin et al. (eds.), *Ambient Temperature and Health in China*,
https://doi.org/10.1007/978-981-13-2583-0_1

from significantly increased foggy days [10]. The increasing intensity and frequency of summer heat waves in Guangdong Province resulted in the increased risk of heat stroke and cardiovascular and respiratory diseases [11].

Extreme weather and climate events have many important impacts in terms of casualties and other health effects [12] and cause increasing morbidity and mortality [13]. Since 1980, the risk of heat-related death or illness has steadily climbed [14]. From 2000 to 2016, the amount of vulnerable people who were exposed to heat wave events has risen by around 125 million [15]. In 2016, 23.5 million people were displaced by weather-related disasters, and most of those displacements were strongly associated with storms or floods [16].

Intergovernmental Panel on Climate Change (IPCC) Fifth Assessment Report concluded that climate change will lead to greater risks of death, disease, and injuries because of more intense heat waves and fires; increased risks of malnourishment resulting from reduced food production in poor regions; but modest reductions in cold-related morbidity and mortality in some areas [13]. In China, high temperature subsidies for employees who work outdoors on extremely hot days, taking account of employment structure and population growth, are projected to rise from 38.6 billion RMB Yuan per year during 1979–2005 to 250 billion RMB Yuan per year in the 2030s [17].

In this chapter, the global climate change was firstly described in brief. Then climate change and extreme weather and climate events in China were summarized in detail; Finally, future climate change projection of both the world and China was presented.

1.2 Global Climate Change in Brief

The global climate system has changed significantly with the main features of warming since the beginning of the Industrial Revolution (about 1750). The global warming is more significant especially since the 1950s. The global mean surface temperature presents a warming of 0.85 °C from 1880 to 2012 [18], and the warming rate over the past 60 years (1951–2010) is 0.12 °C/decade. The global mean temperature for 2013–2017, approximately 1 °C above that for 1850–1900, is the highest 5-year average on record [19]. The year 2016, about 1.1 °C above the pre-industrial period, was the warmest year on record for both the northern and southern hemispheres and for both land areas and oceans. In 2017, global mean temperatures were 1.1 ± 0.1 °C above the pre-industrial levels [19].

The precipitation over global land has changed a little since 1901. And the averaged precipitation has increased over the mid-latitude land regions of the northern hemisphere. Meanwhile, the area-averaged long-term trends for other latitudes are positive or negative (low confidence) [18].

The world sea levels also continued to rise. Global mean sea level has gone up by 190 mm over the period 1901–2010, with an average rate of 1.7 mm/a. Since the early 1900s, the rise rate of global mean sea level has increased. The rate was higher at 3.2 mm/a from 1993 to 2010; similarly high rates occurred during 1920–1950 [19].

Extreme temperatures have changed greatly in the past decades. Frosts, cold days, and cold nights have become more rare, while heat waves, warm days, and warm nights become more frequent, and the intensity of heat wave disasters in the world is increasing from 1951 to 2010 [18]. For example, the rare high temperature heat waves in the Midwest of Europe in the summer of 2003 broke the record since 1780, and in 2015 Europe again had a large, long, and rare heat wave.

There are more land areas where the amount of heavy precipitation events has risen than where it has decreased. For example, the intensity or frequency of heavy precipitation events, in North America and Europe, has increased [18].

1.3 Climate Change and Extreme Weather Events in China

1.3.1 Changes in Air Temperature Over China

Annual mean air temperatures over China show a significant rise of 1.21 °C between 1901 and 2017, and the warmest period is in the past two

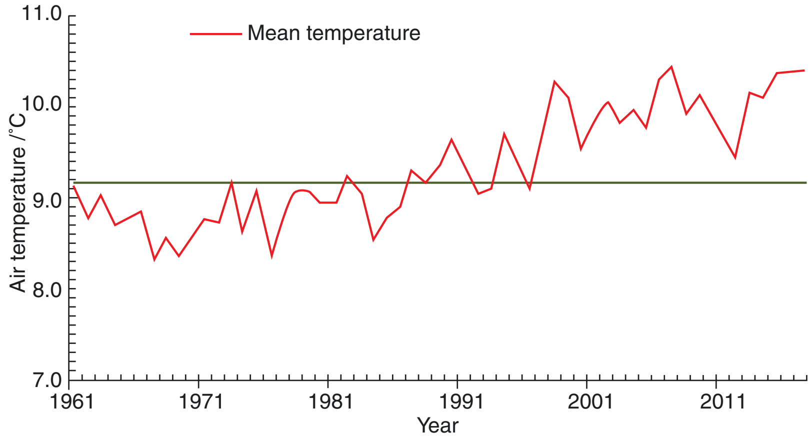


Fig. 1.1 Annual mean surface air temperature over China from 1961 to 2017

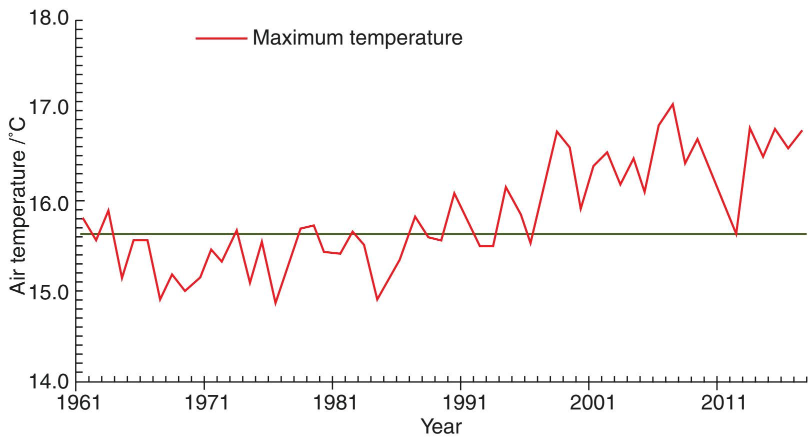


Fig. 1.2 Annual surface maximum air temperature over China from 1961 to 2017

decades since the beginning of the twentieth century [15].

From 1961 to 2017, annual mean air temperatures over China were rising, with a rate of 0.32 °C/decade (Fig. 1.1). The warming in China is above the global average.

Annual mean surface maximum temperatures over China increased at a rate of 0.27 °C/decade from 1961 to 2017, which is less than that of the mean air temperatures (Fig. 1.2). The mean maximum temperature was relatively stable before the 1990s and has been significantly rising since then. From a seasonal perspective, it rose considerably in winter but only slightly in summer.

Annual mean surface minimum temperatures over China rose at a rate of 0.42 °C/decade from 1961 to 2017, which is greater than both that of the mean air temperatures and that of the maximum air temperatures (Fig. 1.3). It rose slowly before 1987 and has been increasing much faster since 1987. The mean minimum temperature in each season shows an increasing trend, which is most noticeable in winter [20].

The rate of warming over China in recent 20 years has slowed down [21]. In the last 20 years, the warming rate of the land surface mean temperature declines (Fig. 1.1). Such a slowdown can be found in the changes of both maximum and minimum temperature (Figs. 1.2 and 1.3).

During 1961–2017, the regional annual mean surface air temperature in China was overall rising but exhibited remarkable regional difference (Fig. 1.4). The Qinghai-Tibet region even reported a temperature rise of 0.37 °C/decade during 1961–2017. The warming rates of North China, Northwest China, and Northeast China are 0.33, 0.30, and 0.30 °C/decade, respectively. East China reported a temperature

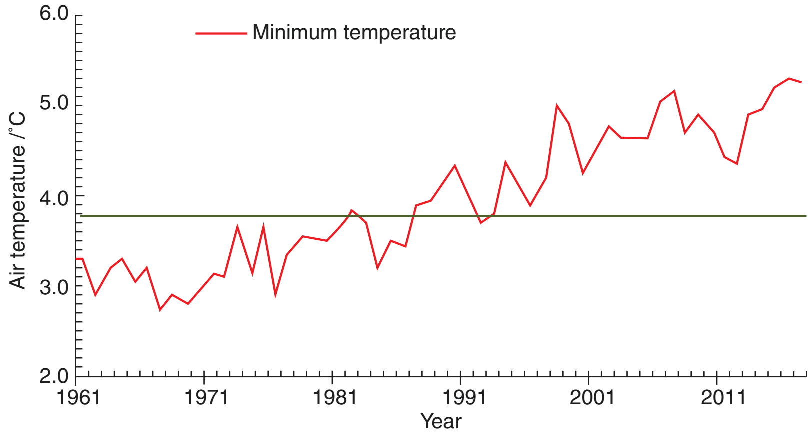


Fig. 1.3 Annual surface minimum air temperature over China from 1961 to 2017

rise of 0.24 °C/decade. The warming rates of Central China, South China, and Southwest China are 0.18, 0.17, and 0.16 °C/decade, respectively [22].

1.3.2 Changes in Precipitation Over China

The national average annual precipitation over China showed no significant linear trend from 1961 to 2017. In the 1990s, China statistically had more precipitation. In the first decade of this century, China had less precipitation. However, the precipitation averaged over China kept being above normal in the past 6 years (Fig. 1.5).

During 1961–2017, China noticeably differed in the trends of regional averaged precipitation (Fig. 1.6). The Qinghai-Tibet region became wetter, with an increasing trend of 8.9 mm/decade, while Southwest China was on a dry side, with a decreasing trend of 13.0 mm/decade. The mean annual precipitations of North China, Northeast China, Northwest China, Central China, and East China reported no linear trend though with some inter-decadal fluctuations. From the beginning of the twenty-first century, the average annual precipitations of North China, South China, and Northwest China increased gradually, while those of Central China and Southwest China were generally with a decreasing trend.

1.3.3 Changes in Extreme Weather and Climate Events

The extreme weather and climate events in China are characterized by large variation, high frequency, periodic and seasonal occurrences, broad regional differences, and widespread impacts. A variety of weather and climate events, including heat waves, freezing, drought, rainstorms, typhoons, dust storms, gales, and hazes, happen frequently in many regions across the country [20].

1.3.3.1 High Temperature

The mean number of annual high temperature days (daily maximum temperature ≥35.0 °C) over China exhibited an upward trend during 1961–2017, with a rising rate of 0.5 day/decade (Fig. 1.7). The periodic variation was significant. From the 1960s to the mid-1980s, there was a decreasing trend, and there was a marked increasing trend that has been maintained since the late 1980s (Fig. 1.5). From the beginning of the

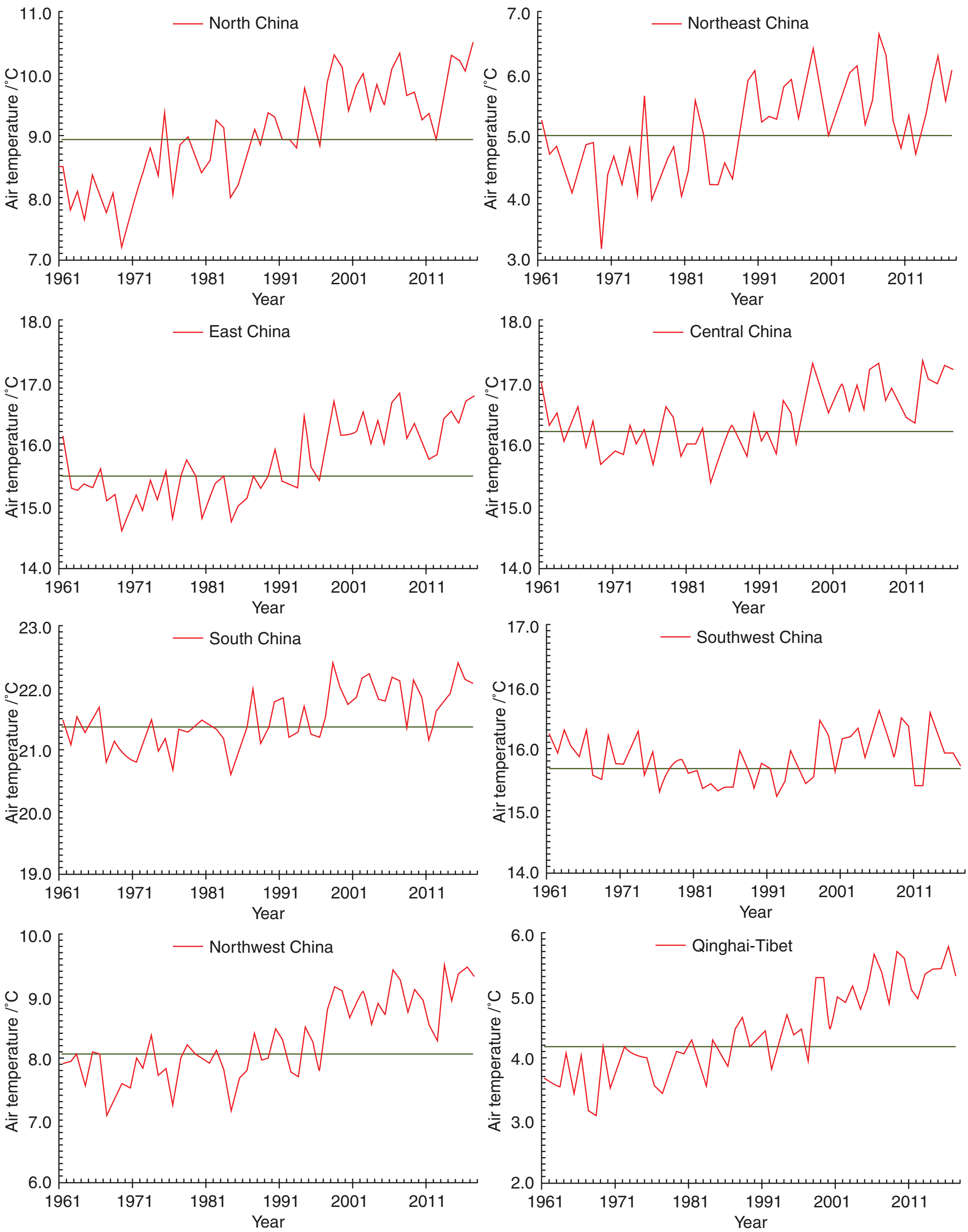
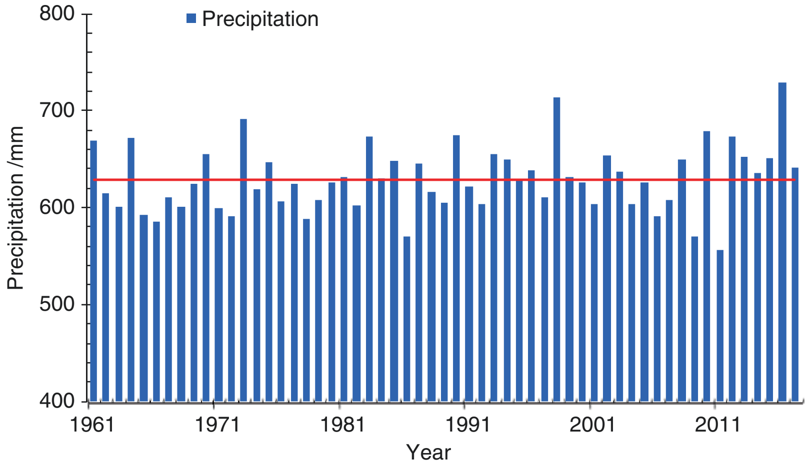


Fig. 1.4 Regional averaged surface air temperature from 1961 to 2017

Fig. 1.5 Annual precipitation over China from 1961 to 2017



twenty-first century, the average number of annual high temperature days was 9.7 days, which is 2.8 days more than normal (reference period, 1971–2000).

1.3.3.2 Heavy Rainfall

During 1961–2017, China saw significantly decreased rain days, but the heavy rainfall days (daily rainfall ≥50 mm) increased at a rate of 3.9% per decade (Fig. 1.8).

1.3.3.3 Tropical Cyclones and Typhoons

From 1949 to 2017, the number of tropical cyclones landing in China with a maximum sustained wind speed near the bottom center ≥17.2 m/s showed a mild upward trend and great inter-annual variability; there were a maximum of 12 (in 1971) and a minimum of 3 (in 1950 and 1951) during the period (Fig. 1.9). The number of typhoons (with a maximum sustained wind speed near the bottom center ≥32.7 m/s) presented an increasing trend, which was particularly significant since the beginning of the twenty-first century.

1.3.3.4 Sandstorm

From 1961 to 2017, the number of sand-dust days showed a downward trend in Northern China. Since the 1980s, the amount of sand-dust days has declined sharply (Fig. 1.10). In most regions, there were much fewer dust storm days during the 1980s and 1990s than during the 1950s and 1960s.

1.3.4 Sea Level Change Around China

Annual mean sea level around China increased at a mean rate of 3.3 mm/a from 1980 to 2017, which was higher than that of the world. At the last 6 years, the coastal sea level has been in the highest level since 1980, and the top 6 of the sea level from high to low are in 2016, 2012, 2014, 2013, 2017, and 2015. In 2016, the annual mean sea level around China was 82 mm higher than average for the 1993–2011 period and the highest since 1980 [9]. Observed at the tide gauge station of Hong Kong Victoria Harbor, the annual mean sea level experienced a fluctuated rise at a rate of 3.2 mm/a from 1954 to 2017, which rose rapidly during 1990–1999 and then moved down slowly. Bohai Bay sea levels show a prominent rising trend of 3.3 mm/a from 1950 to 2015. The increasing speed has been particularly rapid at a rate of 4.7 mm/a from 1980 to 2015 [23].

1.4 Projection of the Future Climate Change

Under the Coupled Model Inter comparison Project Phase 5 (CMIP5), climate change projection experiments consider four sets of possible emission scenarios in the future, denoted the Representative Concentration Pathways. And RCP2.6, RCP4.5, RCP6.0, and RCP8.5 refer to the scenarios in which most stringent, moderate,

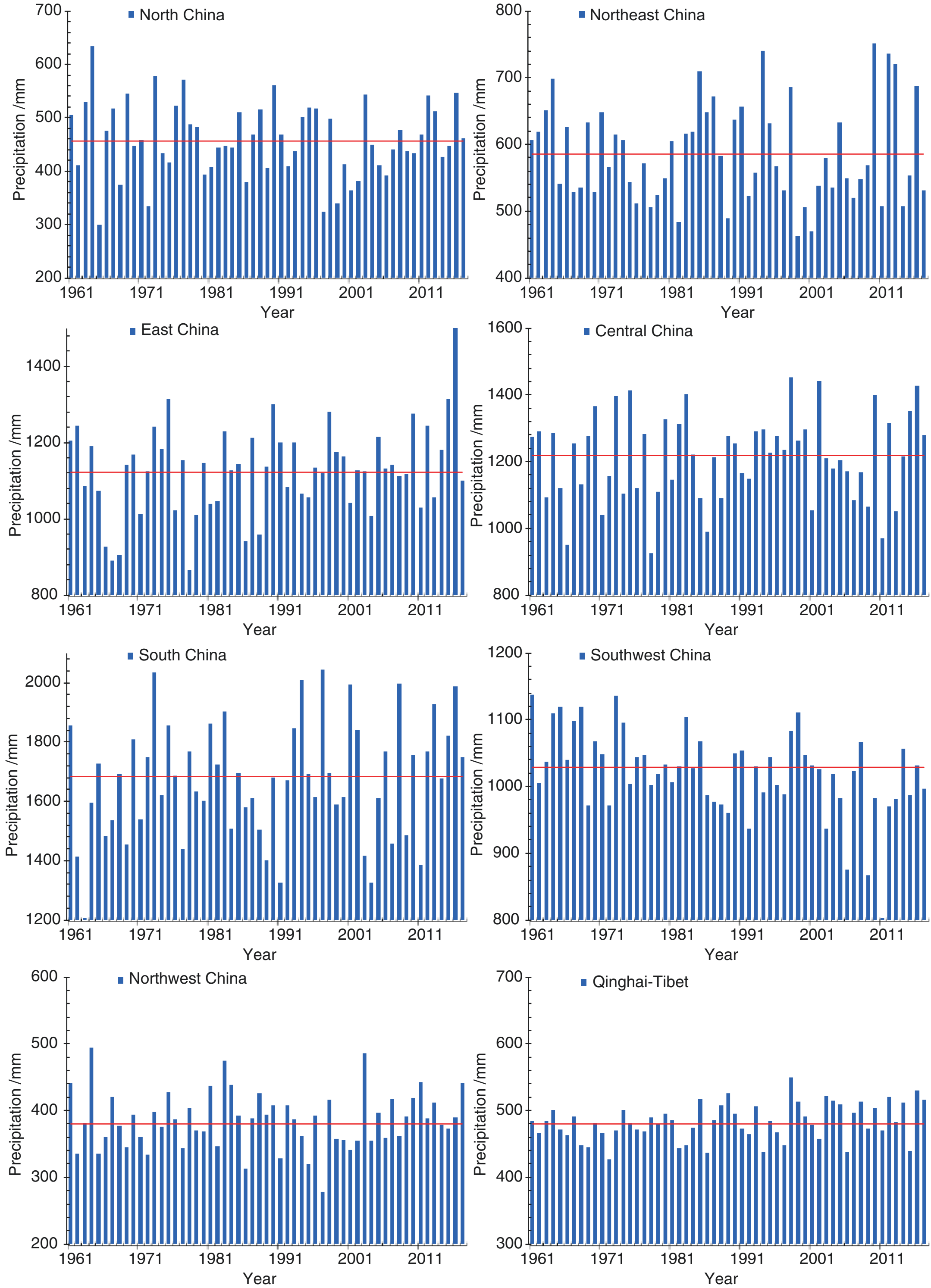


Fig. 1.6 Regional averaged annual precipitation from 1961 to 2017

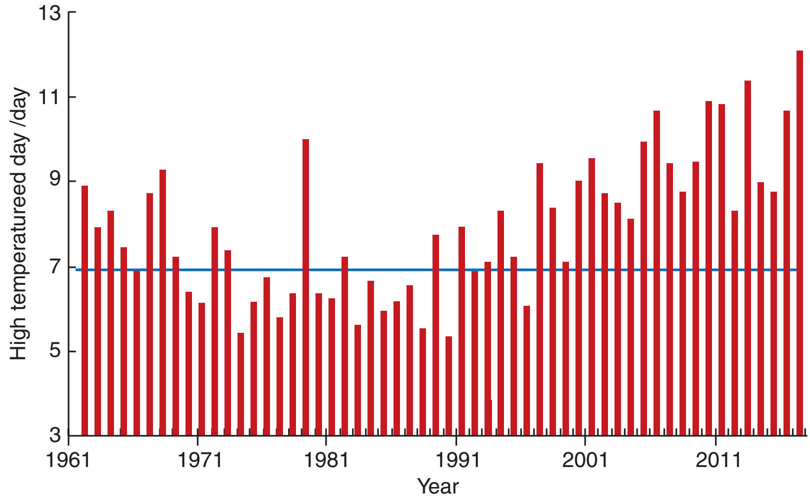


Fig. 1.7 Annual high temperature days over China from 1961 to 2017

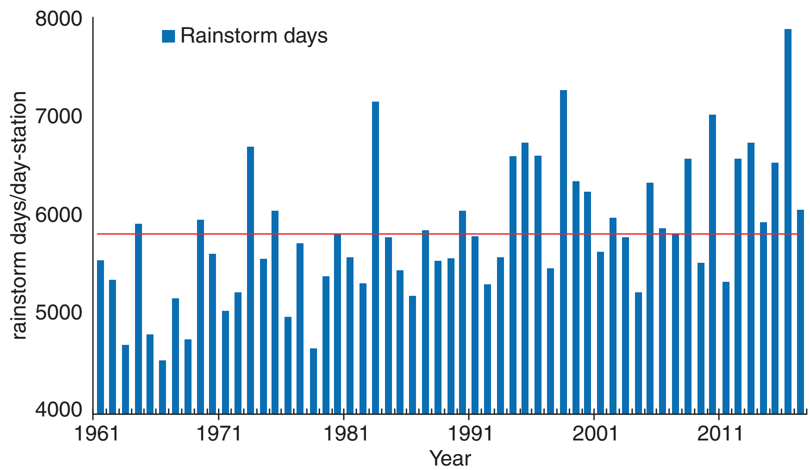


Fig. 1.8 Cumulative annual rainstorm days over China from 1961 to 2017

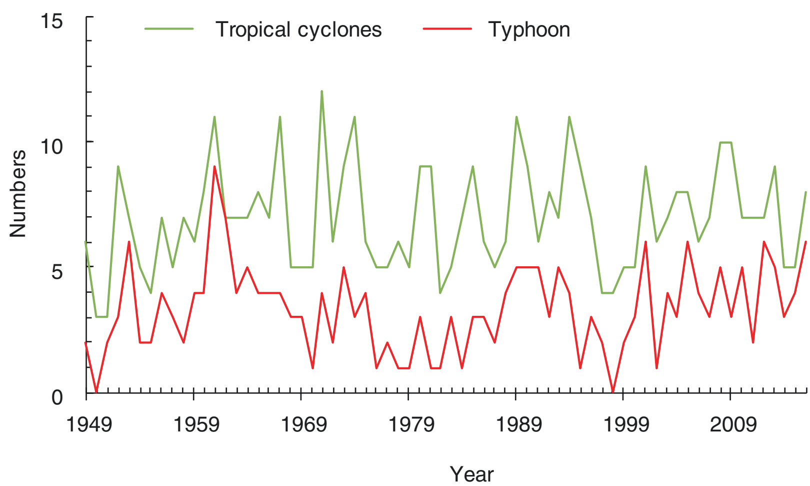


Fig. 1.9 The numbers of tropical cyclones and typhoons landing China from 1948 to 2017

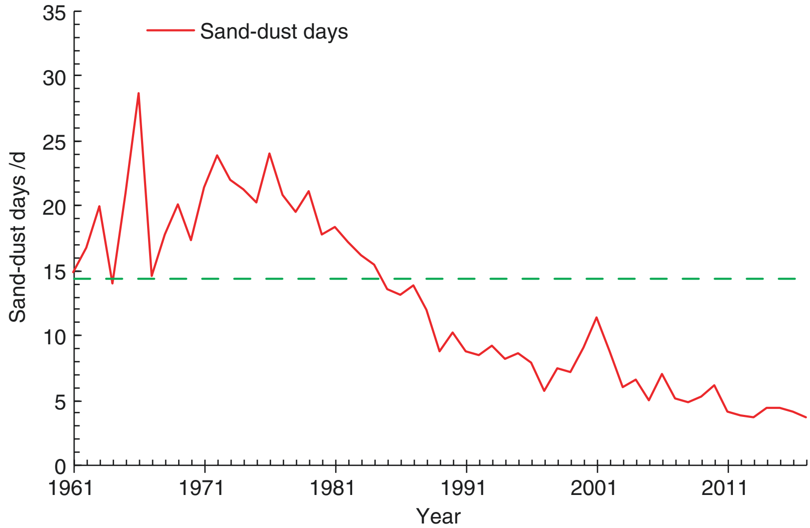


Fig. 1.10 Variation of annual sand-dust storm days averaged over Northern China during 1961–2017

and no restriction will be given on the greenhouse gases emission, respectively, and radiative forcing values will be +2.6, +4.5, +6.0, and + 8.5 W/m^2 in 2100 relative to pre-industrial values, respectively [24].

1.4.1 Future Global Climate Change

It is projected that global warming will continue based on the CMIP5 models [25]. Relative to 1986–2005, the global average surface temperature will increase by 0.3–0.7 °C for 2016–2035 and by 1.0 °C (0.3–1.7 °C), 1.8 °C (1.1–2.6 °C), 2.2 °C (1.4–3.1 °C), and 3.7 °C (2.6–4.8 °C) for RCP2.6, RCP4.5, RCP6.0, and RCP8.5 by the end of the twenty-first century [3]. By the end of the twenty-first century, global average surface temperature change is projected to exceed 1.5 °C for RCP4.5, RCP6.0, and RCP8.5, relative to 1850–1900.

CMIP5 models project that the global precipitation will gradually increase throughout the twenty-first century with continued global warming. The models results show that the precipitation will increase by about 1–3% if surface temperature rises by 1 °C. And the change in the horizontal mean precipitation will reflect a typical response of "wetter in wet areas and dryer in the dry areas."

As global mean temperatures increase, fewer cold and more hot temperature extreme events will occur in most places. Heat waves will happen with increasing frequency, magnitude, and duration. Nevertheless, occasional cold winter extremes will go on happening. The monsoon precipitation at a global scale will increase in amount and intensity. East Asian summer monsoons, in particular, will remarkably intensify. And the winter monsoon in East Asia will weaken in the twenty-first century [18].

Under RCP2.6 scenario, the global mean sea level will rise by 260–550 mm in the next 100 years. It is very likely that the sea level of over 95% global oceans will rise, and the sea level rise in about 7% of the coastal areas will not exceed 20% of the global average. Under RCP8.5, the global average sea level will rise by 450–820 mm.

1.4.2 Future Climate Change Over China

1.4.2.1 Temperature

Under the low- (RCP2.6), medium- (RCP4.5), and high-emission (RCP8.5) scenarios, the mean temperature over China will rise by 1.3, 2.6, and 5.0 °C, respectively, in 2081–2100 relative to 1986–2005. Under all scenarios, the range of warming over China will be higher than that of the world, as the temperature rise in China only takes into account the warming of the land, not the ocean.

The highest daily maximum temperature will rise by 1.3, 1.5, and 2.0 °C for RCP 2.6, RCP 4.5, and RCP 8.5 by the mid-twenty-first century and by 1.5, 2.7, and 5.5 °C by the end of the twenty-first century, respectively [20]. The lowest daily minimum temperature will go up by 1.5, 1.7, and 2.2 °C by the mid-twenty-first century and by 1.6, 2.9, and 5.8 °C by the end of the twenty-first century, respectively [20].

Under the 2.0 °C and 1.5 °C target, the annual mean surface air temperature (SAT) over China will increase by 2.4–2.7 °C and 1.7–2.0 °C, respectively. The SAT over Northwestern China would rise by 2.6–2.7 °C for the 2.0 °C target, much higher than that over Southeast China (1.9–2.1 °C). For the 1.5 °C target, the SAT would rise by 1.9–2.1 °C and 1.3–1.5 °C over the two regions, respectively [26].

Under the RCP4.5 scenario, there will be more stronger extreme warm events and fewer extreme cold events over China. The heat wave duration index will be 2.6 times higher than current level by 2046–2065. But the cold wave duration index will be 71% less than that in 1986–2005 by the end of the twenty-first century [27].

1.4.2.2 Precipitation

Under RCP2.6 and RCP8.5, the mean precipitation in China will grow 0.05 mm/day (2%) and 0.15 mm/day (5%) by 2100, respectively. The precipitation in the north of China may increase by 5–15% by the end of the twenty-first century, while that in the south of China will not change significantly [21].

Under global warming, the extreme precipitation in China will increase; extreme snowfall events will increase in the north and will decrease in the south; the cold waves in China will abate. The extreme drought events will increase with a significant increase of the days of high temperature and heat waves [21].

In the Eastern Monsoon Region of China, extreme floods and droughts will be an increasing trend. The amount of intensive precipitation events and the intensity and frequency of floods and droughts are projected to increase during 2020–2040. The frequency of extreme drought events is projected to rise fluctuately over the next 30–50 years [28].

Under the RCP8.5 scenario, high flood risk will mainly appear in Eastern China, Hebei, Beijing, Tianjin, and eastern Sichuan in the future. The major cities in Northeast China, parts of Shaanxi and Shanxi, and some coastal areas in southeastern China also will encounter high flood risks [29].

By the end of the twenty-first century, there will be great risk of drought disasters in North China, East China, and central Northeast and Southwest China. The areas with high risk of drought disasters will increase significantly [20].

1.4.2.3 Sea Level

Under RCP 8.5, the sea level around China will rise by 400–600 mm by the end of the twenty-first century, relative to the twentieth century. In the next 30 years, it is projected that the coastal sea levels of the Bohai Sea will rise by 65–135 mm, Yellow Sea by 60–130 mm, East China Sea by 75–145 mm, and South China Sea by 60–130 mm [23].

1.5 Summary

The global mean surface temperature showed a rise of 0.85 °C from 1880 to 2012, and the rate of temperature rise between 1951 and 2012 (0.12 °C/decade) was almost twice the rate between 1880 and 2012. The rising of the global average sea level has accelerated, and the rate of increase reached 3.2 mm/a between 1993 and 2010. The global mean surface temperature will continue to increase by the end of the twenty-first century. Heat waves, heavy precipitation, and other climate extremes will happen more frequently.

During 1961–2017, annual mean air temperatures over China are rising. The north part of China secured a warming rate apparently faster than that of the southern counterparts. Meanwhile the western China exhibited greater warming rates exceeding the eastern part of the country. China noticeably differed in the trends of regional averaged precipitation. The Qinghai-Tibet region became wetter, while Southwest China was on a dry side. The rest parts of the country reported on linear trend though with some inter-decadal fluctuations. Temperature in China will keep rising in the future and go up by 1.3–5.0 °C by the end of the twenty-first century. And annual precipitation in China will also increase.

During 1961–2017, weather and climate extremes have changed significantly in China. The numbers of high temperature days, rainstorm days, and the amount of tropical cyclones landing in China have increased, and the amount of sand-dust days in Northern China has decreased. In the future, some extreme weather and climate events over China will increase. The number of high temperature and heat waves will substantially increase. Extreme drought events will increase, while the drought events in China will happen less frequently.

References

1. Zhou X. Potential impacts of climate change on human health. Adv Clim Change Res (in Chinese). 2010;6(4):235–40.
2. Hales S. Quantitative risk assessment of the effects of climate change on selected causes of death, 2030s and 2050s. Geneva: World Health Organization; 2014.
3. Parry ML, Canziani OF, Palutikof JP, Van dL, Paul J, Hanson CE. IPCC, 2007: climate change 2007: impacts, adaptation and vulnerability. Contribution of working group II to the fourth assessment report of the intergovernmental panel on climate change. Contribution of working group II to the third assessment report. 2007;19(2):81–111.
4. Lin H, Liu T, Song T, Lin L, Xiao J, Lin J, He J, Zhong H, Hu W, Deng A, Peng Z, Ma W, Zhang Y. Community involvement in dengue outbreak control: an integrated rigorous intervention strategy. PLoS Negl Trop Dis. 2016;10(8):e0004919.
5. Semenza JC, Menne B. Climate change and infectious diseases in Europe. Lancet Infect Dis. 2009;9(6):365–75.
6. Fan J, Lin H, Wang C, Bai L, Yang S, Chu C, Yang W, Liu Q. Identifying the high-risk areas and associated meteorological factors of dengue transmission in Guangdong Province, China from 2005 to 2011. Epidemiol Infect. 2013;142(3):634–43.
7. Ren YJ, Cui JX, Wan SQ, Liu M, Chen ZH, Liao YF, Wang JJ. Climate change impacts on Central China and adaptation measures. Adv Clim Chang Res. 2013;4(4):215–22.
8. Chen Z, Yang H, Zeng H, et al. Analysis on the seasonal, monthly and every ten days' distributed properties of diseases at respiratory tract, heart and cerebral blood vessels in Wuhan. J Math Med (in Chinese). 2000;13(5):413–5.
9. Peng WX, Zhang ZJ, Zhuang JL, Zhou YB, Jiang QW. Potential impact of climate changes on spatial distribution of schistosomiasis in China. Sci Technol Rev. 2006;24(7):58–60.
10. Chen S, Shi Y, Wang L, Dong A. Impact of climate variation on fog in China. J Geogr Sci (in Chinese). 2006;16(4):430–8.
11. Zeng WL, Lao XQ, Rutherford S, Xu YJ, Xu XJ, Lin HL, Liu T, Luo Y, Xiao JP, Hu MJ, Chu C, Ma WJ. The effect of heat waves on mortality and effect modifiers in four communities of Guangdong Province, China. Sci Total Environ. 2014;482-483:214–21.
12. Zhai P, Liu J. Extreme weather/climate events and disaster prevention and mitigation under global warming background. Eng Sci. 2012;9:55–63.
13. Field CB. Climate change 2014: impacts, adaptation and vulnerability: Working Group II contribution to the fifth assessment report of the Intergovernmental Panel on Climate Change. Guangdong Agric Sci. 2014;285(34):25987–95.
14. Mora C, Dousset B, Caldwell IR, Powell FE, Geronimo RC, Bielecki CR, Counsell CWW, Dietrich BS, Johnston ET, Louis LV. Global risk of deadly heat. Nat Clim Chang. 2017;7(7):501.
15. Watts N, Amann M, Ayeb-Karlsson S, Belesova K, Bouley T, Boykoff M, Byass P, Cai W, Campbell-Lendrum D, Chambers J. The Lancet Countdown on health and climate change: from 25 years of inaction to a global transformation for public health. Lancet. 2017;391(10120):581–630.
16. Watts N, Amann M, Ayeb-Karlsson S, Belesova K, Bouley T, Boykoff M, Byass P, Cai W, Campbell-Lendrum D, Chambers J, Cox P, Daly M, Dasandi N, Davies M, Depledge M, Depoux A, Dominguez-Salas P, Drummond P, Ekins P, Flahault A, Frumkin H, Georgeson L, Ghanei M, Grace D, Graham H, Grojsman R, Haines A, Hamilton I, Hartinger S, Johnson A, Kelman I, Kiesewetter G, Kniveton D, Liang L, Lott M, Lowe R, Mace G, Odhiambo Sewe M, Maslin M, Mikhaylov S, Milner J, Latifi A, Moradi-Lakeh M, Morrissey K, Murray K, Neville T, Nilsson M, Oreszczyn T, Owfi F, Pencheon D, Pye S, Rabbaniha M, Robinson E, Rocklöv J, Schütte S, Shumake-Guillemot J, Steinbach R, Tabatabaei M, Wheeler N, Wilkinson P, Gong P, Montgomery H, Costello A. The Lancet Countdown on health and climate change: from 25 years of inaction to a global transformation for public health. Lancet. 2018;391(10120):581–630.
17. Zhao Y, Sultan B, Vautard R, Braconnot P, Wang HJ, Ducharne A. Potential escalation of heat-related

working costs with climate and socioeconomic changes in China. Proc Natl Acad Sci U S A. 2016;113(17):4640.
18. Ciais P, Sabine C, Bala G, Bopp L, Brovkin V, Al E, House JI. Climate change 2013: the physical science basis. Contribution of working group I to the fifth assessment report of the intergovernmental panel on climate change change. Comput Geom. 2013;18(2):95–123.
19. Nicholls RJ, Brown S, Goodwin P, Wahl T, Lowe J, Solan M, Godbold JA, Haigh ID, Lincke D, Hinkel J. Stabilization of global temperature at 1.5°C and 2.0°C: implications for coastal areas. Philos Trans R Soc A Math Phys Eng Sci. 2018;376(2119):20160448.
20. Editor C, Qin D, Edi DC. China national assessment report on risk management and adaptation of climate extremes and disasters. Beijing: Science Press; 2015.
21. (TNARCCEC) TTNARoCCEC. The Third National Assessment report on climate change: summary for policy makers. Beijing: Science Press; 2016.
22. Chen F, Wang J, Jin L, Zhang Q, Li J, Chen J. Rapid warming in mid-latitude Central Asia for the past 100 years. Front Earth Sci China. 2009;3(1):42.
23. Liu KX, Wang H, Fu SJ, Gao ZG, Dong JX, Feng JL, Gao T. Evaluation of sea level rise in Bohai Bay and associated responses. Adv Clim Chang Res. 2017;8(1):48–56.
24. Flachsland C. Mitigation of climate change: contribution of working group III to the fifth assessment report of the intergovernmental panel on climate change. Fisioter Mov. 2015;11(311-312):604–5.
25. Qin DH, Stocker T. Highlights of the IPCC working group. I. Fifth assessment report. Progressus Inquisitiones De Mutatione Climatis. 2014;10(1):1–6.
26. Fu YH, Lu RY, Guo D. Changes in surface air temperature over China under the 1.5 and 2.0 °C global warming targets. Adv Clim Chang Res. 2017;8(1):1–8.
27. Yao Y, Luo Y, Huang JB. Evaluation and projection of temperature extremes over China based on CMIP5 model. Adv Clim Chang Res. 2012;3(4):179–85.
28. Xia J, Duan QY, Yong L, Xie ZH, Liu ZY, Xing-Guo MO. Climate change and water resources: case study of Eastern Monsoon Region of China. Adv Clim Chang Res. 2017;8(2):63–7.
29. Xu Y, Zhang B, Zhou BT, Dong SY, Yu L, Li RK. Projected flood risks in China based on CMIP5. Adv Clim Chang Res. 2014;5(2):57–65.

2 Ambient Temperature and Mortality in Chinese Population

Xiaojie Wang, Zengliang Ruan, Yin Yang, Siqi Ai, Lingli Zhang, Xiangyan Sun, and Hualiang Lin

Abstract

Numerous evidence revealed that climate change could have adverse effects on human health, while in developing countries, especially in China, less evidence covering different climatic zones is available due to data unavailability. We searched studies which investigated the association between ambient temperature and mortalities in six databases. We performed random-effects model to calculate pooled estimated for mortalities in association with per 1 °C increase (or decrease). We finally included 17 in 819 identified articles. Short-term exposures to inappropriate temperature were significantly associated with mortalities, per 1 °C increase corresponded to a 1.2% (95% CI: 1.1%, 1.3%) increase in all-cause mortality, a 2.6% (95% CI: 2.4%, 2.9%) increase in cardiovascular mortality, and a 1.2% (95% CI: 1.0%, 1.3%) increase in respiratory mortality. And each 1 °C decrease caused a 3.1% (95% CI: 2.7%, 3.5%) in all-cause mortality, a 1.5% (95% CI: 1.2%, 1.9%) increase in cardiovascular mortality, and a 3.3% (95% CI: 2.8%, 3.9%) increase in respiratory mortality. Our findings indicated that the increase and decrease in ambient temperature have relationships with mortalities among Chinese population and cold effect was more durable and pronounced than hot effect.

Keywords

Mortality · Temperature · China · Heat exposure · Cold exposure

2.1 Introduction

In the last 130 years, the world has warmed by approximately 0.85 °C. Since 1850, temperatures have been significantly warmer than previous decade [1]. Although global warming can bring some local benefits, such as reduced winter deaths in temperate climes and increased food production in some areas, climate change has adverse effects on overall health. Extreme high air temperatures contribute directly to deaths from cardiovascular and respiratory disease, particularly among elderly people. For example, more than 70,000 excess deaths were recorded in the heat wave of summer 2003 in Europe [2].

Existing evidence shows that meteorological factors have apparent association with death, such as temperature, relative humidity, atmospheric pressure, wind velocity, etc. Study area

X. Wang · Z. Ruan · Y. Yang · S. Ai · L. Zhang
X. Sun · H. Lin (✉)
Department of Epidemiology, School of Public Health, Sun Yat-sen University, Guangzhou, China
e-mail: ruanzliang3@mail.sysu.edu.cn; Yangyin3@mail.sysu.edu.cn; aisq@mail2.sysu.edu.cn; sunxy39@mail2.sysu.edu.cn; linhualiang@mail.sysu.edu.cn

H. Lin et al. (eds.), *Ambient Temperature and Health in China*,
https://doi.org/10.1007/978-981-13-2583-0_2

was mainly located in coastal area and economic developed area in China; few studies have focused on the effects of meteorological factors on mortality among county-level city and economically backward area.

With global warming, ambient temperature has the greatest impact on death among the meteorological factors. Increasing evidence indicated that exposure to inappropriate temperature could have adverse effects on human health worldwide. Most of these studies demonstrated that the relationship between temperature and mortality was generally U-, V-, or J-shaped, with higher risks of mortality in extreme cold and hot temperature. However, the associations vary among different studies due to differences in geographic locations, population characteristics, and weather conditions, so more comprehensive studies with a wider variety of climate zone and population structure are needed to assess the overall association among Chinese population [3–5].

Cardiovascular disease and respiratory disease are one of the leading causes of death worldwide. An estimated 17.3 million people died from cardiovascular disease in 2008, representing 30% of all global deaths. Low- and middle-income countries are disproportionally affected: over 80% of cardiovascular disease deaths take place in low- and middle-income countries and occur almost equally in men and women [6]. Respiratory disease includes asthma, chronic obstructive pulmonary disease (COPD), pneumonia, etc. According to the latest World Health Organization (WHO) estimates, currently 64 million people have COPD, and three million people died of COPD. WHO predicts that COPD will become the third leading cause of death worldwide by 2030 [7]. A lot of studies demonstrated cardiovascular disease and respiratory disease were related to meteorological factors, especially to temperature.

Many recent epidemiological studies have investigated that extreme temperatures have various adverse effects on human health in China [8, 9], while most studies were limited to a single city or a small number of cities in China [10, 11]. However, these results cannot fully show the real effects due to the wide range of climatic, sociodemographic, and cultural characteristics of China. Therefore, a study overview to summarize the relationship between ambient temperature and mortality among Chinese population is warranted.

In this chapter, we examined the ambient temperature and mortality in Chinese population including Mainland China, Hong Kong, Taiwan, and Macao. This study will provide useful information to develop intervention strategies for cold and hot temperature exposures in China.

2.2 Materials and Methods

2.2.1 Literature Search and Data Extraction

We searched the major electronic databases including MEDLINE database, PubMed database, Ovid database, China National Knowledge Infrastructure (CNKI) database, Chinese Wanfang database, and Chinese VIP database. We used the following combinations of keywords: (1) temperature, weather, climate change, heat, cold, and season and (2) adverse effect, health, disease, death, and mortality. In order to reflect the health effects of exposure to inappropriate temperature among Chinese populations, we searched potential articles on temperature over the China published between January 2000 and December 2017. References of all included articles were searched for any additional studies.

We converted the effect estimates reported in each study into the ER in deaths per 1 °C increase (or decrease) in daily average temperature if different scales or indicators were used. And we contacted authors to apply for additional data as necessary. Two investigators have extracted data independently, and conflicts were adjudicated by a third investigator.

2.2.2 Study Selection Criteria

Eligible studies fell into following categories:

1. All epidemiological studies, in both English and Chinese, involved the health impacts of exposure to temperature.
2. Original studies provided quantitative exposure-response relationships between

ambient temperature and health outcomes (e.g., relative risk, odds ratios, excess risk [ER], or hazard ratios and their 95% confidence intervals [95% CI]).

3. At least 1 year of daily data relating to a general population.
4. Studies were not identical or similar in terms of location or study period.
5. Study location must be located in Mainland China, Hong Kong, Taiwan, and Macao.

We selected the most recent studies if more than two published articles have the same study period, location, and population. We presented a flow diagram of the study selection process (Fig. 2.1).

2.2.3 Statistical Analysis

We used random-effects meta-analysis to estimate the overall association between ambient temperature and mortality as well as the corresponding 95% confidence interval. The excess risk was used as a summary statistic. To check the robustness of the effect estimation, we conducted a sensitivity analysis by individually excluding the studies with the largest and the smallest effect estimates from the meta-analyses.

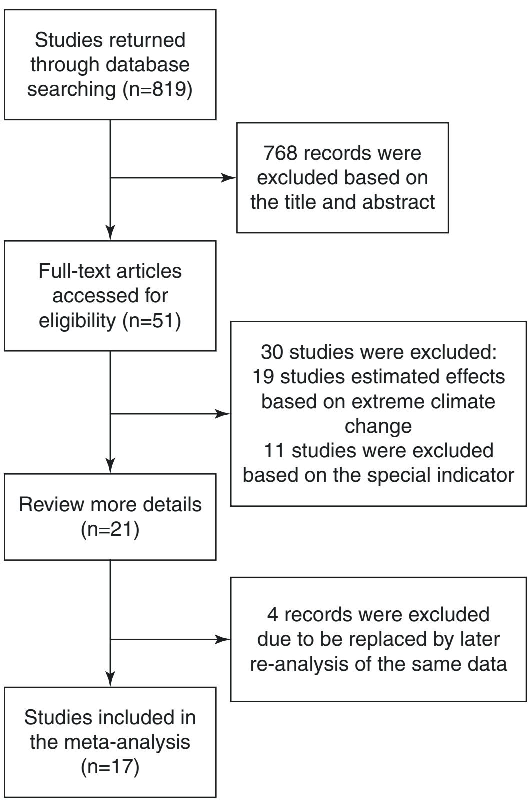


Fig. 2.1 Procedure for literature search

We applied I^2 test to examine heterogeneity. I^2 statistic was used to estimate the percentage of total variation across studies because of heterogeneity rather than chance. I^2 can be calculated as the following formula: $I^2 = 100\%*(Q - \text{df})/Q$ (Q, Cochrane's heterogeneity statistics; df, degree of freedom). We defined more than 50% heterogeneity as substantial heterogeneity. If no substantial heterogeneity exits in the combined data, we used fixed-effects model to calculate overall estimate, and if substantial heterogeneity is present, a random-effects model is more appropriate [12]. To further confirm the robustness of the results, we have showed the results with both fixed- and random-effects models.

Finally, publication bias was evaluated using funnel plots and Egger's linear regression method. All analysis was done and performed using R version 2.13.0 (R Foundation for Statistical Computing, Vienna, Austria). A value of $p < 0.05$ was considered significant.

2.3 Results

The process of study selection is shown in Fig. 2.1. Our search stratifies and initially identified a total of 819 articles, among which 768 were excluded as they were irrelevant to the study topic by examining the abstract. The remaining 51 underwent in-depth review, 19 of them were excluded due to their estimated effect based on extreme climate change such as cold spells and heat waves; 11 studies were excluded based on the special meteorological indicators (diurnal temperature range; universal thermal climate index; temperature changes between neighboring days; apparent temperature); and 4 studies showed, at the same time, geographical area with similar information removed. The remaining 17 studies were included in the meta-analysis. Among them, 12 articles examined the relationships between all-cause mortality and temperature, 12 reported the effects of temperature on cardiovascular mortality, and 10 estimated the associations between ambient temperature and respiratory mortality.

2.3.1 Short-Term Effects on All-Cause Mortality

We systematically searched for all articles containing the association between temperature and mortality. A total of 12 studies reporting the short-term effects of temperature on all-cause mortality were finally included after excluding studies from the same study area (Table 2.1).

The pooled associations between temperature exposure and mortalities were separately reported for the heat and cold exposure. For hot effects, 51 of the 84 estimates of all-cause mortality were statistically significant; and for cold effects, 71 of the 84 estimates were statistically significant. Based on random-effects models in the meta-analyses, we estimated that a 1 °C increase was related to a 1.2% increase (95% CI: 1.1%, 1.3%) in all-cause mortality, and 1 °C decrease was corresponded to a 2.6% increase (95% CI: 2.4%, 2.9%) in all-cause mortality.

We observed significant heterogeneity across the study areas. For hot effects, one study in Fuzhou reported a considerable positive association between heat exposure and all-cause mortality (ER = 21.7%, 95% CI: 12.0%, 32.3%) [13], while negative effect was observed in Lhasa (ER = 7.9%, 95% CI: –16.6%, 39.6%) and in Urumqi (ER = 0.9%, 95% CI: –1.9%, 3.7%) [14]. For cold effects, study from Hong Kong reported a positive but nonsignificant association between cold exposure and all-cause mortality (ER = 2.1%, 95% CI: –2.3%, 4.6%) [15]; however, a large positive effect was reported in Guangzhou (ER = 9.6%, 95% CI: 7.5%, 11.7%) [16].

2.3.2 Short-Term Effects on Cardiovascular Mortality

A total of 70 individual effect estimates were identified by our literature search for the short-term effects on cardiovascular mortality (Table 2.2).

Statistically significant associations between temperature and cardiovascular mortality were reported in most of the study cities. For hot effects, 44 of the 72 estimates of all-cause mortality were statistically significant; and for cold effects, 56 of the 72 estimates were statistically significant. We observed pooled ER for cardiovascular mortality for each 1 °C increment was 1.2% (95% CI: 1.0%, 1.3%); the pooled ER was 3.1% (95% CI: 2.7%, 3.5%) for each 1 °C decrement.

Between-city heterogeneity was observed in the short-term cardiovascular mortality effects of temperature. For hot effects, studies from Changsha reported a positive but nonsignificant association between heat exposure and cardiovascular mortality (ER = 8.2%, 95% CI: –14.1%, 36.4%) [17], and another study in Harbin also reported the same results (ER = 2.1%, 95% CI: –0.3%, 4.6%) [13], while a large effect was observed in Kunming (ER = 14.3%, 95%CI: 3.8%, 25.8%) and Guangzhou (ER = 22.6%, 95% CI: 10.2%, 36.4%) [17]. For cold effects, the positive relationships were observed between cold exposure and cardiovascular mortality in Nanjing (ER = 5.1%, 95% CI: 1.6%, 16.4%) and Chengdu (ER = 3.5%, 95% CI: 1.0%, 12.8%) [18], while large but nonsignificant results were found in Zhuhai (ER = 10.3%, 95% CI: –6.5%, 30.0%) [17].

2.3.3 Short-Term Effects on Respiratory Mortality

We finally included 60 individual effect estimates in our meta-analysis to investigate the short-term effects on respiratory mortality (Table 2.3).

A number of study cities presented significant relationships between temperature and respiratory mortality. For hot effects, 29 of the 60 estimates of all-cause mortality were statistically significant; and for cold effects, 45 of the 60 estimates were statistically significant. The short-term effects of heat exposure on the respiratory mortality were 1.5% (95% CI: 1.2%, 1.9%), and the short-term effects of cold exposure on the respiratory mortality were 3.3% (95% CI: 2.8%, 3.9%).

Table 2.1 Summary of studies on the all-cause mortality effects of ambient temperature

Study	Location	Period year	Hot effects	Cold effects
Chan (2010)	Hong Kong	1998–2006	5.5 (2.2, 9.0)	2.1 (−2.3, 4.6)
Wu (2013)	Zhuhai	2006–2010	2.3 (0.4, 4.2)	11.1 (7.8, 14.5)
Wu (2013)	Guangzhou	2006–2010	2.9 (2.0, 3.9)	9.6 (7.5, 11.7)
Wu (2013)	Changsha	2006–2009	2.0 (0.3, 3.7)	6.1 (2.3, 9.9)
Wu (2013)	Kunming	2006–2009	1.7 (0.4, 3.0)	4.4 (3.3, 5.6)
Pei (2011)	Fuzhou	2004–2007	21.7 (12.0, 32.3)	21.7 (12.0, 32.3)
Pei (2011)	Shantou	2005–2007	2.8 (1.1, 4.6)	2.8 (1.1, 4.6)
Guo (2011)	Tianjin	2005–2007	2.0 (0.7, 3.4)	3.0 (0.9, 5.2)
Zhang (2014)	Shanghai	2001–2008	1.6 (1.3, 2.0)	2.0 (1.7, 2.3)
Ma (2016)	Nanjing	2008–2010	1.2 (1.0, 1.4)	3.0 (1.3, 6.5)
Ma (2016)	Chengdu	2008–2010	1.0 (1.0, 1.1)	2.8 (1.1, 7.0)
Zhang (2016)	Wuhan	2003–2010	17.7 (12.6, 22.9)	2.4 (1.7, 3.1)
Lin (2015)	Taiwan	2000–2008	1.1 (0. 9, 1.4)	1.2 (1.1, 1.3)
Zhang (2017)	Tianmen	2009–2012	1.2 (1.1, 1.4)	2.2 (1.5, 3.3)
Zhang (2017)	Yingcheng	2009–2012	1.2 (1.1, 1.4)	1.9 (1.2, 3.1)
Zhang (2017)	Macheng	2009–2012	1.1 (0.9, 1.2)	1.3 (0.8, 2.2)
Zhang (2017)	Wufeng	2009–2012	1.0 (1.0, 1.0)	1.3 (0.6, 2.8)
Zhang (2017)	Gucheng	2009–2012	1.0 (0.9, 1.1)	0.9 (0.5, 1.6)
Li (2016)	Chongqing	2010–2013	3.0 (2.0, 5.0)	6.0 (4.0, 8.0)
Ma (2014)	Xi'an	2001–2004	2.7 (−0.0, 5.5)	2.3 (0.9, 3.8)
Ma (2014)	Shenyang	2005–2008	3.0 (1.1, 5.0)	0.9 (0.0, 1.7)
Ma (2014)	Lanzhou	2004–2008	0.1 (−2.7, 3.0)	−0.5 (−1.5, 0.6)
Ma (2014)	Hangzhou	2002–2004	1.0 (−3.4, 5.6)	1.8 (−1.0, 4.7)
Ma (2014)	Anshan	2001–2004	3.3 (0.3, 6.3)	0.8 (−0.7, 2.4)
Huang (2015)	Beijing	2006–2011	1.0 (0.2, 1.8)	3.3 (0.2, 6.6)
Huang (2015)	Xuanhua	2006–2011	1.9 (0.6, 3.3)	3.6 (1.2, 6.1)
Huang (2015)	Taiyuan	2006–2011	0.9 (−0.1, 1.9)	7.4 (5.0, 9.8)
Huang (2015)	Huguan	2006–2011	1.0 (−0.4, 2.4)	5.4 (3.0, 7.9)
Huang (2015)	Hohhot	2006–2011	1.0 (−0.2, 2.2)	11.0 (7.1, 14.9)
Huang (2015)	Bayannur	2006–2011	0.5 (−0.5, 1.5)	7.9 (5.2, 10.7)
Huang (2015)	Dalian	2006–2011	0.8 (−0.0, 1.6)	1.7 (0.4, 3.0)
Huang (2015)	Fengcheng	2006–2011	0.5 (−0.6, 1.5)	2.8 (0.6, 5.0)
Huang (2015)	Fuxin	2006–2011	1.3 (−1.5, 4.1)	2.3 (0.7, 3.8)
Huang (2015)	Changchun	2006–2011	0.7 (0.1, 1.2)	0.7 (−0.6, 2.0)
Huang (2015)	Jilin	2006–2011	0.8 (−0.2, 1.8)	2.5 (0.5, 4.5)
Huang (2015)	Harbin	2006–2011	9.9 (6.7, 13.2)	1.7 (0.7, 2.6)
Huang (2015)	Suzhou	2006–2011	4.8 (2.9, 6.7)	2.8 (1.4, 4.2)
Huang (2015)	Zhangjiagang	2006–2011	0.5 (−0.1, 1.8)	2.3 (1.2, 3.4)
Huang (2015)	Jinhu	2006–2011	0.9 (−0.3, 2.1)	2.6 (0.9, 4.4)
Huang (2015)	Xiangshui	2006–2011	0.5 (−2.2, 3.2)	3.0 (1.0, 5.0)
Huang (2015)	Anji	2006–2011	0.9 (−0.3, 2.1)	4.0 (2.6, 5.5)
Huang (2015)	Anqing	2006–2011	1.9 (0.0, 3.8)	2.1 (−0.2, 4.5)
Huang (2015)	Jingxian	2006–2011	−0.4 (−2.1, 1.2)	3.1 (1.1, 5.1)
Huang (2015)	Huian	2006–2011	3.1 (−0.5, 6.7)	4.4 (2.5, 6.3)
Huang (2015)	Qiandao	2006–2011	0.8 (−0.0, 1.6)	1.5 (−1.0, 4.0)
Huang (2015)	Yantai	2006–2011	1.5 (0.7, 2.3)	1.9 (0.1, 3.7)
Huang (2015)	Penglai	2006–2011	1.8 (0.9, 2.7)	0.9 (−0.8, 2.7)

(continued)

Table 2.1 (continued)

Study	Location	Period year	Hot effects	Cold effects
Huang (2015)	Tanghe	2006–2011	1.5 (0.1, 2.9)	3.0 (0.8, 5.1)
Huang (2015)	Gucheng	2006–2011	0.8 (−0.7, 2.3)	3.7 (1.7, 5.7)
Huang (2015)	Liuyang	2006–2011	1.1 (0.3, 1.9)	4.2 (3.1, 5.2)
Huang (2015)	Pingjiang	2006–2011	2.9 (0.3, 5.7)	1.7 (0.1, 3.4)
Huang (2015)	Sihui	2006–2011	0.4 (−1.0, 1.7)	4.7 (2.9, 6.4)
Huang (2015)	Wuhua	2006–2011	2.5 (1.2, 3.8)	4.2 (2.5, 5.9)
Huang (2015)	Binyang	2006–2011	1.1 (−3.5, 5.8)	3.3 (2.0, 4.5)
Huang (2015)	Hepu	2006–2011	2.6 (0.6, 4.7)	5.8 (4.0, 7.6)
Huang (2015)	Pengzhou	2006–2011	1.1 (−0.1, 2.3)	3.1 (1.6, 4.6)
Huang (2015)	Zizhong	2006–2011	2.4 (1.3, 3.5)	6.0 (4.1, 7.9)
Huang (2015)	Xichong	2006–2011	1.4 (−0.1, 2.8)	5.3 (2.6, 8.1)
Huang (2015)	Zunyi	2006–2011	1.1 (−0.1, 2.3)	3.8 (2.2, 5.4)
Huang (2015)	Meitan	2006–2011	0.5 (−0.7, 1.8)	5.1 (2.6, 7.6)
Huang (2015)	Yuxi	2006–2011	1.0 (−0.4, 2.3)	3.0 (0.6, 5.6)
Huang (2015)	Guangnan	2006–2011	0.7 (−0.7, 2.0)	3.0 (1.5, 4.6)
Huang (2015)	Lhasa	2006–2011	7.9 (−16.6, 39.6)	3.1 (−1.3, 7.7)
Huang (2015)	Zhangye	2006–2011	0.0 (−1.9, 2.0)	0.8 (−0.4, 2.0)
Huang (2015)	Xining	2006–2011	0.1 (−1.4, 1.6)	0.5 (−2.6, 3.7)
Huang (2015)	Yinchuan	2006–2011	0.9 (−0.3, 2.2)	5.1 (3.3, 7.0)
Huang (2015)	Zhongwei	2006–2011	0.3 (−0.7, 1.4)	0.6 (−1.0, 2.3)
Huang (2015)	Urumqi	2006–2011	0.9 (−1.7, 3.7)	1.3 (−0.0, 2.7)
Huang (2015)	Anyang	2006–2011	1.3 (1.0, 1.6)	2.9 (1.8, 4.7)
Huang (2015)	Xiangyang	2006–2011	1.2 (1.0, 1.3)	1.6 (1.1, 2.2)
Huang (2015)	Qiqihar	2006–2011	1.0 (0.8, 1.2)	1.1 (0.6, 2.2)
Huang (2015)	Baoji	2006–2011	1.2 (0.9, 1.5)	1.8 (1.2, 2.7)
Huang (2015)	Neijiang	2006–2011	1.3 (1.1, 1.5)	1.7 (1.4, 2.2)
Huang (2015)	Wenshan	2006–2011	1.1 (1.0, 1.2)	1.8 (1.4, 2.3)
Huang (2015)	Nanxiong	2006–2011	1.2 (1.1, 1.3)	2.3 (1.7, 3.0)
Huang (2015)	Changzhi	2006–2011	1.2 (0.9, 1.5)	3.2 (2.0, 5.1)
Huang (2015)	Quanzhou	2006–2011	1.2 (1.1, 1.3)	2.0 (1.5, 2.6)
Huang (2015)	Ankang	2006–2011	1.0 (0.8, 1.2)	2.8 (1.7, 4.5)
Huang (2015)	Huai'an	2006–2011	1.2 (1.0, 1.4)	1.8 (1.3, 2.5)
Huang (2015)	Yueyang	2006–2011	1.1 (0.9, 1.3)	1.4 (1.0, 1.8)
Huang (2015)	Chuzhou	2006–2011	1.1 (0.9, 1.3)	2.1 (1.5, 2.9)
Huang (2015)	Jiamusi	2006–2011	1.3 (1.1, 1.4)	1.5 (1.2, 2.0)
Huang (2015)	Huzhou	2006–2011	1.2 (1.0, 1.4)	2.3 (1.8, 3.1)

Different regions show heterogeneity on the short-term respiratory mortality effects of temperature. For example, the estimated effect of a 1 °C increment on respiratory mortality was 13.4% (95% CI: 6.3%, 19.8%) in Fuzhou, while another study in Hong Kong found non-statistically significant association (ER = 1%, 95% CI: –4.1%, 6.4%) [13, 15]. In addition, one study demonstrated a large significant cold effect on respiratory mortality (ER = 9.3%, 95% CI: 1.7%, 17.4%) in Tianjin [10], while one study in Taiwan has not found statistically significant association between cold temperature and respiratory mortality (ER = 1.5%, 95% CI: –0.1%, 3.2%) [19].

Table 2.2 Summary of studies on the cardiovascular mortality effects of ambient temperature

Study	Location	Period year	Hot effects	Cold effects
Chan (2010)	Hong Kong	1998–2006	8.5 (1.4, 16.2)	4.4 (−4.1, 13.7)
Zeng (2012)	Zhuhai	2006–2010	25.9 (10.4, 43.6)	10.3 (−6.5, 30.0)
Zeng (2012)	Guangzhou	2006–2010	13.4 (4.7, 23)	22.6 (10.2, 36.4)
Zeng (2012)	Kunming	2006–2009	−0.8 (−4.5, 3.0)	14.3 (3.8, 25.8)
Pei (2011)	Fuzhou	2004–2007	12.8 (6.3, 19.8)	12.8 (6.3, 19.8)
Guo (2011)	Tianjin	2005–2007	2.8 (1.0, 4.7)	4.1 (1.1, 7.1)
Zhang (2014)	Shanghai	2001–2008	2.0 (1.5, 2.6)	20.8 (2.3, 3.2)
Ma (2016)	Nanjing	2008–2010	1.2 (1.0, 1.5)	5.1 (1.6, 16.4)
Ma (2016)	Chengdu	2008–2010	1.1 (1.0, 1.2)	3.5 (10.0, 12.8)
Zhang (2016)	Wuhan	2003–2010	21.6 (15.1, 28.4)	3.7 (2.6, 4.7)
Lin (2015)	Taiwan	2000–2008	1.2 (0. 7, 2.1)	1.4 (1.1, 1.7)
Yang (2015)	Chaohu	2008–2011	2.92 (−2.19, 8.3)	1.1 (0.4, 1.7)
Yang (2015)	Maanshan	2008–2011	4.9 (−0.1, 10.1)	2.2 (1.6, 2.8)
Yang (2015)	Tianchang	2008–2011	2.1 (−2.6, 6.9)	0.9 (−0.1, 1.9)
Huang (2017)	Hefei	2008–2011	4.5 (1.2, 7.9)	4.1 (1.9, 6.2)
Huang (2017)	Changsha	2008–2011	4.4 (1.4, 7.5)	4.9 (2.9, 6.9)
Huang (2017)	Nanning	2008–2011	9.8 (−1.7, 18.7)	2.8 (0.7, 5.1)
Huang (2017)	Haikou	2008–2011	4.2 (−13.9, 17.8)	5.8 (1.2, 10.7)
Li (2016)	Chongqing	2010–2013	5.0 (3.0, 7.0)	9.0 (6.0, 12.0)
Huang (2015)	Beijing	2006–2011	1.9 (0.6, 3.1)	5.1 (1.1, 9.3)
Huang (2015)	Xuanhua	2006–2011	1.6 (−0.1, 3.3)	3.7 (−0.1, 7.6)
Huang (2015)	Hohhot	2006–2011	1.8 (0.3, 3.2)	13.4 (7.9, 19.1)
Huang (2015)	Bayannur	2006–2011	−0.4 (−1.5, 0.8)	9.4 (5.8, 13.2)
Huang (2015)	Dalian	2006–2011	5.3 (2.1, 8.5)	3.9 (1.8, 5.9)
Huang (2015)	Fengcheng	2006–2011	0.4 (−0.8, 1.5)	3.9 (1.2, 6.7)
Huang (2015)	Fuxin	2006–2011	0.4 (−0.5, 1.2)	2.0 (0.3, 3.7)
Huang (2015)	Changchun	2006–2011	0.6 (−0.1, 1.3)	0.9 (−0.8, 2.7)
Huang (2015)	Jilin	2006–2011	3.9 (−0.5, 8.5)	1.8 (−0.5, 4.2)
Huang (2015)	Harbin	2006–2011	1.3 (0.7, 1.9)	0.6 (−0.6, 1.8)
Huang (2015)	Yian	2006–2011	−0.1 (−1.0, 0.8)	24.6 (6.3, 46.1)
Huang (2015)	Zhangjiagang	2006–2011	1.6 (0.4, 2.8)	2.7 (0.8, 4.7)
Huang (2015)	Jinhu	2006–2011	0.7 (−2.5, 3.9)	4.3 (1.5, 7.1)
Huang (2015)	Hangzhou	2006–2011	1.3 (−1.2, 3.8)	2.8 (−0.1, 5.9)
Huang (2015)	Anji	2006–2011	1.1 (−3.5, 5.9)	6.2 (3.7, 8.7)
Huang (2015)	Huian	2006–2011	0.5 (−6.1, 7.6)	4.4 (1.5, 7.4)
Huang (2015)	Nanchang	2006–2011	1.4 (−0.1, 2.9)	4.2 (0.2, 8.4)
Huang (2015)	Wuning	2006–2011	−1.0 (−7.8, 6.2)	7.7 (4.7, 10.7)
Huang (2015)	Qiandao	2006–2011	2.1 (0.4, 3.9)	3.1 (0.4, 5.8)
Huang (2015)	Penglai	2006–2011	1.6 (0.3, 2.8)	2.3 (−0.1, 4.7)
Huang (2015)	Tanghe	2006–2011	1.5 (0.3, 2.7)	3.7 (1.3, 6.1)
Huang (2015)	Xinyang	2006–2011	1.1 (−0.1, 2.4)	3.8 (1.6, 6.0)
Huang (2015)	Liuyang	2006–2011	1.8 (−1.0, 4.6)	4.9 (3.6, 6.2)
Huang (2015)	Pingjiang	2006–2011	4.4 (1.3, 7.7)	2.0 (−0.0, 4.1)
Huang (2015)	Wuhua	2006–2011	1.3 (−0.1, 2.7)	3.9 (1.9, 6.0)
Huang (2015)	Binyang	2006–2011	2.6 (−2.7, 8.1)	4.4 (2.7, 6.1)
Huang (2015)	Hepu	2006–2011	2.2 (−0.6, 5.2)	5.2 (2.8, 7.6)
Huang (2015)	Zizhong	2006–2011	1.3 (0.2, 2.4)	5.0 (2.6, 7.4)

(continued)

Table 2.2 (continued)

Study	Location	Period year	Hot effects	Cold effects
Huang (2015)	Xichong	2006–2011	0.2 (−1.3, 1.6)	5.2 (1.6, 8.9)
Huang (2015)	Zunyi	2006–2011	1.0 (−0.4, 2.4)	4.1 (1.7, 6.5)
Huang (2015)	Meitan	2006–2011	0.3 (−1.1, 1.7)	1.7 (−0.7, 4.2)
Huang (2015)	Guangnan	2006–2011	−0.6 (−1.7, 0.6)	3.5 (1.1, 5.9)
Huang (2015)	Lhasa	2006–2011	−1.5 (−38.2, 56.9)	6.7 (−0.2, 14.1)
Huang (2015)	Tongchuan	2006–2011	1.5 (−0.2, 3.3)	4.1 (0.7, 7.5)
Huang (2015)	Zhangye	2006–2011	0.3 (−2.2, 3.3)	0.4 (−1.4, 2.2)
Huang (2015)	Xining	2006–2011	3.2 (−4.0, 10.9)	2.1 (−5.4, 10.3)
Huang (2015)	Zhongwei	2006–2011	−0.0 (−1.2, 1.1)	0.8 (−1.4, 3.1)
Huang (2015)	Urumqi	2006–2011	0.5 (−0.5, 1.6)	0.3 (−1.8, 2.3)
Huang (2015)	Anyang	2006–2011	1.1 (1.0, 1.6)	3.1 (1.8, 5.3)
Huang (2015)	Xiangyang	2006–2011	1.1 (0.9, 1.4)	1.6 (1.0, 2.4)
Huang (2015)	Qiqihar	2006–2011	0.9 (0.7, 1.2)	0.7 (0.3, 1.5)
Huang (2015)	Baoji	2006–2011	1.4 (1.0, 1.8)	1.4 (0.8, 2.4)
Huang (2015)	Neijiang	2006–2011	1.3 (1.1, 1.5)	1.6 (1.2, 2.2)
Huang (2015)	Wenshan	2006–2011	1.0 (0.9, 1.2)	1.8 (1.2, 2.7)
Huang (2015)	Nanxiong	2006–2011	1.2 (1.0, 1.4)	2.6 (1.6, 4.0)
Huang (2015)	Changzhi	2006–2011	1.2 (0.9, 1.6)	3.3 (1.8, 6.0)
Huang (2015)	Quanzhou	2006–2011	1.1 (0.9, 1.3)	2.1 (1.3, 3.4)
Huang (2015)	Ankang	2006–2011	0.9 (0.6, 1.3)	3.7 (1.9, 7.2)
Huang (2015)	Huai'an	2006–2011	1.2 (1.0, 1.5)	2.4 (1.4, 3.9)
Huang (2015)	Yueyang	2006–2011	1.1 (0.9, 1.3)	1.4 (1.0, 2.0)
Huang (2015)	Chuzhou	2006–2011	1.1 (0.9, 1.4)	2.4 (1.5, 3.7)
Huang (2015)	Jiamusi	2006–2011	1.3 (1.0, 1.6)	1.5 (1.0, 2.4)
Huang (2015)	Huzhou	2006–2011	1.1 (0.9, 1.5)	3.3 (2.1, 5.2)

2.4 Discussion

In recent years there has been a great increase in interest in time-series studies of temperature and mortality. Increasing evidence showed statistically significant associations between temperature and mortality. While less attention has been paid to the effects of temperature in China, most of studies have focused on the effects of temperatures in a single city or only a few cities. In this meta-analysis, we identified 18 studies on the short-term associations between temperature and mortality among Chinese population. We aim to identify and quantify the association between temperatures and mortality among Chinese population through a systematic review and meta-analysis.

To our knowledge, this is the first meta-analysis to quantitatively assess the estimates of ambient temperature effects on mortality among Chinese population. In this analysis, we combined 84, 72, and 60 individual effect estimates on the all-cause mortality, cardiovascular disease, and respiratory disease. The results reveal a statistically significant increase of mortalities associated with a 1 °C increase (or decrease) in ambient temperature.

Our estimates indicated that both hot and cold temperature exposures have adverse effects on mortalities. The pooled results show that a 1 °C increase on hot days was related to a 1.2% (95% CI: 1.1%, 1.3%) increase in all-cause mortality, a 1.2% (95% CI: 1.0%, 1.3%) increase in cardiovascular mortality, and a 1.5% (95% CI: 1.2%, 1.9%) increase in respiratory mortality, respectively. And a 1 °C decrease was associated with a 2.6% increase (95% CI: 2.4%, 2.9%) in all-cause mortality, 3.1% (95% CI: 2.7%, 3.5%) increase

Table 2.3 Summary of studies on the respiratory mortality effects of ambient temperature

Study	Location	Period year	Hot effects	Cold effects
Chan (2010)	Hong Kong	1998–2006	1.0 (−4.1, 6.4)	0.0 (−3.6, 4.1)
Pei (2011)	Fuzhou	2004–2007	13.4 (6.3, 19.8)	13.4 (6.3, 19.8)
Guo (2011)	Tianjin	2005–2007	3.4 (−0.8, 7.7)	9.3 (1.7, 17.4)
Wang (2009)	Shenyang	1992–2000	0.2 (0.0, 0.3)	0.5 (0.4, 0.5)
Zhang (2014)	Shanghai	2001–2008	2.0 (1.0, 3.0)	2.0 (1.0, 3.0)
Ma (2016)	Nanjing	2008–2010	1.3 (1.1, 2.1)	0.1 (0.0, 0.7)
Ma (2016)	Chengdu	2008–2010	1.0 (0.8, 1.1)	5.3 (1.3, 21.4)
Zhang (2016)	Wuhan	2003–2010	19.4 (6.0, 34.5)	3.9 (1.6, 6.2)
Chung (2009)	Taiwan	1994–2007	1.5 (−0.1, 3.2)	1.5 (−0.1, 3.2)
Li (2016)	Chongqing	2010–2013	2.0 (−1.0, 5.0)	6.0 (2.0, 11.0)
Huang (2015)	Beijing	2006–2011	1.5 (−0.5, 3.6)	1.9 (−2.3, 6.2)
Huang (2015)	Qianxi	2006–2011	0.6 (−4.2, 5.7)	7.4 (0.3, 15.0)
Huang (2015)	Xuanhua	2006–2011	0.0 (−1.8, 1.9)	0.8 (−3.5, 5.4)
Huang (2015)	Huguan	2006–2011	1.8 (−1.2, 4.8)	11.7 (6.0, 17.7)
Huang (2015)	Bayannur	2006–2011	1.4 (−5.9, 9.2)	3.9 (0.3, 7.7)
Huang (2015)	Fengcheng	2006–2011	2.9 (0.1, 5.7)	13.3 (0.2, 28.1)
Huang (2015)	Fuxin	2006–2011	2.1 (−0.4, 4.6)	5.6 (1.0, 10.3)
Huang (2015)	Changchun	2006–2011	1.6 (−0.1, 3.3)	0.7 (−13.4, 17.0)
Huang (2015)	Jilin	2006–2011	7.1 (−5.4, 21.2)	0.8 (−5.9, 7.9)
Huang (2015)	Harbin	2006–2011	0.7 (−0.3, 1.8)	2.7 (−2.0, 7.6)
Huang (2015)	Jinhu	2006–2011	2.7 (−3.0, 8.9)	5.1 (−0.0, 10.5)
Huang (2015)	Xiangshui	2006–2011	0.0 (−6.6, 7.1)	1.6 (−3.0, 6.5)
Huang (2015)	Tongxiang	2006–2011	2.3 (0.4, 4.3)	5.0 (2.4, 7.7)
Huang (2015)	Huian	2006–2011	1.6 (−1.1, 4.5)	9.9 (3.8, 16.4)
Huang (2015)	Wuning	2006–2011	4.2 (−4.8, 14.0)	2.8 (−1.8, 7.6)
Huang (2015)	Yantai	2006–2011	4.2 (1.2, 7.2)	6.5 (−0.9, 14.4)
Huang (2015)	Tanghe	2006–2011	1.2 (−0.9, 3.3)	3.9 (0.2, 7.7)
Huang (2015)	Xinyang	2006–2011	3.1 (0.1, 6.2)	8.7 (4.9, 12.8)
Huang (2015)	Gucheng	2006–2011	1.5 (−1.1, 4.2)	8.2 (3.8, 12.7)
Huang (2015)	Liuyang	2006–2011	1.4 (0.2, 2.7)	5.1 (3.2, 7.1)
Huang (2015)	Pingjiang	2006–2011	1.3 (−0.3, 3.0)	2.9 (0.4, 5.5)
Huang (2015)	Sihui	2006–2011	7.3 (−0.8, 16.1)	6.7 (3.9, 9.6)
Huang (2015)	Wuhua	2006–2011	3.2 (1.4, 5.0)	3.6 (0.9, 6.4)
Huang (2015)	Hepu	2006–2011	2.6 (−0.4, 5.7)	5.6 (2.6, 8.7)
Huang (2015)	Pengzhou	2006–2011	0.0 (−1.2, 1.3)	2.0 (−0.5, 4.7)
Huang (2015)	Zizhong	2006–2011	1.4 (0.0, 2.9)	7.0 (3.6, 10.6)
Huang (2015)	Xichong	2006–2011	2.1 (0.2, 4.0)	8.5 (3.8, 13.3)
Huang (2015)	Zunyi	2006–2011	2.4 (0.5, 4.2)	5.7 (2.6, 9.0)
Huang (2015)	Meitan	2006–2011	4.1 (−3.3, 12.1)	4.2 (1.0, 7.4)
Huang (2015)	Guangnan	2006–2011	0.6 (−0.9, 2.2)	3.6 (1.3, 6.0)
Huang (2015)	Meixian	2006–2011	1.2 (−1.7, 4.2)	5.2 (0.2, 10.5)
Huang (2015)	Hanyin	2006–2011	5.3 (−3.2, 14.6)	6.7 (0.5, 13.2)
Huang (2015)	Zhangye	2006–2011	3.4 (−0.5, 7.6)	2.6 (0.6, 4.6)
Huang (2015)	Yinchuan	2006–2011	1.4 (−7.7, 11.4)	1.9 (−1.7, 5.6)
Huang (2015)	Urumqi	2006–2011	1.3 (1.0, 1.6)	3.9 (−0.6, 8.6)
Huang (2015)	Anyang	2006–2011	1.3 (0.9, 1.8)	3.1 (1.6, 6.1)
Huang (2015)	Xiangyang	2006–2011	1.4 (0.9, 1.9)	2.8 (1.4, 5.7)

(continued)

Table 2.3 (continued)

Study	Location	Period year	Hot effects	Cold effects
Huang (2015)	Qiqihar	2006–2011	1.1 (0.6, 2.0)	0.9 (0.2, 5.8)
Huang (2015)	Baoji	2006–2011	1.1 (0.6, 2.1)	3.0 (1.1, 7.7)
Huang (2015)	Neijiang	2006–2011	1.3 (1.0, 1.6)	1.7 (1.1, 2.6)
Huang (2015)	Wenshan	2006–2011	1.1 (1.0, 1.3)	2.0 (1.4, 2.9)
Huang (2015)	Nanxiong	2006–2011	1.3 (1.0, 1.6)	3.3 (2.0, 5.4)
Huang (2015)	Changzhi	2006–2011	1.5 (0.9, 2.7)	8.9 (3.1, 25.6)
Huang (2015)	Quanzhou	2006–2011	1.4 (1.0, 1.8)	3.3 (1.5, 7.5)
Huang (2015)	Ankang	2006–2011	1.2 (0.7, 2.2)	3.6 (1.3, 9.6)
Huang (2015)	Huai'an	2006–2011	1.4 (0.9, 2.2)	2.2 (0.8, 5.9)
Huang (2015)	Yueyang	2006–2011	1.3 (1.0, 1.6)	1.9 (1.2, 3.0)
Huang (2015)	Chuzhou	2006–2011	1.2 (0.7, 1.9)	1.7 (0.7, 4.0)
Huang (2015)	Jiamusi	2006–2011	1.4 (1.1, 2.0)	2.7 (1.5, 4.8)
Huang (2015)	Huzhou	2006–2011	1.2 (0.8, 1.8)	1.9 (1.0, 3.6)

in cardiovascular mortality, and 3.3% (95% CI: 2.8%, 3.9%) increase in respiratory mortality, respectively. The results show a statistically significant increase of mortalities associated with a 1 °C increase or a 1 °C decrease in ambient temperature among Chinese population.

We found that hot effects and cold effects were different, in which heat temperatures have a smaller effect on mortality than cold temperatures. Furthermore, the hot effects of all-cause mortality, cardiovascular disease, and respiratory disease were the same, while the cold effects show differences, with the largest cold effects on respiratory disease.

The pooled estimates from this meta-analysis are consistent with same previous studies. For example, a meta-analysis published in 2013 summarized that cold effects were relatively larger than hot effects, which reported an ER of all-cause mortality increased by 2.0% (95% CI: 1.0%, 3.0%) for the heat exposure and 4.0% (95% CI: 2.0%, 7.0%) for the cold exposure [20]. And another systematic review and meta-analysis were conducted; the risk of cardiovascular mortality increased by 5.5% (95% CI: 5.0%, 6.0%) for the cold exposure and 1.3% (95% CI: 1.1%, 1.5%) for the heat exposure [21]. Conversely, few studies observed larger hot effect than cold effect. For example, Zhang's study in Wuhan observed larger hot effect on mortalities than cold effect (all-cause mortality, 25.2% vs. 1.7%; cardiovascular mortality, 34.1% vs. 3.0%; respiratory mortality, 24.3% vs. 1.1%) [22].

The results of our meta-analysis reveal relatively stronger association between cold exposure and respiratory mortality. Series of studies also reported the same results, for example, a study in Dublin observed larger effects on respiratory mortality than all-cause mortality and cardiovascular mortality [23]. The underlying mechanism was still unclear and may be due to a synergy between temperature and air pollution on the respiratory system but not on the cardiovascular system. This result suggests that we should strengthen the protection and prevention among people suffering from chronic cardiovascular or respiratory diseases in China.

We conducted a number of sensitivity analyses to examine the robustness of the effect estimation; the results were shown in Table 2.4. When excluding single study with the largest or smallest effect, we observed generally consistent associations between short-term exposure to heat (or cold) temperature and mortalities. For example, when excluding the largest hot effect of all-cause mortality, the estimate still stables (ER = 1.2%, 95% CI: 1.1%, 1.3%). We also obtained robust effects when we alternatively used fixed-effect meta-analysis.

All outcomes showed substantial (I^2 = 67.31–94.17%) and statistically significant heterogeneity in the point estimates for temperature among included studies. The results of Egger's tests revealed that there was significant publication bias in the meta-analyses (Table 2.5).

Table 2.4 Sensitivity analyses for the pooled estimates of temperature (per 1 °C increment or decrement) on mortalities

	Hot effects			Cold effects		
Models	All-cause	Cardiovascular	Respiratory	All-cause	Cardiovascular	Respiratory
Model A	1.2 (1.1, 1.3)	1.2 (1.0, 1.3)	1.5 (1.2, 1.9)	2.6 (2.4, 2.9)	3.1 (2.7, 3.5)	3.3 (2.8, 3.9)
Model B	1.2 (1.1, 1.3)	1.2 (1.0, 1.3)	1.5 (1.2, 1.9)	2.6 (2.3, 2.9)	3.1 (2.7, 3.5)	3.3 (2.7, 3.8)
Model C	1.2 (1.1, 1.3)	1.2 (1.0, 1.3)	1.6 (1.3, 1.9)	2.7 (2.4, 3.0)	3.1 (2.7, 3.5)	3.4 (2.8, 3.9)
Model D	1.1 (1.0, 1.1)	1.1 (1.1, 1.2)	1.2 (1.1, 1.2)	1.6 (1.5, 1.6)	2.1 (1.9, 2.2)	2.6 (1.8, 3.3)

A: all studies were included; B: the study with the largest effect size was excluded; C: the study with the smallest effect size was excluded; and D: fixed-effect meta-analysis

Table 2.5 Heterogeneity and publication bias of included studies

	Hot effects			Cold effects		
	All-cause	Cardiovascular	Respiratory	All-cause	Cardiovascular	Respiratory
Number of cities	84	72	60	84	72	60
Heterogeneity						
I^2	86.31%	67.31%	78.71%	94.17%	83.69%	87.56%
p-value	0.00	0.00	0.00	0.00	0.00	0.00
Publication bias						
Egger's regression test, *p*-value	0.00	0.00	0.00	0.00	0.00	0.00

Previous epidemiologic evidence showed that climatological, socioeconomic, demographic, community-level, and individual factors have a role in modification of the association between temperature and mortality [24, 25].

A great number of studies demonstrated that age group might modify the relationship between temperature and mortality. One study in China reported larger mortality effect of temperature in older age group than younger age group [24]. This evidence has also been observed in several previous studies [26–28]. For example, Ma's study in Shanghai reported increasing trend in risk with age in temperature, which clarifies the elderly to be the most vulnerable to the short-term exposure of temperature. The underlying reasons might be that pre-existing disorders and difficulty in thermoregulation come with age [29, 30].

Gender was usually considered a potential effect modifier. One study in China found higher risk of dying among females than males [24]. Another study in Australia reported effect estimate among females was even more than 20 times that among males [28]; and one study in Suzhou also support this view [31]. One previous experimental study reported that one possible mechanism might be that female were more heat intolerant than male possibly due to sex-specific differences in thermoregulatory and physiological mechanisms [32].

A series of evidence demonstrated that community-level factors could modify the relationship between temperature and mortality [14, 25, 33], such as population density, green coverage, economic situation, educational level and adaptive capacity. For example, Huang's study observed higher mortality risk in areas with a lower educational level, which is consistent with previous studies [34, 35]. One possible reason might be that higher educated people tend to pay more attention to their health.

One interesting finding was that 1-degree change for latitude could influence the relationship between ambient temperature and mortality. A great number of studies observed that higher-latitude countries demonstrated higher effects of heat temperature on the risk of mortality, while it showed lower effects of cold temperature on the risk of mortality [36, 37]. The underlying reason might be that residents in high-latitude regions usually live in colder environment for longer time compared with those in low-latitude regions, so they are better adapted to low temperatures, and are more vulnerable to high temperatures.

2.5 Conclusion

Climate change could lead to serious public health problems in China. This chapter quantitatively estimated the effects of ambient temperature exposures on mortalities among Chinese population; the pooled estimates were found to be statistically significant for both heat and cold exposures and mortality categories. For both hot and cold effects, this study provided evidences to support the associations between heat and cold exposures and the risk of mortality from all-cause, cardiovascular, and respiratory mortality. In addition, we found the cold effects were larger than hot effects among Chinese population. We also found the pooled cold effect on respiratory mortality was obviously greater than all-cause and cardiovascular mortality. This meta-analysis suggests that more attention should be paid to the health effects caused by cold weather, especially for people suffering from cardiovascular and respiratory diseases in China.

Acknowledgements We are grateful for the support of National Key R&D Program of China (Grant No: 2018YFA0606200).

References

1. IPCC. Climate change 2013: the physical science basis. In: Stocker TF, Qin D, Plattner G-K, Tignor M, Allen SK, Boschung J, Nauels A, Xia Y, Bex V, Midgley PM, editors. Contribution of working group I to the fifth assessment report of the intergovernmental panel on climate change. Cambridge: Cambridge University Press; 2013. 1535p.
2. Robine JM, Cheung SL, Le RS, Van OH, Griffiths C, Michel JP, Herrmann FR. Death toll exceeded 70,000 in Europe during the summer of 2003. C R Biol. 2008;331(2):171–8.
3. Castillejos M, Borja-Aburto VH, Dockery DW, Gold DR, Loomis D. Airborne coarse particles and mortality. Inhal Toxicol. 2000;12(Supp 1):61–72.
4. Gasparrini A, Guo Y, Hashizume M, Lavigne E, Zanobetti A, Schwartz J, Tobias A, Tong S, Rocklöv J, Forsberg B. Mortality risk attributable to high and low ambient temperature: a multicountry observational study. Lancet. 2015;386(9991):369–75.
5. Guo Y, Antonio G, Armstrong BG, Benjawan T, Aurelio T, Eric L, Pan X, Ho K, Masahiro H. Temperature variability and mortality: a multi-country study. Environ Health Perspect. 2016;124(10):1554–9.
6. Wang H, Naghavi M, Allen C, Barber RM, ZA B. Global, regional, and national life expectancy, all-cause mortality, and cause-specific mortality for 249 causes of death, 1980-2015: a systematic analysis for the Global Burden of Disease Study 2015. Lancet. 2016;388(10053):1459.
7. Bousquet J, Khaltaev N, Bousquet J, Khaltaev N. Global surveillance, prevention and control of chronic respiratory diseases: a comprehensive approach. J Pharm Technol. 2008;24(2):122.
8. Yuan J, Lau EH, Li K, Leung YH, Yang Z, Xie C, Liu Y, Liu Y, Ma X, Liu J. Effect of live poultry market closure on Avian Influenza A(H7N9) virus activity in Guangzhou, China, 2014. Emerg Infect Dis. 2015;21(10):1784.
9. Ma W, Wang L, Lin H, Liu T, Zhang Y, Rutherford S, Luo Y, Zeng W, Zhang Y, Wang X. The temperature-mortality relationship in China: an analysis from 66 Chinese communities. Environ Res. 2015;137:72.
10. Guo Y, Barnett AG, Pan X, Yu W, Tong S. The impact of temperature on mortality in Tianjin, China: a case-crossover design with a distributed lag nonlinear model. Environ Health Perspect. 2011;119(12):1719–25.
11. Yang J, Ou CQ, Yan D, Zhou YX, Chen PY. Daily temperature and mortality: a study of distributed lag non-linear effect and effect modification in Guangzhou. Environ Health. 2012;11(1):63.
12. Higgins JP, Thompson SG. Quantifying heterogeneity in a meta-analysis. Stat Med. 2002;21(11):1539.
13. Pei D, Li L. Threshold analysis of ambient temperature in five cities based on population daily mortality. Chin J Dis Control Prev. 2011;15(5):372–6.
14. Huang Z, Lin H, Liu Y, Zhou M, Liu T, Xiao J, Zeng W, Li X, Zhang Y, Ebi KL. Individual-level and community-level effect modifiers of the temperature–mortality relationship in 66 Chinese communities. BMJ Open. 2015;5(9):e009172.
15. Chan EYY, Goggins WB, Kim JJ, Griffiths SM. A study of intracity variation of temperature-related mortality and socioeconomic status among the Chinese population in Hong Kong. J Epidemiol Community Health. 2012;66(4):322–7.
16. Wu W, Xiao Y, Li G, Zeng W, Lin H, Rutherford S, Xu Y, Luo Y, Xu X, Chu C. Temperature–mortality relationship in four subtropical Chinese cities: a time-series study using a distributed lag non-linear model. Sci Total Environ. 2013;449(449):355–62.
17. Zeng W, Li G, Xiao Y, Xu Y, Xu X, Liu T, Luo Y, Xiao J, Ma W. The impact of temperature on cardiovascular disease deaths in 4 cities, China: a time-series study. Chin J Epidemiol. 2012;33(10):1021–5.
18. Ma X, Li R, Luo K, Zhang R, Wang Z, Xu Q. Association between temperature and mortality in

three cities in China. Basic Clin Med. 2016;36(6): 805–10.

19. Chung JY, Honda Y, Hong YC, Pan XC, Guo YL, Kim H. Ambient temperature and mortality: an international study in four capital cities of East Asia. Sci Total Environ. 2009;408(2):390–6.
20. Hu M, Ma W, Zhang Y, Liu T, Lin H, Luo Y, Xiao J. Relationship between temperature and the risks of mortality in China: a meta-analysis. Chin J Epidemiol. 2013;34(9):922–6.
21. Moghadamnia MT, Ardalan A, Mesdaghinia A, Keshtkar A, Naddafi K, Yekaninejad MS. Ambient temperature and cardiovascular mortality: a systematic review and meta-analysis. PeerJ. 2017;5(8):e3574.
22. Zhang Y, Li C, Feng R, Zhu Y, Wu K, Tan X, Ma L. The short-term effect of ambient temperature on mortality in Wuhan, China: a time-series study using a distributed lag non-linear model. Int J Environ Res Public Health. 2016;13(7):722–34.
23. Goodman PG, Dockery DW, Clancy L. Cause-specific mortality and the extended effects of particulate pollution and temperature exposure. Environ Health Perspect. 2004;112(2):179–85.
24. Ma W, Zeng W, Zhou M, Wang L, Rutherford S, Lin H, Liu T, Zhang Y, Xiao J, Zhang Y. The short-term effect of heat waves on mortality and its modifiers in China: an analysis from 66 communities. Environ Int. 2015;75:103–9.
25. Zanobetti A, Oneill MS, Gronlund CJ, Schwartz J. Susceptibility to mortality in weather extremes: effect modification by personal and small-area characteristics. Epidemiology. 2013;24(6):809–19.
26. Ma W, Yang C, Tan J, Song W, Chen B, Kan H. Modifiers of the temperature-mortality association in Shanghai, China. Int J Biometeorol. 2012;56(1):205–7.
27. Ryti NRI, Guo Y, Jaakkola JJK. Global association of cold spells and adverse health effects: a systematic review and meta-analysis. Environ Health Perspect. 2016;124(1):12–22.
28. Yu W, Vaneckova P, Mengersen K, Pan X, Tong S. Is the association between temperature and mortality modified by age, gender and socio-economic status? Sci Total Environ. 2010;408(17):3513–8.
29. Hajat S, Kovats RS, Lachowycz K. Heat-related and cold-related deaths in England and Wales: who is at risk? J Occup Environ Med. 2007;64(2):93.
30. Stafoggia M, Forastiere F, Agostini D, Caranci N, De'Donato F, Demaria M, Michelozzi P, Miglio R, Rognoni M, Russo A. Factors affecting in-hospital heat-related mortality: a multi-city case-crossover analysis. J Epidemiol Community Health. 2008;62(3):209–15.
31. Wang C, Chen R, Kuang X, Duan X, Kan H. Temperature and daily mortality in Suzhou, China: a time series analysis. Sci Total Environ. 2013;466-467(1):985.
32. Barnett AG. Temperature and cardiovascular deaths in the US elderly: changes over time. Epidemiology. 2007;18(3):369–72.
33. Reid CE, Oneill MS, Gronlund CJ, Brines SJ, Brown DG, Diezroux AV, Schwartz J. Mapping community determinants of heat vulnerability. Environ Health Perspect. 2009;117(11):1730–6.
34. O'Neill MS, Ebi KL. Temperature extremes and health: impacts of climate variability and change in the United States. J Occup Environ Med. 2009;51(1):13.
35. Zeka A, Zanobetti A, Schwartz J. Individual-level modifiers of the effects of particulate matter on daily mortality. Am J Epidemiol. 2006;163(9):849–59.
36. Kim J, Shin J, Lim YH, Honda Y, Hashizume M, Guo YL, Kan H, Yi S, Kim H. Comprehensive approach to understand the association between diurnal temperature range and mortality in East Asia. Sci Total Environ. 2016;539:313–21.
37. Shaposhnikov D, Revich B, Gurfinkel Y, Naumova E. The influence of meteorological and geomagnetic factors on acute myocardial infarction and brain stroke in Moscow, Russia. Int J Biometeorol. 2014;58(5):799.

3 Extreme Temperature Events and Mortality/Morbidity in China

Jun Yang, Junliang Wu, Mengmeng Li, and Boguang Wang

Abstract

The ongoing climate change is likely to change the intensity, frequency, and duration of extreme weather events, which cause prominent health and economic burden worldwide. This chapter summarizes the impact of heat wave/cold spell on mortality and morbidity among Chinese population. Large amount of studies have demonstrated that heat waves and cold spells are significantly associated with elevated death risk in China. The association can be modified by individual characteristics, such as gender, age, socioeconomic status, underlying diseases and places of death. However, the number of studies on morbidity was much fewer, particularly for those from multicities. Health-oriented early warning system on extreme temperature event needs to be applied at both national and provincial scale to protect public health. Furthermore, the projection on the health impact of future heat wave and cold spell in the context of climate change is also warranted.

Keywords

Heat wave · Cold spell · Mortality · Morbidity China

J. Yang (✉) · J. Wu · M. Li · B. Wang
Institute for Environmental and Climate Research, Jinan University, Guangzhou, China
e-mail: yangjun_eci@jnu.edu.cn; tbongue@jnu.edu.cn

3.1 Introduction

According to the fifth assessment report of IPCC, the global temperature has been increasing at a faster rate of about 0.17 °C per decade since 1970, which is more than twice as fast as the 0.07 °C rise per decade during 1880–2015 [1]. The ongoing climate change could lead to changes in severity, frequency, duration, and timing of extreme temperature events, which may cause mounting numbers of economic and health loss around the world. An astonishing number of excess deaths and hospitalizations occurred during several devastating heat waves and cold spells in last decades. For example, the 2003 heat wave in Europe is estimated to have caused nearly 15,000 deaths from August 1 to August 20 in France alone [2], and the 2006 heat wave in California led to 16,166 additional emergency department visits and 1182 excess hospitalizations [3]. For the cold spell, the 1987 Czech Republic cold spell resulted in 274 cardiovascular excess deaths [4], and the 2006 Moscow cold spell caused over 370 excess deaths [5].

In China, the frequency of extreme temperature event has changed significantly over the past 60 years, with generally increasing trend for heat wave but opposite trend for cold spell [6]. In total, the frequency of cold spell has declined remarkably by 0.2 times per decade. In contrast, China has experienced an increasing number of heat waves. Distributions of cold spell and heat

H. Lin et al. (eds.), *Ambient Temperature and Health in China*,
https://doi.org/10.1007/978-981-13-2583-0_3

wave show significant spatial heterogeneity across China. The frequency of cold spell generally decrease from the northern regions to the southern, while increasing trend of heat wave can be observed in most parts of China except for Jianghan area and western Huanghuai area [7]. Notably, the 2008 cold spell and 2013 heat wave were the most serious temperature events during the past decades in majority of China. In January and February 2008, the subtropical southern Chinese regions went through a severe continuous cold spell with long duration, abnormal lower temperature, and thick snow deposition [8]. During this cold spell, the average temperature was 2–4 °C lower than that during the same period in neighboring years. This cold spell caused direct economic loss of over 22.3 billion US dollars and 129 human lives, and 1.5 million people were displaced [9]. For the heat wave in the midsummer of 2013, it was the strongest heat wave occurred since 1951 in most southeastern regions, including Jianghuai, Jianghan, and Chongqing. The highest temperature observed at Xinchang, Zhejiang, was 44.1 °C on 11 August. A study in Nanjing detected that a total economic loss of 4.27 billion US dollars and 656 excess deaths were caused by the heat wave [10]. However, the national assessment of the economic and health losses due to the 2013 heat wave was unavailable.

To provide basic evidence for health-oriented early warning system and tailor the preventive action to protect public health, it is of great importance to quantify the adverse impact of heat wave and cold spell on human health and identify the relevant vulnerable subpopulations. In China, there has been an increasing interest for scientists and researchers in evaluating the health risk of extreme temperature events since the last decade [7, 11–25], which can provide evidence to draw a whole picture of the health burden relating to these adverse events in China. In this summary, we will perform a systematic review and meta-analysis to understand the impact of heat wave and cold spell on mortality and morbidity in China.

3.2 Literature Search and Data Extraction

We searched the English-language databases of PubMed, Scopus, and Web of Science and Chinese-language databases of the China National Knowledge Infrastructure and Wanfang Data for the epidemiological investigations on the effects of heat wave and cold spell on mortality and morbidity in China, separately. The combinations of the searching keywords were as follows: (1) cold spell ("extreme temperature" or "cold temperature" or "climate change" or "coldspell" or "cold spell" or "coldwave" or "cold wave" or "coldsurge" or "cold surge"), heat wave ("extreme temperature" or "high temperature" or "hot temperature" or "climate change" or "heat wave" or "heatwave"), (2) "human health" or "morbidity" or "mortality" or "emergency visit" or "hospitalization", and (3) "China" or "Chinese" or "Hong Kong" or "Taiwan". We limited the literature search to original studies published between 1 January 1980 and 31 December 2017.

Studies that met the following five eligibility criteria were included: the study (1) provided evidence on the association between cold spell and/or heat wave and human mortality or morbidity; (2) was an original study; (3) had an adequate definition of cold spell and heat wave as specified below; (4) used the health outcomes of mortality or morbidity, to be included in the meta-analysis; and (5) also had to provide quantitative evidence on the relationship between cold spell and/or heat wave and mortality of morbidity using risk ratio measure, such as relative risk (RR) and odds ratio (OR). Our criteria for the adequate definition of cold spell and heat wave were composed of two components: (1) the intensity of temperature, expressed as a relative or absolute measure, and (2) the minimal duration of 2 consecutive days or large temperature change within one or several days. Furthermore, if there were more than one investigation focusing on the same topic in the same city, only the one with higher data quality would be included into the meta-analysis.

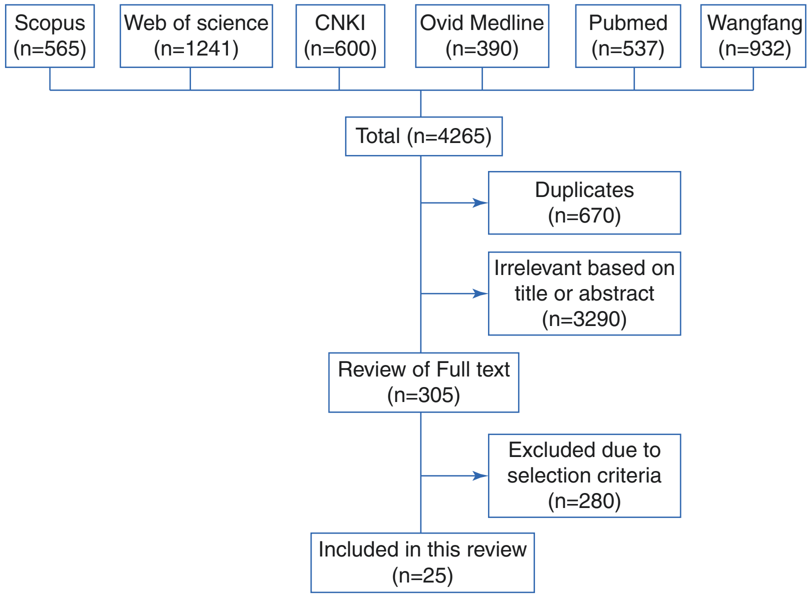


Fig. 3.1 Flow diagram of study selection on heat wave and health in China

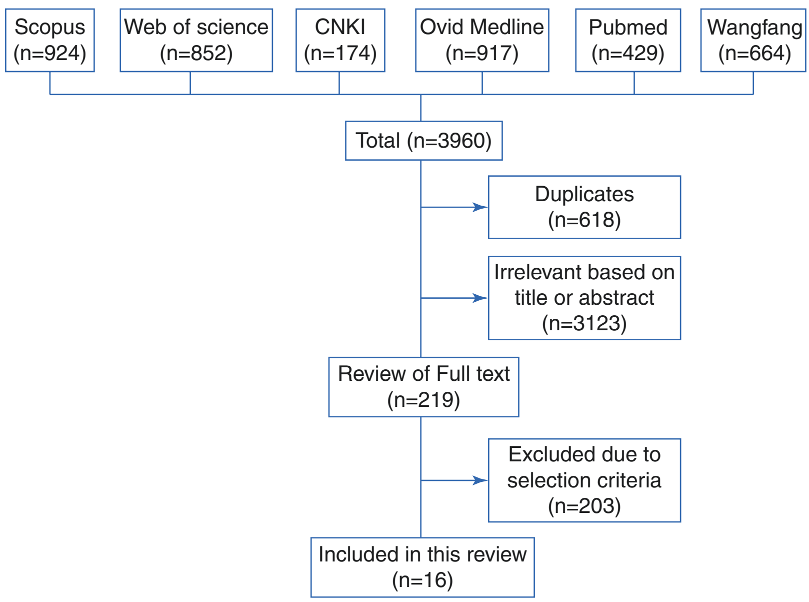


Fig. 3.2 Flow diagram of study selection on cold spell and health in China

The step-by-step process of literature search is provided in Figs. 3.1 and 3.2. In total, 4265 papers on heat wave and 3960 papers on cold spell were identified in the initial search. After reviewing the full texts, 25 papers on heat wave and 16 on cold spell were included into the meta-analysis. The majority of these studies were conducted in some metropolitan cities, such as Beijing, Shanghai, Guangzhou, Jinan, Nanjing, and Wuhan. Among these included studies, 13 focused on the association between heat wave and mortality (Table 3.1), 11 on the association between cold spell and mortality (Table 3.2), 12 on the association between heat wave and mor-

Table 3.1 The summary of included studies on heat wave and mortality in China

Source	Location	Time period	Definition of heat wave	Main outcomes and stratification	Main findings
Luan, et al. [26]	Beijing	2009–2010	At least 3 consecutive days with daily maximum temperature over 35 °C	Non-accidental, CVD, IHD, stroke, RD, and COPD; male and female; those aged 0–64, 65–84, and 85+ years	Deaths from cardiorespiratory diseases were at greater risk to heat wave, particularly for the IHD and COPD. Females and the elderly were more vulnerable to heat wave
Zhang et al. [27]	Wuhan, Hubei province	2003–2010	45 heat wave definitions, with temperature thresholds (90.0th, 92.5th, 95th, 97.5th, and 99.0th percentile of daily mean/ maximum/ minimum temperature) and durations of ≥2, ≥3, and ≥4 days in May–September	Non-accidental death; male and female; those aged <65 and ≥65 years	There was a significant increase in mortality during heat wave in Wuhan, China, while effects of heat waves on mortality varied greatly by different heat wave definitions. Heat wave defined as at least 3 consecutive days with daily mean temperature had the best predictive ability. Females and the elderly were more vulnerable to stronger and longer heat wave
Gao et al. [17]	Beijing, Tianjin, Nanjing, Shanghai, and Changsha	2006–2011	Beijing and Tianjin as being 2 or more consecutive days with the daily mean temperatures exceeded 30.2 °C and 29.5 °C, respectively; Nanjing, Shanghai, and Changsha as ≥3 consecutive days with daily mean temperatures above 32.9 °C, 32.3 °C, and 34.5 °C	Non-accidental death	Non-accidental mortality rates were generally higher during the identified heat wave than the corresponding control periods in all cities except Shanghai
Yang et al. [25]	Guangzhou, Guangdong province	2003–2006	At least 7 consecutive heat days and daily mean temperature above the 95th percentile	Non-accidental death, CVD, and RD; male and female; those aged 0–64, 65–74, and 75+ years; the illiterate, primary school and secondary or higher; the white-collar worker, blue-collar worker, and the unemployed	The 2005 heat wave had a substantial influence on mortality among the residents in Guangzhou. Those with CVD and RD, females, the elderly and those with lower socioeconomic status were at significantly greater heat wave risk

Table 3.1 (continued)

Source	Location	Time period	Definition of heat wave	Main outcomes and stratification	Main findings
Lan et al. [28]	Harbin, Heilongjiang province	2010	At least 3 consecutive days with daily maximum temperature over 98th percentile	Non-accidental death; male and female; those aged <64 years, 65–74 years, and ≥75 years; the place of death (hospital room, way to hospital, emergency room and home)	The 2010 heat wave was a strong risk factor for mortality in Harbin. Females, those aged between 0 and 64 years old, and those deaths out of hospital were at higher heat wave risk
Chen et al. [12]	Nanjing, Jiangsu prosvince	2007–2013	46 heat wave definitions	Non-accidental, CVD, stroke, IHD, RD, COPD; male and female; those aged 0–64, 65–74, and 75+ years	Different heat wave definitions had considerable impacts on the added effects of heat waves. Heat wave defined as at least 4 consecutive days with daily mean temperature over 98th percentile had the best model fit. Deaths from stroke, IHD, and COPD were at higher heat wave risk. Added effects were higher for females, the elderly, and people with lower education
Ma et al. [22]	66 Chinese communities	2006–2011	At least 2 consecutive days with daily mean temperature ≥95th percentile of the year-round community-specific distribution	Non-accidental death, CVD, CBD, and RD; male and female; those aged 0–64, 65–74, and 75+ years; places of death (at hospital, outside hospital); education attainment (<6 years, 6–9 years, and >9 years)	There was a significant increase in mortality rate during heat waves in 66 Chinese communities with notably spatial heterogeneity. Greater effects heat wave were found among CVD, CBD, RD, the elderly, females, people dying outside of hospital, and those with higher education attainment. Heat wave risk was also more markedly for those living in urban cities or densely populated communities
Huang et al. [29]	Shanghai	Summer of 2003	At least 3 consecutive days with daily maximum temperature over 35 °C	Non-accidental mortality, CVD, stroke, CHD, RD, COPD, and ARI; male and female; those aged 0–4 years, 5–44 years, 45–64 years, and 65+ years	The 2003 heat wave had a substantial effect on mortality in Shanghai. The effect of heat wave on total mortality in males was slightly higher than in females, but the difference was not statistically significant. The elderly (over 65 years) were most vulnerable to the heat wave

(continued)

Table 3.1 (continued)

Source	Location	Time period	Definition of heat wave	Main outcomes and stratification	Main findings
Han et al. [19]	Jinan, Shandong province	2011–2014	At least 3 consecutive days with daily mean temperature above the 95th percentile from May to August	Non-accidental mortality, CVD, stroke, RD, and COPD; male and female; those aged 0–64 years and 65+ years	The increasing number and intensity of heat wave had a deep impact on health. Heat waves significantly increased the risk of deaths due to non-accidental mortality, CVD and stroke. The elderly were more vulnerable during heat wave exposure
Tian et al. [30]	Beijing	2000–2011	18 heat wave definitions by combining heat wave thresholds (87.5th, 90.0th, 92.5th, 95th, 97.5th, and 99th percentiles of daily mean temperature) with durations of ≥2, ≥3, and ≥4 days	CHD death; female and male; those aged <65 years and age ≥65 years	Heat wave definition using 97.5th percentile of daily mean temperature (30.5 °C) and duration ≥2 days produced the best model fit. Women and elderly were more sensitive to heat wave than men and young, respectively. The longer duration of heat wave increased risk of CHD death more than shorter duration for the elderly. The first 2 days of heat wave had the highest health impact
Wang et al. [31]	Suzhou, Jiangsu province	2005–2008	A period of at least 7 consecutive days with daily maximum temperature above 35.0 °C and daily average temperatures above the 97th percentile during the study period	Total mortality	The additional effect of heat wave was not statistically significant
Lin et al. [21]	Taiwan	1994–2007	City-specific 95th, 97th, and 99th percentiles of mean temperature, with durations of 3–5, 6–8, and >8 days	All-cause mortality, CVD, and RD; those aged 65 years and above	Risk estimates of heat wave increased with longer durations. No significant positive associations between heat wave and cardiorespiratory mortality were observed
Lin et al. [20]	Taiwan	1994–2007	97th percentile of daily temperature lasting for 3–5, 6–8, and >8 days	Deaths from CVD, CBD, and IHD	Significant heat wave effects were only found among mortality from IHD in Taipei, heart disease in Taichung, and CBD in Kaohsiung

CVD cardiovascular disease; *RD* respiratory disease; *IHD* ischemic heart disease; *CHD* coronary heart disease; *CBD* cerebrovascular disease; *COPD* chronic obstructive pulmonary disease; *MI* myocardial infarction

Table 3.2 The summary of included studies on cold spell and mortality in China

Source	Location	Time period	Definition of cold spell	Main outcomes and stratification	Main findings
Ma et al. [32]	Shanghai	2001–2009	At least 7 consecutive days with daily average temperature below the 3rd percentile	Non-accidental, CVD, stroke, CHD, RD, COPD; male and female; those aged 0–4, 5–44, 45–64, and ≥65 years	The impact of 2008 cold spell was investigated. The impact was statistically significant for CVD but not for RD. The elderly was more vulnerable to the cold spell
Zhou et al. [33]	15 provinces in subtropical China	2006–2010	At least 5 consecutive days with daily mean temperature ≤ the 5th percentile in each community during December–March of 2006–2010	Non-accidental, CVD, RD, CBD; male and female; those aged 0–64, 65–74, 75–84, and 85+ years	The 2008 cold spell significantly increased mortality risk in subtropical China, and its effect can last for over 3 weeks. The main effect of cold spell was much larger than the added effect in most regions. Those with RD, females, and the elderly were more vulnerable to the cold spell
Xie et al. [24]	Guangzhou, Nanxiong, and Taishan, Guangdong province	2006–2009	At least 5 days with daily minimum temperature below the 5th percentile	Non-accidental, CVD, and RD; those aged 0–64, 65–74, and 75+ years; male and female	The 2008 cold spell was associated with an increase in daily mortality in three subtropical cities of Guangdong province; the elderly suffered most during the 2008 cold spell, and the effects appeared to be more pronounced for RD than that for CVD
Zhang et al. [34]	Wuhan, Hubei province	2001–2011	At least 5 days with daily mean temperature below the 5th percentile	Non-accidental, CVD, and RD; those aged 0–64 and 65+ years; male and female	The effect of 2008 cold spell was much higher than those in other years. Those with CVD and elderly were more vulnerable to cold spell
Zhong et al. [35]	Beijing	1998–2000	A period with temperature decrease of at least 8 °C and minimum temperature less than 4 °C	CVD, CBD, and MI	Six cold spells were identified, most of which showed nonsignificant impact on CVD mortality. And cold spell with much lower temperature but higher air pressure may cause increased CVD mortality
Ding et al. [15]	Guangzhou, Guangdong province	2003–2007	At least 7 consecutive days with daily average temperature below the 3rd percentile	Non-accidental, CVD, IHD, stroke, RD, and COPD; male and female; aged 0–64, 65–74, and 75+ years	Statistically significant effect of cold spell was only observed among non-accidental mortality, those with RD, and females and the elderly
Han et al. [19]	Jinan, Shandong province	2011–2014	At least 3 consecutive days with daily average temperature below the 5th percentile	Non-accidental mortality, CVD, stroke, RD, and COPD; male and female; those aged 0–64 and 65+ years	Cold spells significantly increased the risk of deaths among all subgroups

(continued)

Table 3.2 (continued)

Source	Location	Time period	Definition of cold spell	Main outcomes and stratification	Main findings
Wang et al. [31]	Suzhou, Jiangsu province	2005–2008	At least 7 consecutive days with daily maximum temperature and daily average temperatures below the 3rd percentile	Total mortality	The additional effect of cold spell was not statistically significant
Wang et al. [23]	66 Chinese communities	2006–2011	At least 2 consecutive days with daily mean temperature below the 5th percentile in each community	Non-accidental, CVD, and RD; female and male; 0–64, 65–74, 75–84, and 85+ years; education attainment (primary school, middle school and college or higher)	Cold spells significantly increased mortality risk in China, with a greater effect in southern areas. The mortality risk reached a maximum after 5 days exposure to a cold spell and then decreased and persisted for the next 3 weeks. In terms of regional distribution, the maximum overall effect was observed in southern areas, followed by eastern and central areas. The effects increased with cold spell duration, intensity, and earlier timing
Lin et al. [21]	Taiwan	1994–2007	City-specific 1st, 3rd, and 5th percentiles of mean temperature, with durations of 3–5, 6–8, and >8 days	Those aged 65 years and above; all-cause mortality, CVD, and RD	Risk estimate of cold spell increased by durations. No significant positive associations between cold spell and cardiorespiratory mortality were observed
Lin et al. [20]	Taiwan	1994–2007	5th percentile of daily temperature lasting for 3–5, 6–8, and >8 days	Deaths from CVD, CBD, and IHD	Significant effects of cold spell were only found among mortality from IHD in Taipei, heart disease in Taichung, and CBD in Kaohsiung

CVD cardiovascular disease; *RD* respiratory disease; *IHD* ischemic heart disease; *CBD* cerebrovascular disease; *COPD* chronic obstructive pulmonary disease; *MI* myocardial infarction

Table 3.3 The summary of included studies on the heat wave and morbidity in China

Source	Location	Time period	Definition of heat wave	Main outcomes and stratification	Main findings
Liu et al. [36]	Beijing	2009–2010	At least 3 consecutive days with daily maximum temperature ≥35.0 °C	EDV, including male and female; children aged 0–4 years and the elderly ≥60 years; CVD and RD	Heat wave could increase the risk of EDV, and the sensitive groups were the elderly, children, and RD patients
Wang et al. [37]	Taiwan	2000–2009	97th and 95th percentiles of daily mean temperature lasting for 3–5, 6–8, and >8 days, and 99th percentile lasting for 2–3 days and >3 days	EDV for CVD and RD	Exposure to the first extreme heat event of the 99th percentile temperature was moderately associated with ERV for all causes and circulatory diseases

Table 3.3 (continued)

Source	Location	Time period	Definition of heat wave	Main outcomes and stratification	Main findings
Sun et al. [38]	Pudong, Shanghai	2011–2013	At least 2 or 3 consecutive days with daily maximum temperature above 90th, 95th, and 99th percentiles	EDV and EAD	The morbidity outcomes were strongly associated with heat wave. And the effect of heat wave varied by different heat wave definitions. Negative or nonsignificant effect estimates were found for higher intensity, except for the heat wave above 99th percentile
Ma et al. [39]	Shanghai	2005–2008	At least 7 consecutive days with daily maximum temperature above 35.0 °C and daily average temperatures above 97th percentile during the study period	Hospital admission for all-cause, CVD and RD	Exposure to heat wave was associated with an increased risk of hospital admissions in Shanghai. Higher effects of heat wave were observed among hospital admissions from CVD and RD than the all-cause
Li et al. [40]	Chongqing	2009–2013	At least 3 consecutive days with daily average temperature equal to or over 34 °C. The heat wave intensity was classified into four levels using 25th, 50th, and 75th percentile of temperature multiplying the durations of heat wave as cutoff	Heatstroke, including male and female; those aged 0–14 years, 15–18 years, 19–35 years, 36–55 years, 56–65 years, and >65 years	Number of heatstroke cases increased with the increasing of duration of heat wave and peek at the 11th day of heat wave. Stronger intensity of heat wave was accompanied by higher daily heatstroke cases and higher proportion of severe cases
Zheng et al. [41]	Beijing	2009–2011	At least 3 consecutive days with daily maximum temperature ≥35.0 °C	EDV, including male and female; those aged <65 years and ≥65 years; CVD, hypotension, IHD, and CBD	Heat wave was significantly associated with increased EDV from all types of CVD. And the elderly was more vulnerable to the heat wave. Air pollution and weather variables could not modify the heat wave effects
Liu et al. [42]	Guangzhou and Ningan, Guangdong province	2006–2011	At least 2 consecutive days with daily mean temperature over 95th percentile	Hospital admissions, including male and female; those aged ≤65 years, 66–75 years, and ≥75 years; CVD and RD	The effect of heat wave was acute, and the highest accumulative effect was at lag 0–1 days. Population in rural regions, females, and the elderly were at greater risk of heat wave. RD suffered more serious heat wave effect than CVD
Song et al. [43]	Beijing	2009–2012	At least 2–4 consecutive days with daily mean temperature exceeding the 95th, 96th, 97th, 98th, and 99th percentiles	EDV for RD, including male and female; those aged 0–64 and 65 years; total RD, upper and lower RD	The RRs of heat waves increased with thresholds, and the greatest risk was observed in extremely heat wave. The added effects of heat waves were small and negligible. The added heat wave effect only introduced additional risk in females and upper RD. Compared with males, females have increased vulnerability to the effects of heat wave

(continued)

Table 3.3 (continued)

Source	Location	Time period	Definition of heat wave	Main outcomes and stratification	Main findings
Bai et al. [11]	Ningbo, Zhejiang province	2011–2013	At least 7 consecutive heat days with the maximum temperature over 35 °C	Heat-related illness: male and female; those aged 0–15 years, 16–44 years, 45–64 years, and ≥65 years; heat stroke, heat cramp, and heat exhaustion	Heat wave dramatically increased morbidity of heat-related illnesses in Ningbo city. Heat wave effect was much stronger for severe heat-related illnesses than mild ones. Males were at higher risks of having heat-related conditions during heat wave than females, and all age groups were at risks in terms of heat diseases
Cheng et al. [44]	Huainan, Anhui province	2011–2013	At least 2 or 3 consecutive days with daily mean temperature above 95th, 97.5th, and 99th percentiles	EAD	The effect of heat wave on EAD was acute. The best model fit was the model using heat wave definition as at least 2 consecutive days with daily mean temperature over 95th percentile. Fraction of EAD attributable to heat wave decreased with higher heatwave intensity and longer heatwave duration
Cui et al. [14]	Jinan, Shandong province	2011–2014	At least 3 consecutive days with daily maximum temperature ≥35.0 °C	HS, including male and female; those aged 17–39 years, 40–59 years, 60–79 years, and 80–93 years; mild and severe HS (heat cramp, heat exhaustion and mixture type)	Most of the heat stroke were severe type. The males and urban population suffered higher risk of HS during heat wave
Wang et al. [45]	Taiwan	2000–2008	Temperature in 95th percentile lasting for 3–5, 6–8, or >8 days	Outpatient visits for RD, asthma, and chronic airway obstruction; male and female; aged ≥65 and <65 years	Outpatient visits for RD and asthma were significantly associated with heat wave lasting for 6–8 days

EDV emergency department visit; *EAD* emergency ambulance dispatch; *CVD* cardiovascular disease; *RD* respiratory disease; *IHD* ischemic heart disease; *CBD* cerebrovascular disease; *HS* heat stroke

Table 3.4 The summary of included studies on the cold spell and morbidity in China

Source	Location	Time period	Definition of cold spell	Main outcomes and stratification	Main findings
Guo et al. [18]	Shanghai	2007–2009	Four or more consecutive days with mean temperature below the 5th percentile of the distribution	Pediatric outpatient visits for asthma	Cold spell significantly increased the risk of pediatric outpatient visits for asthma. The severe cold spell also exhibited a long lagged effect on the onset of children's asthma

Table 3.4 (continued)

Source	Location	Time period	Definition of cold spell	Main outcomes and stratification	Main findings
Song et al. [43]	Beijing	2009–2012	At least 2–4 consecutive days with mean temperature below the 1st, 2nd, 3rd, 4th, and 5th percentiles	EDV for RD, including male and female; those aged 0–64 and 65 years; total RD, upper and lower RD	The highest risk of cold spells on RD was observed in relatively mild cold spells. Compared with males, females have increased vulnerability to the effect of cold spell. Lower RD was significantly associated with cold spell. No added effect of cold spell was observed
Wang and Lin [45]	Taiwan	2000–2008	Temperature in 5th percentile lasting for 3–5, 6–8, or >8 days	Outpatient visits for RD, asthma and chronic airway obstruction; male and female; aged ≥65 and <65 years	Cold spell lasting more than 8 days had a significant negative association with outpatient visits for RD
Wang et al. [37]	Taiwan	2000–2009	10th and 5th percentiles of daily mean temperature lasting for 3–5, 6–8, and >8 days, and 1st percentile lasting for 2–3 days and >3 days	EDV for all-cause, CVD and RD	Intensified prolonged cold spell were significantly associated with increased EDV for all causes and RD
Ma et al. [39]	Shanghai	2005–2008	At least 7 consecutive days with daily maximum temperature and daily average temperatures below 3rd percentile during the study period	Hospital admission for all-cause, CVD and RD	Cold spells were associated with increased risk of hospital admissions. The cold spell had a larger impact on hospital admission than the heat wave

EDV emergency department visit; *CVD* cardiovascular disease; *RD* respiratory disease

bidity (Table 3.3), and 5 on the association between cold spell and morbidity (Table 3.4).

3.3 Characteristics of Extreme Temperature Events on Health

3.3.1 Definitions of Heat Wave and Cold Spell

According to the China Meteorological Administration (CMA), there are three types of heat wave alert signals and four types of cold spell alert signals in China [46, 47]. Among these definitions by CMA, the definition as at least 3 consecutive days with daily maximum temperature over 35 °C was mainly used to quantify the health effects of heat wave in China; for the cold spell, the definition of a period with a temperature decrease of at least 8 °C over 48 h with minimum temperature less than 4 °C was always used in studies of health risk assessment of cold spell (Table 3.5).

Since climate characteristics and socioeconomic status vary greatly among different regions in China, people can acclimatize themselves to the local climates through physiological adaptation and using external resources. Thus, the heat or cold vulnerability may be different across regions. In term of this regional discrepancy, many previous studies used the relative threshold of temperatures to define the heat wave and cold spell instead of the absolute threshold that was released by CMA. For example, Wang et al. [23] estimated the effects of cold

Table 3.5 The official definitions of heat wave and cold spell in China

Indicators	Level	Definitions	Signal
Heat	Low	At least three consecutive days with daily maximum temperature over 35 °C	
	Moderate	The maximum temperature above 37 °C in 24 h	
	Severe	The maximum temperature above 40 °C in 24 h	
Cold	Low	A drop in minimum temperature of 8 °C within 48 h, to a high of 4 °C	
	Moderate low	A drop in minimum temperature of 10 °C within 24 h, to a high of 4 °C	
	Moderate high	A drop in minimum temperature of 12 °C within 24 h, to a high of 0 °C	
	Severe	A drop in minimum temperature of 16 °C within 24 h, to a high of 0 °C	

spell on mortality in 66 communities from 7 geographical Chinese regions using definition of at least 2 consecutive days with daily temperature below 5th percentile in cold season [23]. With the same dataset, Ma et al. [22] quantified the mortality risk of heat wave using the definition of at least 2 consecutive days with daily mean temperature above 95th percentile [22]. In addition, studies in Beijing [30], Nanjing [12], and Wuhan [27] compared multiple heat wave definitions by combing different heat wave relative thresholds and different heat wave durations, and then the best heat wave definition was selected based on the model fit. For example, Tian et al. [30] compared 18 heat wave definitions by combing the heat wave thresholds (87.5th, 90.0th, 92.5th, 95th, 97.5th, and 99th percentiles of daily mean temperature) and 3 heat wave durations (≥2, ≥3, and ≥4 days) to assess the impact of heat wave on coronary heart disease mortality in Beijing [30]. Differently, the study in five cities by Gao et al. [17] used the absolute mean temperature by 1-degree increments from 20 °C to the 99th percentile to identify the best heat wave definition [17].

3.3.2 Frequency, Duration, and Timing of Extreme Temperature Events on Health

The frequency, severity, duration, and timing of extreme temperature events may significantly influence their health-related effects. In terms of characteristics of heat wave, the study of Zeng et al. [48] in four communities of Guangdong province reported that a 1 °C increment in daily mean temperature was associated with an increase of 1.2% (95% CI: −5.6–8.5%) in overall mortality, 1.4% (95% CI: −0.6–3.4%) for 1 day increment in heat wave duration and −0.1% (95% CI: −1.2–1.0%) for every 10 days later in the season, even though the effect estimates were not statistically significant. These findings were consistent with previous studies [12, 27, 49, 50]. For instance, every 1-day increase in the heat wave duration was associated with 0.38% increase in mortality risk in 43 US communities [49]; every 5 days longer of heat wave duration resulted in 0.14% (95% CI: 0.01–0.27%) increase in mortality risk in 99 US cities [50]. Heat wave with longer duration and stronger intensity has also confirmed to be at greater mortality risk in other cities [12, 27].

Regarding the characteristics of cold spell, the study of Wang et al. in 66 Chinese communities presented that increments in cold spell duration and intensity were associated with mortality risk increase [23]. For instance, with intensity of 5th percentile of daily mean temperature, cold spells at durations of 2, 3–5, and ≥6 days were associated with increases of 18.9%, 31.9%, and 36.3% in non-accidental mortality. For the timing effect of cold spell, each 10 days earlier occurrence of cold spells (5th percentile of daily mean temperature with durations at 2, 3–5, and ≥6 days) were associated with 1.9% (95% CI: 0.5–3.4%), 1.4% (95% CI: 0.8–2.0%) and 2.4% (95% CI: 1.6–3.3%).

3.4 Association Between Extreme Temperature Events and All-Cause Mortality/Morbidity

3.4.1 Heat Wave Impact on All-Cause Mortality

The study of Ma et al. conducted in 66 communities was the largest study to quantify the mortality risk of heat wave in China [22]. In this study, heat wave corresponded to a total of 5.0% (95% CI: 2.9–7.2%) additional deaths in these communities, showing significant spatial heterogeneity. The greatest mortality risk was identified in northern China, with increment estimate of 6.0% (95% CI: 1.0–11.3%), followed by eastern China (5.2%, 95% CI: 0.4–10.2%), southern China (4.5%, 95% CI: 1.4–7.6%), and Western China (3.9%, 95% CI: −0.6–8.7%).

The fixed-effects meta-analysis or random-effects meta-analysis was applied to combine the effect estimates among different studies. The method was chosen according to the heterogeneity that was tested by Cochran Q and Higgins I^2 statistics [51]. Among the included studies, the largest effect estimate of heat wave on mortality was found in the study of Zhang et al. [27] in Wuhan, with corresponding RR of 1.63 (95% CI: 1.42–1.85) [27], while the lowest estimate was 1.01 (95% CI: 1.00–1.04) in the study of Han et al. [19] in Nanjing [19]. The between-study heterogeneity was statistically significant among these studies (I^2 = 97%; P < 0.0001). The pooled RR across the included studies was 1.20 (95% CI: 1.09–1.32) (Fig. 3.3), which was comparable to the recent multicountry study [52].

Several studies focused on the health effect of the unprecedented heat wave occurred in eastern China in 2013. The study of Du et al. [16] in Shanghai examined the impact of heat wave in each year during 2003–2013 and found that the intensity and duration of 2013 heat wave was much higher than those in 2003–2012, with corresponding maximum temperature of 40.6 and 38.9 °C, and duration of 44 and 37 days. This extreme heat wave caused 1347 deaths in Shanghai, which was 3.9 times higher than the average heat wave-related excess deaths in 2003–2012 [16].

Furthermore, it is of great importance to evaluate the potential additional effects from heat wave by decomposing the heat effect into the temperature term and an added additional term for heat wave, which could help us better understand the

Study	log[Risk Ratio]	SE	Weight	Risk Ratio Random, 95%CI
Huang et al. 2010	0.1222	0.0326	11.6%	1.12 [1.06,1.20]
Lan et al. 2012	0.3436	0.0738	9.5%	1.41 [1.22,1.62]
Yang et al. 2013	0.207	0.0524	10.7%	1.22 [1.10,1.36]
Wang et al. 2014	0.0677	0.0553	10.6%	1.07 [0.96,1.19]
Luan et al. 2015	0.1989	0.0301	11.7%	1.22 [1.15,1.29]
Ma et al. 2015	0.0488	0.0093	12.2%	1.05 [1.03,1.06]
Chen et al. 2015	0.2231	0.0381	11.4%	1.24 [1.16,1.34]
Han et al. 2017	0.0198	0.0101	12.2%	1.01 [1.00,1.04]
Zhang et al. 2017	0.4886	0.0668	9.9%	1.63 [1.42,1.85]
Total(95%CI)			100%	**1.2 [1.09,1.32]**

Heterogeneity: Tau2=0.02; P<0.0001; I2=97%

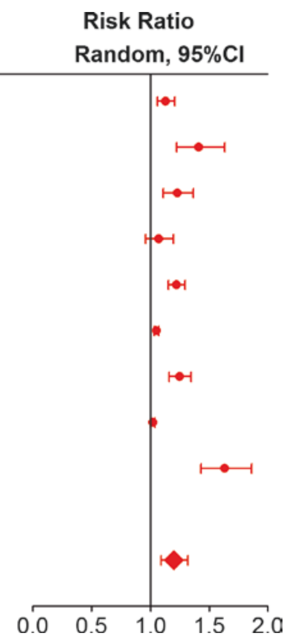


Fig. 3.3 Summary of studies of heat wave and all-cause mortality

mechanism of heat wave impact and better guide the development of the public health interventions. In four communities of Guangdong province, Zeng et al. [48] found that the main effects of heat waves were much greater than the added effects, with corresponding RR of 1.08 (95% CI: 1.03–1.13) and 1.00 (95% CI: 0.96–1.04). In addition, Chen and colleagues found that the added effects of heat waves could be significantly influenced by different heat wave definitions [12].

3.4.2 Heat Wave Impact on All-Cause Morbidity

Table 3.2 presented the studies regarding the extreme temperature events and morbidity. Compared to the mortality, there are fewer numbers of studies examining the influence of heat wave on morbidity. Hospital admissions, outpatient visits, emergency department visits (EDV), and emergency ambulance dispatch (EAD) were frequently used as surrogate indicators. In Shanghai, Guangzhou, and Xingning, Ma and Liu have reported that hospital admissions were significantly associated with heat wave [39, 42], with corresponding RR of 1.02 (95% CI: 1.01–1.04), 1.03 (95% CI: 1.01–1.04), and 1.05 (95% CI: 1.02–1.06). With respect to the heat wave effects on EAD, Sun et al. [38] and Cheng et al. [44], respectively, reported RR of 1.05 (95% CI: 1.01–1.08) and 1.20 (95% CI: 1.05–1.37) in EAD associated with heat wave [38, 44]. And Cheng et al. [44] also found that higher intensity and longer duration corresponded to lower fraction of EAD, with percent change varying from 0.51 to 1.52% [44]. For the EDV, in Beijing, Shanghai, and Taiwan, Liu et al. [36], Sun et al. [38], and Wang et al. [37] reported the significant relationship between heat wave and EDV, with RRs ranging between 1.03 (95% CI: 1.01–1.04) and 1.09 (95% CI: 1.05–1.13) [36–38].

3.4.3 Cold Spell Impact on All-Cause Mortality

The study of Wang et al. [23] conducted in 66 communities was the largest study to quantify the mortality risk of cold spell in China [23]. In this study, the magnitude of cold spell varied greatly by regions. The largest cumulative excess risk was found in southern China, with estimate of 58.7% (95% CI: 40.1–79.9%), followed by the eastern China (39.2%, 95% CI: 26.5–53.1%), the Central China (36.8%, 95% CI: 22.6–52.6%), southwestern China (31.3%, 95% CI: 19.9–43.7%), northwestern China (17.7%, 95% CI: 6.3–30.3%), northern China (1.4%, 95% CI: −13.3–18.5%), and northeastern China (0.2%, 95% CI: −14.1–16.8%).

Among the eight included studies on association between cold spell and mortality, the highest estimate was reported in Wuhan by Zhang et al. [34] and the lowest in Suzhou by Wang et al. [31], with corresponding RRs of 1.56 (95% CI: 1.36–1.78) and 1.03 (95% CI: 0.89–1.20), respectively. Then random-effect meta-analysis was used to combine the effect estimates across these investigations. The pooled RR was 1.25 (95% CI: 1.11–1.40), while the between-study heterogeneity was statistically significant across these studies ($I^2 = 96\%$, $P < 0.001$) (Fig. 3.4). The estimate was much higher than the result of a recent systematic review on global association between cold spell and mortality, reporting RR of 1.10 (95% CI: 1.04–1.17). Most of the included studies in that systematic review were from European countries. These developed countries may have stronger social, institutional, technological, and behavioral adaptation capacity and richer experience in lessening the damage caused by extreme temperature events [1]. Thus, people in these countries have less vulnerability to these adverse weather events.

Additionally, Zhou and colleagues reported that the main effect of cold spell was generally higher than the added effect [33], with a cumulative excess mortality risk of 22.5% (95% CI: 5.2–42.6%) for the main effect and 9.4% (95% CI: −7.8–29.9%) for added effect of cold spell. The authors speculated that it is the cold "snap" contributed by the main effect and that as the event went on over time, people may take preventive measures.

Several studies focused on the effect of the unprecedented 2008 cold spell on mortality in subtropical China. In 36 Chinese subtropical communities, Zhou et al. found that a total of

Study	log[Risk Ratio]	SE	Weight	Risk Ratio Random, 95%CI
Xie et al. 2013	0.4055	0.1139	9.1%	1.50 [1.19,1.87]
Ding et al. 2013	0.077	0.0342	13.4%	1.08 [1.01,1.15]
Ma et al. 2013	0.1222	0.0278	13.7%	1.12 [1.07,1.19]
Wang et al. 2014	0.0392	0.0738	11.4%	1.03 [0.89,1.20]
Zhou et al. 2014	0.3646	0.0329	13.5%	1.43 [1.35,1.53]
Zhang et al. 2016	0.4447	0.07	11.7%	1.56 [1.36,1.78]
Wang et al. 2016	0.3075	0.039	13.2%	1.36 [1.25,1.46]
Han et al. 2017	0.077	0.0095	14.1%	1.08 [1.06,1.10]
Total(95%CI)			100%	**1.25 [1.11,1.4]**

Heterogeneity: Tau2=0.02; P<0.0001; I2=96%

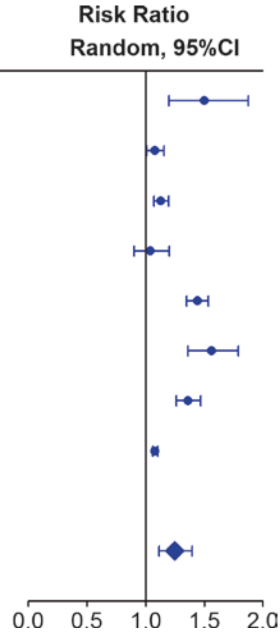


Fig. 3.4 Summary of studies of cold spell and all-cause mortality

Study	log[Risk Ratio]	SE	Weight	Risk Ratio Random, 95%CI
Ma et al. 2013	0.1222	0.0278	28.9%	1.12 [1.07,1.19]
Xie et al. 2013	0.4055	0.1139	18.4%	1.50 [1.19,1.87]
Zhou et al. 2014	0.3646	0.0329	28.5%	1.43 [1.35,1.53]
Zhang et al. 2016	0.4447	0.07	24.2%	1.56 [1.36,1.78]
Total(95%CI)			100%	**1.38 [1.18,1.61]**

Heterogeneity: Tau2=0.02; P<0.0001; I2=91%

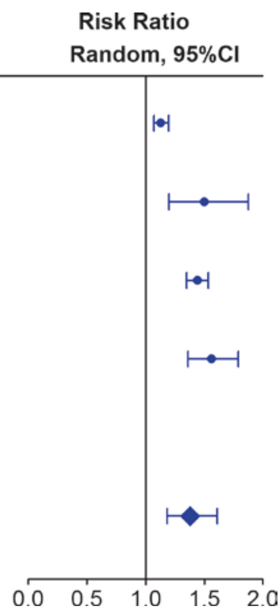


Fig. 3.5 Summary of studies of 2008 cold spell and all-cause mortality

43.8% (95% CI: 34.8–53.4%) and 148,279 additional deaths were attributable to this cold spell, and its adverse effect could last for over 27 days [33]. The magnitude of 2008 cold spell on mortality was found to be much higher than those in other years [33, 34]. For example, the RR of 1.56 (95% CI: 1.36–1.78) was associated with 2008 cold spell in Wuhan, compared to 1.23 (95% CI: 1.08–1.41) for the cold spell in other years [34]. Among these four included studies, the pooled RR was 1.38 (1.18–1.61) for 2008 cold spell (Fig. 3.5).

3.4.4 Cold Spell Impact on All-Cause Morbidity

Cold spell has also been reported to be significantly associated with the increase in the all-cause morbidity. Ma et al. [39] have explored the impact of cold spell on hospital admissions during 2005–2008 in Shanghai, China [39], and detected that cold spell corresponded to 38% (95% CI: 35–40%) increase of all-cause hospital admissions. The effect of cold spell on hospital admissions was larger than that of heat wave (percentage change: 2%, 95% CI: 1–4%) in this study. Additionally, a population-based cohort study assessed the first and prolonged extreme temperature event on emergency room visits (ERV) during 2000–2009 in Taiwan [37] and reported that the ERV risks were found to be significantly associated with extreme cold temperature at 5th percentile lasting for over 8 days, with RR of 1.18 (95% CI: 1.10–1.27).

3.5 Extreme Temperature Events on Cardiovascular Mortality/Morbidity

Cardiovascular diseases (CVD) are among the leading causes of death in the world, causing 17.9 million deaths in 2016 and accounting for 44% of all deaths from noncommunicable diseases [53]. During last decades, the prevalence of CVD has changed differently between developing and developed countries, with a rapid increase in the low-income regions but a fast decline in many high-income countries. Driven by population ageing, changes in diet and physical activity, China is facing an increasing epidemic of CVD. According to the 2017 report on cardiovascular diseases in China, there are nearly 290 million CVD patients, and in 2015, the mortality rates were 298.40 and 264.84 per 100,000 in rural and urban region, respectively.

People with CVD are particularly vulnerable to cold and heat temperature [54, 55]. Expose to cold temperatures may directly lead to an increase in platelets, red blood cell counts, blood pressure, blood viscosity, vasoconstriction and fibrinogen, and plasma cholesterol [56]. On the other hand, exposure to the hot temperature may cause significant physiological alterations, such as change in cardiac output leading to dehydration and hypotension, increase in blood viscosity, and even endothelial cell damage [57]. These temperature variations may add burden to the cardiac system and trigger lethal events such as ischemic heart disease and stroke. As shown in Figs. 3.6, 3.7, 3.8, 3.9 and 3.10, there is a summary of studies of association between extreme temperature events and CVD in China.

Study	log[Risk Ratio]	SE	Weight	Risk Ratio Random, 95%CI
Huang et al. 2010	0.174	0.0495	15.7%	1.19 [1.08,1.31]
Yang et al. 2013	0.2927	0.087	12.5%	1.34 [1.12,1.58]
Lin et al. 2013	0.5188	0.2302	4.4%	1.68 [1.06,2.63]
Luan et al. 2015	0.2469	0.0372	16.6%	1.28 [1.19,1.37]
Ma et al. 2015	0.077	0.0144	17.7%	1.08 [1.04,1.11]
Chen et al. 2015	0.3853	0.0511	15.6%	1.47 [1.32,1.62]
Han et al. 2017	0.0296	0.0151	17.6%	1.03 [1.00,1.06]
Total(95%CI)			100%	**1.23 [1.1,1.37]**

Heterogeneity: Tau2=0.02; P<0.0001; I2=95%

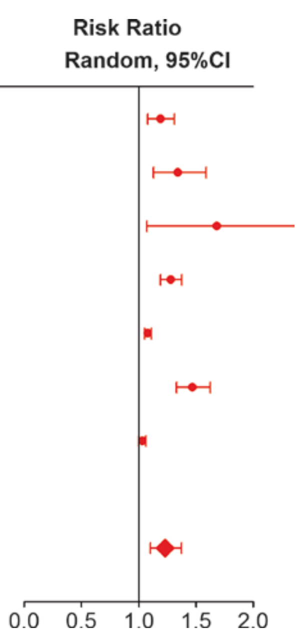


Fig. 3.6 Summary of studies of heat wave and cardiovascular mortality

Study	log[Risk Ratio]	SE	Weight	Risk Ratio Random, 95%CI
Chen et al. 2015	0.4121	0.1046	12.1%	1.50 [1.23,1.85]
Han et al. 2017	0.0583	0.0297	20.8%	1.06 [1.00,1.12]
Huang et al. 2010	0.1906	0.0675	16.5%	1.20 [1.06,1.38]
Lin et al. 2013	0.2852	0.111	11.5%	1.33 [1.06,1.65]
Luan et al. 2015	0.2469	0.0591	17.5%	1.28 [1.14,1.43]
Ma et al. 2015	0.0583	0.0196	21.5%	1.06 [1.02,1.10]
Total(95%CI)			100%	**1.2 [1.08,1.33]**

Heterogeneity: Tau2=0.01; P<0.0001; I2=87%

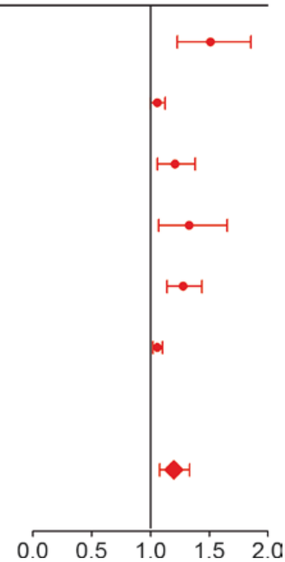


Fig. 3.7 Summary of studies of heat wave and stroke mortality

Study	log[Risk Ratio]	SE	Weight	Risk Ratio Random, 95%CI
Zhong et al. 2010	0.4055	0.1908	8%	1.50 [1.03,2.18]
Xie et al. 2013	0.5128	0.2515	5.9%	1.66 [1.02,2.73]
Ma et al. 2013	0.1906	0.0394	14.9%	1.20 [1.12,1.30]
Ding et al. 2013	0.0953	0.0642	14%	1.09 [0.96,1.24]
Zhou et al. 2014	0.4253	0.0381	14.9%	1.53 [1.41,1.64]
Wang et al. 2016	0.3001	0.0475	14.6%	1.34 [1.22,1.48]
Zhang et al. 2016	0.6729	0.0972	12.4%	1.95 [1.61,2.37]
Han et al. 2017	0.0583	0.0146	15.4%	1.06 [1.03,1.09]
Total(95%CI)			100%	**1.36 [1.16,1.58]**

Heterogeneity: Tau2=0.04; P<0.0001; I2=95%

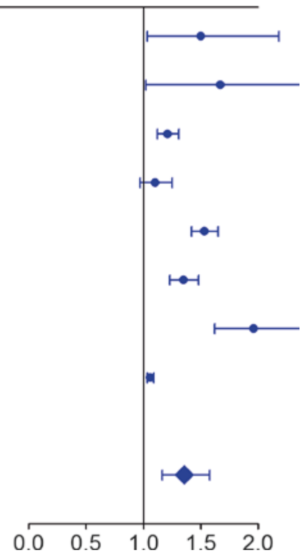


Fig. 3.8 Summary of studies of cold spell and cardiovascular mortality

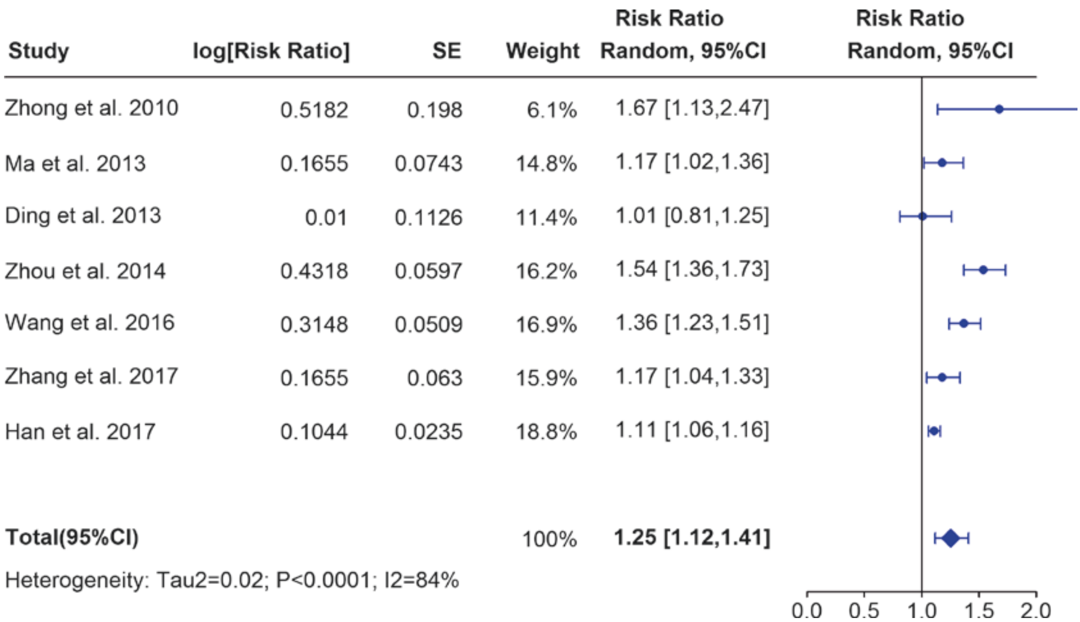


Fig. 3.9 Summary of studies of cold spell and stroke mortality

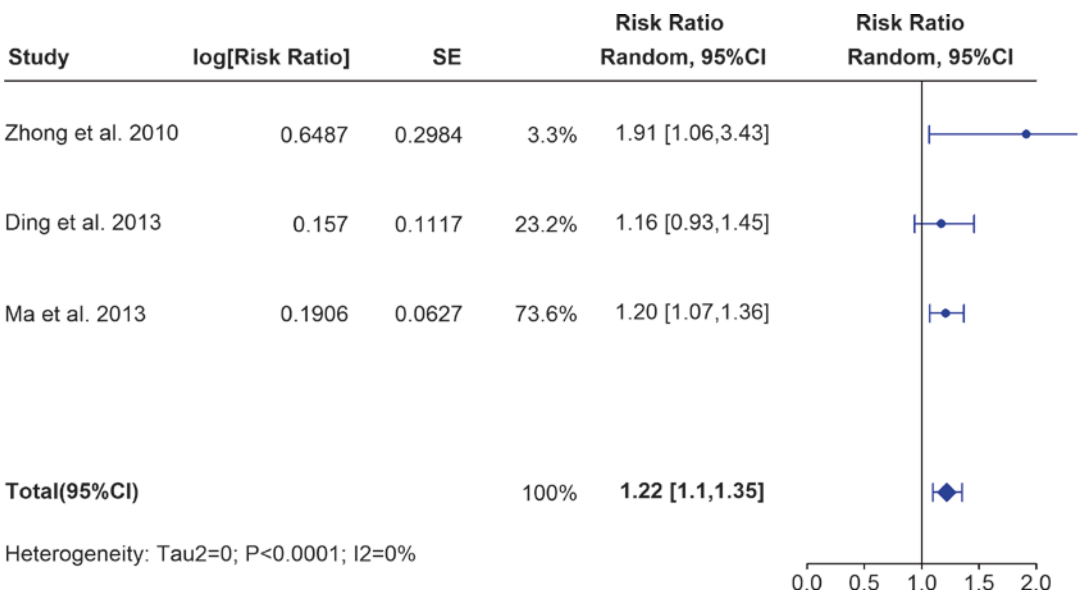


Fig. 3.10 Summary of studies of cold spell and mortality from coronary heart disease

3.5.1 Heat Wave Impact on Cardiovascular Mortality

CVD mortality has been extensively associated with heat wave in previous studies [12, 19, 20, 22, 25, 26, 29, 30], with the RR in CVD mortality ranging from 1.03 (95% CI: 1.00–1.06) in Jinan, Shandong [19], to 1.68 (95% CI: 1.06–2.63) in Taichung, Taiwan [20]. The pooled RR of heat wave on CVD mortality in the seven included studies was 1.23 (95% CI: 1.10–1.37) (Fig. 3.6), and similar effect estimate was observed for stroke mortality, with pooled RR of 1.20 (1.20, 95% CI: 1.08–1.33) (Fig. 3.7). For other cardiovascular-specific mortality, in Beijing and Shanghai, the RRs of coronary heart disease mortality associated with heat wave were reported to be 1.31 (95% CI: 1.17–1.46) and 1.20 (95% CI: 1.02–1.40) [29, 30]; Luan and Zhang found significantly elevated death risks from acute myocardial infarction in Beijing and Jinan, Shandong province [26, 58], with corresponding RRs of 1.33 (95% CI: 1.19–1.50) and 1.60 (95% CI: 1.11–2.29).

3.5.2 Heat Wave Impact on Cardiovascular Morbidity

Investigations on the impact of heat wave on cardiovascular morbidity have been conducted in Beijing, Shanghai, Guangzhou, Xingning, and Taiwan. Ma et al. [39] and Liu et al. [42] have found that heat wave was associated with increased risk of hospital admissions in Shanghai, Guangzhou, and Xingning, with the corresponding RRs of 1.08 (95% CI: 1.05–1.11), 1.02 (95% CI: 1.01–1.03), and 1.03 (95% CI: 1.02–1.05) [39, 42]. Regarding the EDV, Wang and Zheng [41] reported that the EDV increased dramatically during the heat wave, with RRs ranging from 1.23 (95% CI: 0.98–1.54) to 1.83 (95% CI: 1.77–1.92).

3.5.3 Cold Spell Impact on Cardiovascular Mortality

Among the included studies, the highest estimate of cold spell on CVD mortality was reported in the study of Zhang et al. [34] in Wuhan, with RR of 1.95 (95% CI: 1.61–2.37), while the lowest effect estimate was 1.09 (95% CI: 0.96–1.24) in the study of Ding in Guangzhou [15]. The pooled RR of cold spell on mortality was 1.36 (95% CI: 1.16–1.58) (Fig. 3.8). For the cardiovascular-specific death, the pooled RR was 1.25 (95% CI: 1.12–1.41) for stroke mortality and 1.22 (95% CI: 1.10–1.35) for CHD mortality (Figs. 3.9 and 3.10).

3.5.4 Cold Spell Impact on Cardiovascular Morbidity

To date, only Wang and Ma have reported the association between cold spell and cardiovascular morbidity in China [37, 39]. However, only statistically significant effect of cold spell on CVD morbidity was observed in the study of Ma et al. [39], with RR of 1.32 (95% CI: 1.28–1.37).

3.6 Impact of Extreme Temperature Events on Respiratory Mortality/Morbidity

Respiratory diseases cause a substantial healthcare burden around the world. These diseases are another leading cause of deaths among people after exposure to the extreme temperature. Exposure to extreme temperature may cause pathophysiological responses of the respiratory epithelium at a tissue level, such as bronchospasms and inflammatory changes [59, 60]. As shown in Figs. 3.11, 3.12, 3.13, 3.14 and 3.15, there is a summary of studies of extreme temperature events and respiratory diseases in China.

3.6.1 Heat Wave Impact on Respiratory Mortality

Among the included studies on the association between heat wave and respiratory mortality, the highest estimate was found in the study of Luan et al. [26] in Beijing [26], with RR of 1.40 (95% CI: 1.19–1.64), while the lowest RR (1.01, 95% CI: 0.93–1.11) was observed in the study of Han et al. [19] in Jinan [19]. The random-effect meta-analysis was used to combine the effect of heat wave on respiratory mortality among seven included studies. The pooled RR was 1.17 (95% CI: 1.06–1.29) (Fig. 3.11). In comparison to the total respiratory mortality, the effect of heat wave was higher among deaths from chronic obstructive pulmonary disease (COPD), with pooled RR of 1.25 (95% CI: 1.05–1.49) (Fig. 3.12). In addition, Luan and Huang have evaluated the effect of heat

Study	log[Risk Ratio]	SE	Weight	Risk Ratio Random, 95%CI
Huang et al. 2010	0.207	0.0955	12%	1.22 [1.02,1.48]
Yang et al. 2013	0.27	0.1277	8.9%	1.30 [1.01,1.68]
Lin et al. 2013	0.1222	0.0727	14.8%	1.12 [0.97,1.30]
Ma et al. 2015	0.0488	0.0198	20.9%	1.05 [1.01,1.09]
Luan et al. 2015	0.3365	0.0829	13.5%	1.40 [1.19,1.64]
Chen et al. 2015	0.2776	0.0977	11.8%	1.31 [1.08,1.59]
Han et al. 2017	0.0198	0.0471	18.1%	1.01 [0.93,1.11]
Total(95%CI)			100%	**1.17 [1.06,1.29]**

Heterogeneity: Tau2=0.01; P<0.0001; I2=77%

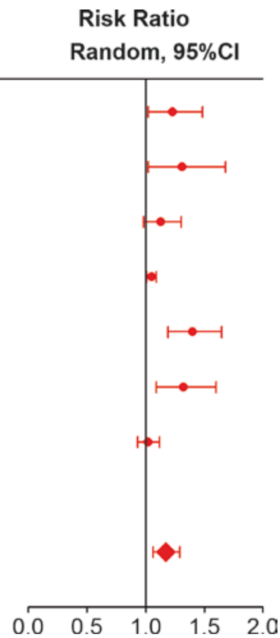


Fig. 3.11 Summary of studies of heat wave and respiratory mortality

Study	log[Risk Ratio]	SE	Weight	Risk Ratio Random, 95%CI
Huang et al. 2010	0.174	0.1043	25%	1.19 [0.97,1.45]
Chen et al. 2015	0.392	0.1287	21.4%	1.47 [1.14,1.90]
Luan et al. 2015	0.3853	0.1253	21.8%	1.47 [1.14,1.87]
Han et al. 2017	0.0392	0.0626	31.8%	1.03 [0.91,1.17]
Total(95%CI)			100%	**1.25 [1.05,1.49]**

Heterogeneity: Tau2=0.02; P<0.0001; I2=69%

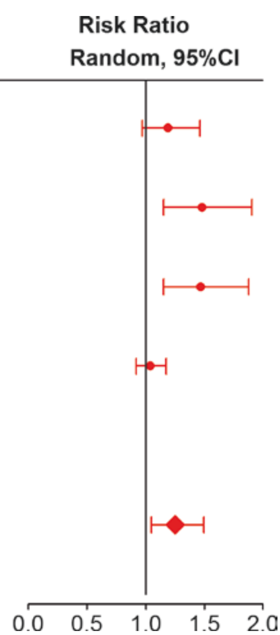


Fig. 3.12 Summary of studies of heat wave and COPD mortality

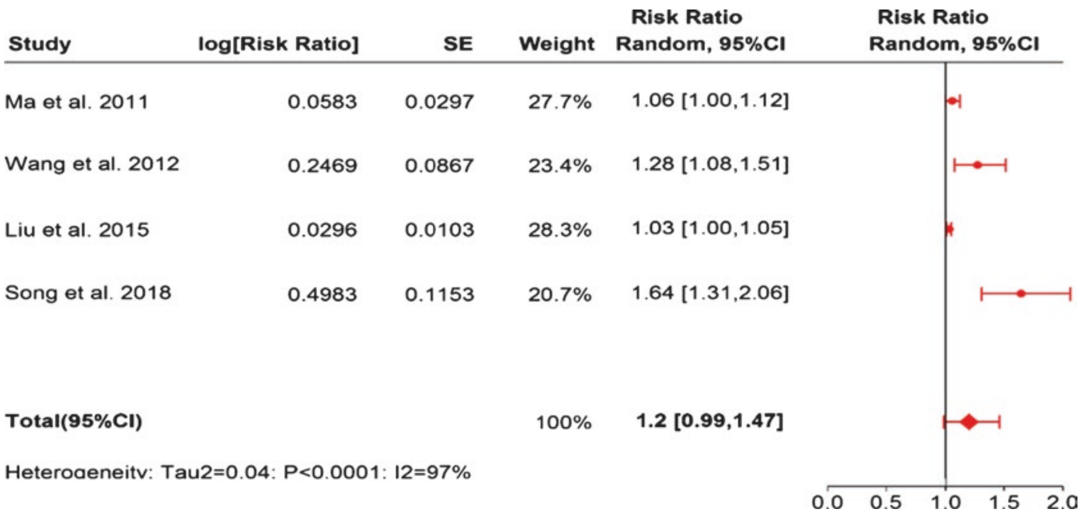


Fig. 3.13 Summary of studies of heat wave and respiratory morbidity

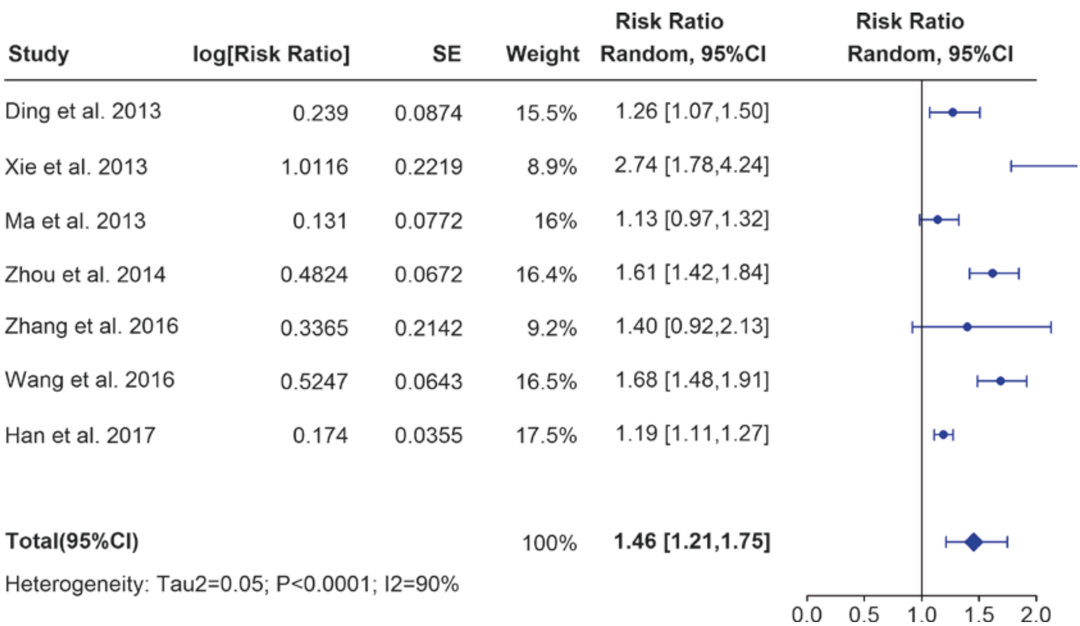


Fig. 3.14 Summary of studies of cold spell and respiratory mortality

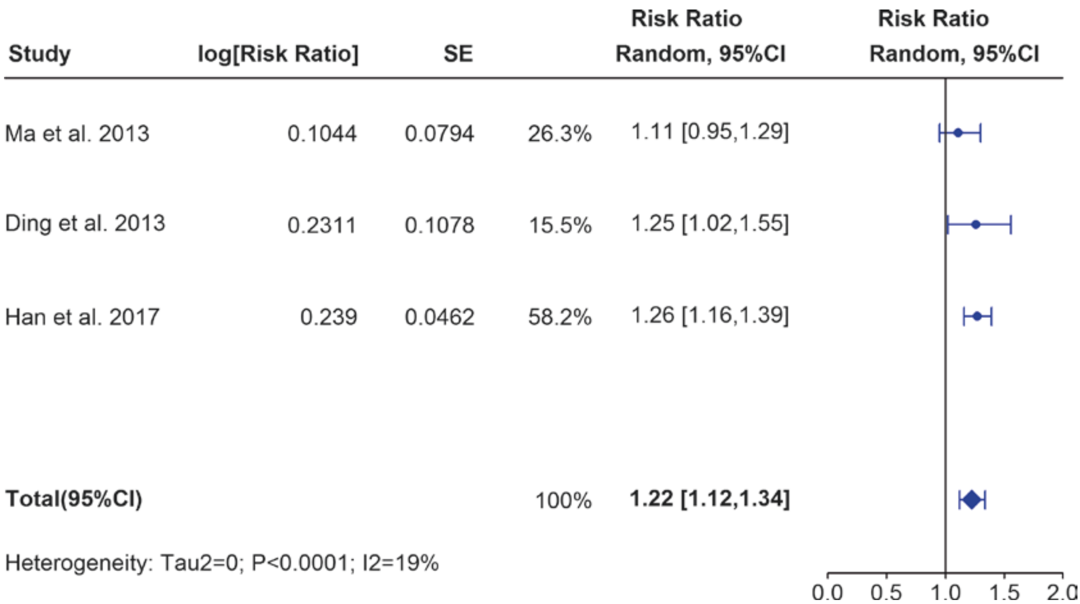


Fig. 3.15 Summary of studies of cold spell and COPD mortality

wave on respiratory infection mortality, but no significant effects were observed [26, 29].

3.6.2 Heat Wave Impact on Respiratory Morbidity

The elevated respiratory morbidity rate was significantly associated with heat wave. Among the four included studies on the association between heat wave and respiratory morbidity [37, 39, 42, 43], the highest effect estimate was found in the study of Song et al. [43] in Beijing examining the impact of heat wave on the emergency department visits, with RR of 1.64 (95% CI: 1.21–2.06), while the lowest estimate was 1.03 (1.00–1.05) in the study of Liu et al. [42] in two cities of Guangdong province [42]. The pooled RR of heat wave on respiratory morbidity was 1.20 (95% CI: 0.99–1.47) in the four included studies (Fig. 3.13).

3.6.3 Cold Spell Impact on Respiratory Mortality

Among the included studies on the association between cold spell and respiratory mortality, the highest estimate was found in the study of Xie et al. [24] in three cities of Guangdong province, with RR of 2.74 (95% CI: 1.78–4.24), while the lowest RR (1.19, 95% CI: 1.11–1.27) was in the study of Han et al. in Jinan [19]. The random-effect meta-analysis was applied to combine the effects of cold spell on respiratory mortality among seven included studies. The pooled RRs of cold spell on respiratory mortality and COPD mortality were 1.46 (95% CI: 1.21–1.75) and 1.22 (95% CI: 1.12–1.34), respectively (Figs. 3.14 and 3.15).

3.6.4 Cold Spell Impact on Respiratory Morbidity

To date, limited data are available on the association between cold spell and morbidity from respiratory disease. In Shanghai, Ma et al. [39] found elevated hospital admissions of respiratory disease associated with cold spell, with the RR of 1.32 (95% CI: 1.24–1.40); in Beijing and Taiwan, Song and Wang found a significant association between cold spell and respiratory emergency department visits, with RRs ranging from 1.28 (95% CI: 1.08–1.52) to 1.89 (95% CI:

1.30–2.73) [37, 43]; Wang and colleagues reported that cold spell lasting more than 8 days did not significantly increase the risk in outpatient visits for asthma and chronic airway obstruction but had a significant and negative correlation with outpatient visits for respiratory diseases [45]. Furthermore, Guo et al. [18] found a significantly elevated risk for children's asthma caused by cold spell across different days of lag during 2007–2009, with highest RR of 1.30 (95% CI: 1.13–1.48). And the 2008 cold spell lasting for 20 days caused higher risk (1.75, 95% CI: 1.48–2.00), compared to the morbidity rates among the same periods in 2007 and 2009.

3.7 Others

In addition to the common cardiovascular diseases and respiratory diseases, the heat-related illnesses are particularly affected by heat wave. The study of Bai et al. [11] in a coastal city of China found that heat-related illnesses increased dramatically during the heat wave in the summer of 2011–2013 [11]. A total of 679 excess illnesses were associated with the heat wave in 2013 in this city, in comparison to the average values for the same period during 2011–2012. The largest effect estimate of heat wave on the severe heat-related diseases was detected in 2013, with tenfold increased RR (10.69, 95% CI: 2.10–54.4). Individuals with more severe forms of heat-related illness were particularly influenced by the heat wave. The elevated heat stroke by the heat wave was also confirmed in the study of Li et al. [40] in Chongqing, and the number of daily cases increased by the duration of heat wave, peaking at the 11th day of the heat wave.

3.7.1 Individual Modifiers

Among the included studies, a few have assessed the individual effect modifiers of the association between heat wave/cold spell and health [12, 15, 22, 23, 25, 29, 34]. This evidence could provide important information to identify the vulnerable subpopulation and help to develop tailored intervention measures to protect the public health from climate change and extreme temperature events [61]. Age, gender, and education level are viewed as important effect modifiers and have been extensively examined in these prior studies.

3.7.1.1 Age

The elderly were consistently identified to be at greater risk to cold spell and heat wave, compared to the youth. Among the included studies, the effects of both cold spell and heat wave were not statistically significant among the young people, while most effects were statistically significant among the elderly. The pooled RRs of heat wave on mortality were 1.09 (95% CI: 0.99–1.21) and 1.20 (95% CI: 1.07–1.34) for people less than 65 years and over 65 years, and the corresponding RRs by cold spell were 1.14 (95% CI: 1.10–1.18) and 1.31 (95% CI: 1.14–1.50) (Figs. 3.16, 3.17, 3.18 and 3.19). And multiple studies found that the effects of extreme temperature events have greater effects on people aged 75 years and older than those aged between 65 and 74 years [25, 26, 28, 33]. Human body functions on homeostasis and thermoregulation are attenuated with age, which may contribute to higher deleterious effects of heat wave and cold spell on the elderly. Moreover, the older individuals always suffer from higher prevalence of chronic diseases, such as cardiovascular disease, respiratory disease, and diabetes disease, and are more likely to have mobility limitation, which may further increase their vulnerabilities to the extreme temperature events [61, 62]. Thus, the elderly living alone are particularly vulnerable to the extreme weather and should be paid more attention by the communities and families. However, unlike most previous studies, Bai and colleagues found that not only the elderly but the youth are at risk of heat-related illnesses during extreme heat exposure, which may be because young adults are exposed to outdoor heat more frequently and influenced by the work-related mental health conditions [11].

Study	log[Risk Ratio]	SE	Weight	Risk Ratio Random, 95%CI
Huang et al. 2010	0.1663	0.0862	6.2%	1.09 [0.78,1.51]
Lan et al. 2012	0.1263	0.4383	8.7%	1.55 [1.21,1.98]
Yang et al. 2013	0.1072	-0.0513	10.2%	0.94 [0.76,1.17]
Chen et al. 2015	0.0724	0.0488	13.7%	1.05 [0.91,1.21]
Luan et al. 2015	0.0538	0.0953	15.6%	1.09 [0.98,1.22]
Ma et al. 2015	0.0149	0.0392	18.7%	1.03 [1.01,1.07]
Han et al. 2017	0.0215	-0.0305	18.4%	0.96 [0.92,1.01]
Zhang et al. 2017	0.1277	0.3365	8.6%	1.40 [1.09,1.79]
Total(95%CI)			100%	**1.09 [0.99,1.21]**

Heterogeneity: Tau2=0.01; P=0.0004; I2=89%

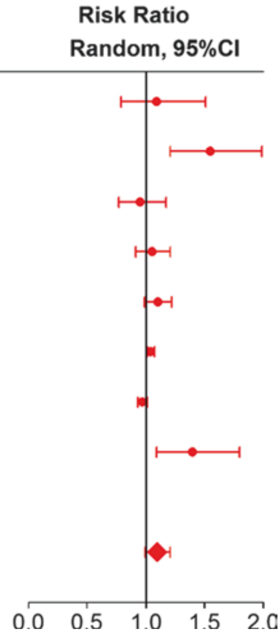


Fig. 3.16 Summary of studies of heat wave and all-cause mortality in the youth (0–64 years)

Study	log[Risk Ratio]	SE	Weight	Risk Ratio Random, 95%CI
Huang et al. 2010	0.0326	0.1222	13.2%	1.12 [1.06,1.20]
Lin et al. 2011	0.0249	0.0488	13.5%	1.05 [0.99,1.10]
Lan et al. 2012	0.0915	0.2927	10.3%	1.34 [1.12,1.60]
Yang et al. 2013	0.1685	0.2469	6.4%	1.28 [0.92,1.78]
Luan et al. 2015	0.093	0.2776	10.2%	1.31 [1.10,1.58]
Ma et al. 2015	0.0148	0.0488	13.7%	1.05 [1.01,1.08]
Chen et al. 2015	0.133	0.1989	8%	1.22 [0.94,1.58]
Han et al. 2017	0.013	0.0296	13.7%	1.03 [1.00,1.05]
Zhang et al. 2017	0.0772	0.5365	11.1%	1.71 [1.46,1.98]
Total(95%CI)			100%	**1.2 [1.07,1.34]**

Heterogeneity: Tau2=0.02; P<0.0001; I2=97%

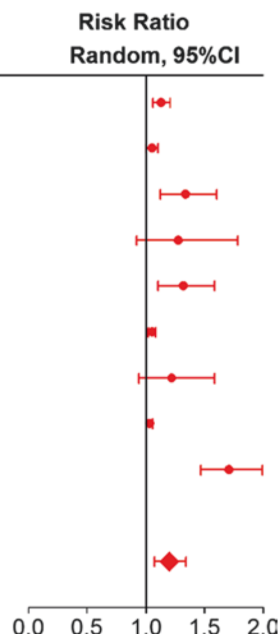


Fig. 3.17 Summary of studies of heat wave and all-cause mortality in the elderly (≥65 years)

3.7.1.2 Gender

Gender is also an important effect modifier of the relationship between extreme temperature events and health. Generally, females suffered from greater effect of heat wave on mortality than males, and the pooled RRs were 1.29 (95% CI: 1.12–1.47) and 1.14 (95% CI: 1.06–1.22) for females and males, respectively (Figs. 3.20 and 3.21), which was also confirmed in studies using

Study	log[Risk Ratio]	SE	Weight	Risk Ratio Random, 95%CI
Ding et al. 2013	0.0857	0.0953	4.3%	1.09 [0.92,1.30]
Xie et al. 2013	0.2198	0.3365	0.7%	1.40 [0.91,2.15]
Ma et al. 2013	0.0738	0.0392	5.8%	1.03 [0.89,1.20]
Zhou et al. 2014	0.0452	0.1655	15.4%	1.17 [1.07,1.28]
Wang et al. 2016	0.0513	0.1398	12%	1.15 [1.04,1.27]
Zhang et al. 2016	0.1372	0.207	1.7%	1.22 [0.93,1.60]
Han et al. 2017	0.0229	0.131	60.2%	1.13 [1.08,1.19]
Total(95%CI)			100%	**1.14 [1.1,1.18]**

Heterogeneity: Tau2=0; P=0.7441; I2=0%

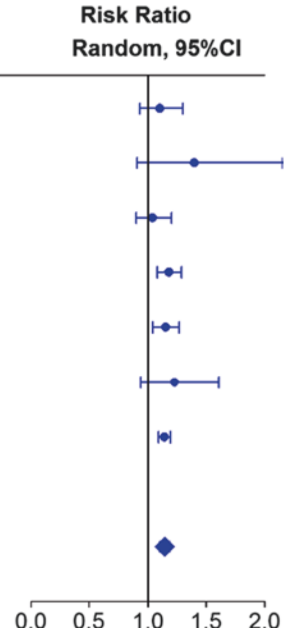


Fig. 3.18 Summary of studies of cold spell and all-cause mortality in the youth (0–64 years)

Study	log[Risk Ratio]	SE	Weight	Risk Ratio Random, 95%CI
Ding et al. 2013	0.044	0.077	15%	1.08 [0.99,1.17]
Ma et al. 2013	0.0276	0.131	15.5%	1.13 [1.07,1.20]
Xie et al. 2013	0.1457	0.5008	9.4%	1.65 [1.24,2.19]
Zhou et al. 2014	0.0278	0.4121	15.5%	1.50 [1.42,1.59]
Zhang et al. 2016	0.0792	0.5128	13.2%	1.66 [1.42,1.95]
Wang et al. 2016	0.0276	0.2852	15.5%	1.33 [1.25,1.40]
Han et al. 2017	0.0095	0.077	15.8%	1.08 [1.06,1.10]
Total(95%CI)			100%	**1.31 [1.14,1.5]**

Heterogeneity: Tau2=0.03; P<0.0001; I2=98%

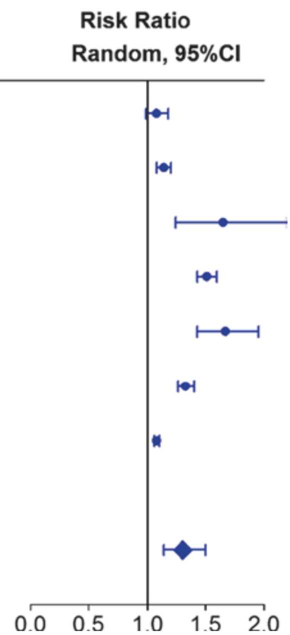


Fig. 3.19 Summary of studies of cold spell and all-cause mortality in the elderly (≥65 years)

morbidity as health outcome [11, 41–43]. However, inconsistent results on gender effects were found for the cold spell. Some studies identified higher effect of cold spell among females than males [19, 23, 33], but others reported an opposite trend [15, 24, 34]. The combined RRs of cold spell on mortality were 1.28 (95% CI: 1.14–1.43) for males and 1.26 (95% CI: 1.11–1.42) for females (Figs. 3.22 and 3.23). The discrepancy may be related to different gender-between expo-

Study	log[Risk Ratio]	SE	Weight	Risk Ratio Random, 95%CI
Huang et al. 2010	0.046	0.1484	13.2%	1.15 [1.05,1.26]
Lan et al. 2012	0.0985	0.27	7.2%	1.30 [1.07,1.58]
Yang et al. 2013	0.0715	0.0677	9.9%	1.07 [0.93,1.23]
Luan et al. 2015	0.032	0.1398	15%	1.15 [1.08,1.22]
Chen et al. 2015	0.0452	0.1655	13.3%	1.17 [1.07,1.28]
Ma et al. 2015	0.0099	0.0392	17%	1.03 [1.01,1.06]
Zhang et al. 2017	0.0923	0.3716	7.7%	1.45 [1.21,1.73]
Han et al. 2017	0.0151	0.0296	16.7%	1.03 [1.00,1.06]
Total(95%CI)			100%	**1.14 [1.06,1.22]**

Heterogeneity: Tau2=0.01; P<0.0001; I2=90%

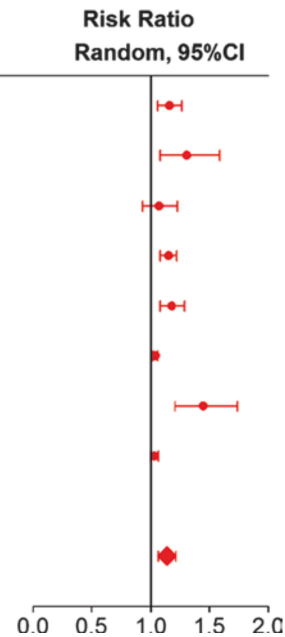


Fig. 3.20 Summary of studies of heat wave and all-cause mortality in males

Study	log[Risk Ratio]	SE	Weight	Risk Ratio Random, 95%CI
Huang et al. 2010	0.0436	0.0953	13.1%	1.09 [1.00,1.19]
Lan et al. 2012	0.1139	0.4383	10.1%	1.55 [1.23,1.93]
Yang et al. 2013	0.0792	0.3784	11.7%	1.45 [1.25,1.70]
Ma et al. 2015	0.0146	0.0583	13.8%	1.06 [1.03,1.09]
Chen et al. 2015	0.0451	0.2624	13.1%	1.30 [1.19,1.42]
Luan et al. 2015	0.0408	0.2624	13.2%	1.30 [1.20,1.40]
Zhang et al. 2017	0.0908	0.6098	11.2%	1.84 [1.54,2.19]
Han et al. 2017	0.02	0.0392	13.7%	1.03 [1,1.08]
Total(95%CI)			100%	**1.29 [1.12,1.47]**

Heterogeneity: Tau2=0.03; P<0.0001; I2=97%

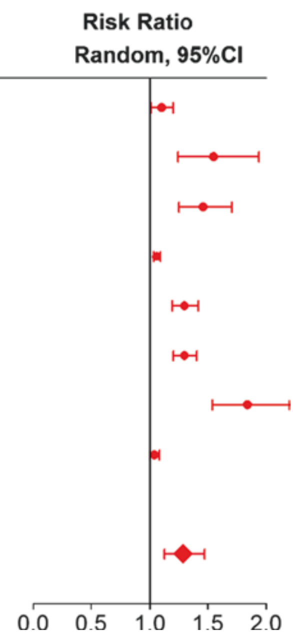


Fig. 3.21 Summary of studies of heat wave and all-cause mortality in females

Study	log[Risk Ratio]	SE	Weight	Risk Ratio Random, 95%CI
Xie et al. 2013	0.1457	0.5008	8%	1.65 [1.24,2.19]
Ding et al. 2013	0.0482	0.1044	15.4%	1.11 [1.00,1.22]
Ma et al. 2013	0.0361	0.157	16.2%	1.16 [1.09,1.25]
Zhou et al. 2014	0.0381	0.3293	16%	1.38 [1.28,1.49]
Wang et al. 2016	0.0451	0.2624	15.6%	1.30 [1.19,1.42]
Zhang et al. 2016	0.0943	0.47	11.7%	1.59 [1.32,1.92]
Han et al. 2017	0.0142	0.0862	17.1%	1.09 [1.06,1.12]
Total(95%CI)			100%	**1.28 [1.14,1.43]**

Heterogeneity: Tau2=0.02; P<0.0001; I2=92%

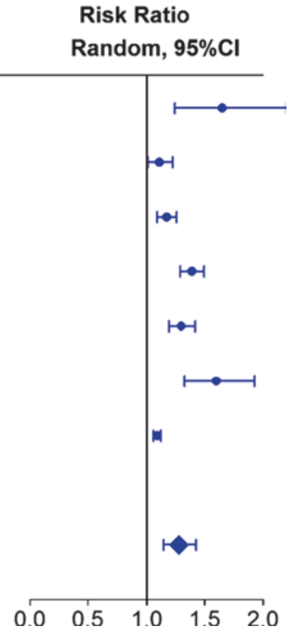


Fig. 3.22 Summary of studies of cold spell and all-cause mortality in males

Study	log[Risk Ratio]	SE	Weight	Risk Ratio Random, 95%CI
Ma et al. 2013	0.0393	0.077	16.1%	1.08 [0.99,1.16]
Ding et al. 2013	0.0565	0.0488	15.1%	1.05 [0.93,1.17]
Xie et al. 2013	0.1649	0.2927	7.8%	1.34 [0.96,1.85]
Zhou et al. 2014	0.0354	0.3988	16.3%	1.49 [1.39,1.59]
Wang et al. 2016	0.0411	0.3507	16%	1.42 [1.31,1.53]
Zhang et al. 2016	0.1013	0.4055	11.8%	1.50 [1.22,1.82]
Han et al. 2017	0.0186	0.1133	16.9%	1.11 [1.07,1.16]
Total(95%CI)			100%	**1.26 [1.11,1.42]**

Heterogeneity: Tau2=0.02; P<0.0001; I2=93%

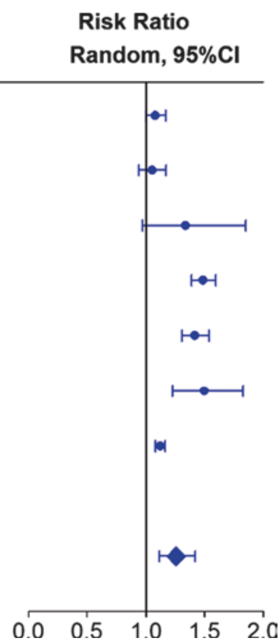


Fig. 3.23 Summary of studies of cold spell and all-cause mortality in females

sure opportunities, working characteristics, personal behaviors, and thermoregulatory functions to ambient temperature [61].

3.7.1.3 Education

Educational level could also modify the association between extreme temperature events and health. Yang and coauthors [25] identified a decreasing trend of heat wave impact on health by education and reported RRs of 1.52 (95% CI: 1.20–1.93) for the illiterate, 1.23 (95% CI: 1.05–1.45) for those with primary school, and 1.10 (95% CI: 0.91–1.32) for those with secondary or higher educational level. Chen et al. [12] also confirmed that the less-educated were at higher risk to heat wave than those with higher educational level. However, Ma et al. [22] reported higher risk for persons with a higher education level. For the cold spell, Wang et al. [23] reported that the risk of cold spell was much larger for those with lower educational level, with RRs of 1.45 (95% CI: 1.28–1.65), 1.03 (95% CI: 0.88–1.21), and 0.94 (95% CI: 0.75–1.17) for those with primary school, middle school, and college or above, respectively. Educational level was generally viewed as an important indicator of socioeconomic status. People with lower educational level always have poorer living and working conditions, limited access to health-care service, but relatively higher prevalence of health problems [25, 61]. Furthermore, the blue-collar workers were found to be at higher mortality risk from heat wave compared with their white-collar counterparts [25]. The heterogeneity in exposure level may explain this difference. Blue-collar workers are always engaged in construction, manufacturing, mining, maintenance, and other physical workers, while the white-collar workers always perform professional, managerial, or administrative work. Therefore, those blue-collar workers may be exposed to the extreme high temperature more frequently and intensively.

3.7.1.4 Place of Death

Place of death was the significant effect modifier of the association between temperature extreme events and health, particularly for the heat wave. Several studies have consistently found that impact of heat wave was more noticeable for people dying outside of hospital than those dying in the hospital [12, 22, 28, 63]. For instance, Chen et al. [12] reported that the RRs of heat wave on those dying out of hospital and in hospital were 1.29 (95% CI: 1.19–1.41) and 1.07 (95% CI: 0.93–1.22), respectively. The discrepancy caused by places of deaths may be associated with air conditioning and air filtration outside and inside the hospital. It may also reflect the socioeconomic status difference such as access to the health-care service and health insurance. For the cold spell, only Zhou and coworkers [33] examined the influence of places of death on cold spell impact and found that the highest death risk of cold spell was found at home in the rural areas, while the emergency rooms was the place with the highest death risk in urban cities. They speculated that people with severe diseases in the urban areas may be sent to an emergency department during the extreme cold weather, but in the rural regions, people with illness could not get access to the emergency services.

3.8 Community-Level Socioeconomic Modifiers

City- or community-specific socioeconomic factors can modify the health risk of extreme temperature events. To date, very few studies have assessed the effect modification of extreme temperature events by community- or city-level factors in China. The study of Ma et al. [22] presented that people in the urban cities or communities with densely population suffered higher mortality risk from heat wave than their rural counterparts, which suggests 46.2% of the total amount of the between-community residual heterogeneity. People living in the urban communities suffered 5.11% (95% CI: 1.03–9.34%) higher mortality risk by heat wave than those in rural areas. An interquartile range change in population density was associated with 2.97% (95% CI: 0.3–5.71%) increase in mortality by heat wave. However, other community characteristics such as number of air conditioners in per hundred household, the rate of unemployment, the concentration of PM_{10}, GDP, latitude, temperature, diurnal temperature range, and relative humidity did not statistically modify the association between heat wave and mortality. In contrary to most previous studies, the study in Nanjing reported the stroke mortality risk caused by heat wave is much higher in rural areas than in urban areas, with RRs of 1.89 (95% CI: 1.63–2.17) and 0.94 (95% CI: 0.76, 1.15) [13]. The authors speculated that this discrepancy may be due to the higher population vulnerability to heat exposure in rural areas, with lower quality of medical services and lower coverage of air conditioners. Also, poor air quality could enhance the health impacts of heat wave [64]. The underlying explanation is that strong sunlight during extreme heat weather could increase the production of secondary pollutants such as ultrafine particles, contributing to greater health burden.

3.9 Early Warning System for Extreme Temperature Events

Health-oriented early warning systems against extreme temperature events are effective implementation to alleviate the economic lost and health risk. The development of these systems requires close collaboration among all relevant stakeholders so that the issues of great concern can be recognized and addressed timely. According to Ebi [65], the main components of the early warning system include identification and forecasting the extreme temperature events, an effective and timely response plan, and a continuing assessment of the system and its components. In China, only a few health-based heat wave early warning systems have been developed in a limited number of major cities. Thus, we only discussed the current evidence of heat-health early system in China.

In 2000, Hong Kong introduced a Very Hot Weather Warning (VHWW) to alert the relevant government departments to implement actions and to remind the public about taking protective measures against extreme hot weather, which is based on a weather stress index and acclimatization effect. Chau and coauthors [66] examined the association between VHWW and elderly mortality, reporting that VHWW may reduce 1.23 (95% CI: 0.32–2.14) deaths from IHD and 0.97 (95% CI: 0.02–1.92) deaths from stroke for the elderly per day. In 2002, Shanghai put forward a framework of heat-health early warning system in China [67]. This system collects the 24-h and 48-h forecast data on ambient temperature, dew point temperature, wind speed, wind direction, air pressure, and cloud in 2:00, 8:00, 14:00, and 20:00, uses the spatial synoptic classification method to identify whether there will be moist tropical plus (MT+) air mass (an extremely hot and humid air mass), then predicts the excess death number at MT+ weather situation, and finally publishes the warning signal for the upcoming heat wave. There are some limitations in this system. Firstly, only age and gender were considered in this operational system, so other important vulnerable populations, such as heat-related illnesses, cardiovascular diseases, and stroke, could not be identified; secondly, only the accuracy of the predicted excess death number by heat wave can be assessed, the effectiveness of intervention measures to heat wave could not be evaluated in this system. Regarding to these disadvantages, Chinese Center for Disease Control and Prevention has established a more comprehensive heat-health early warning system in four cities with different climatic zones, including Nanjing, Chongqing, Shenzhen, and Harbin [68]. This system uses generalized additive model to predict the health risk of upcoming heat waves, after controlling for various confounding variables, such as air pollution, daily range of temperature, relative humidity, day of the week, and long-term trends. Several health risk indicators were also included, such as heat-related illnesses, cardiovascular disease, stroke, and respiratory disease. The evaluation of correlation of early warning signals and health risk in Nanjing and Harbin showed that this early warning signal responses timely with good operation and efficiently forecasts the children's respiratory system diseases and heat stroke. However, the sensitivity and specificity of this system are relatively low, with corresponding estimates of 72.7% and 65.1% [8, 69]. Thus, the functions and parameters of this system still need to be improved in the future. Given that these prior findings only analyzed the correlation instead of causation, more in-depth investigation is required to evaluate the causation effect of early warning of extreme temperature events on health in the future.

3.10 Summary

In this chapter, we summarized the health effects of heat wave and cold spell on health in China. The findings may provide scientific evidence for the further development and implementation of heat and cold warning system in China. The summary information of human risk due to these adverse temperature events may provide a valuable knowledge for the policymaker to develop the community-based intervention measures to protect public health from the extreme temperature events.

Over the past decades, there are mounting numbers of studies examining the health risk of heat wave and cold spell in China. However, most studies focused on the death risk associated with these temperature events. And the majority of the studies exploring the impact of temperature extreme on morbidity were mainly from one single city. Therefore, more well-designed multicity studies are warranted for systematic assessment of morbidity risk attributable to temperature extremes in China. Furthermore, since only very limited number of cities have implemented the health-oriented heat wave early warning system, the health-oriented early warning system, including not only heat wave but also cold spell, is encouraged to be introduced to other regions in China. And the cost-effective evaluation of these early warning systems is also needed. Finally, in the context of climate change, the projection of future heat wave and cold spell impact on health in China is also required, which can help to allocate the public health resources to prepare for these future challenges.

Acknowledgments This study was supported by the Guangdong Nature Science Foundation (no. 2018A030310655), the National Natural Science Foundation of China (91544215, 41373116), and the Fundamental Research Funds for the Central Universities (no. 21618323).

References

1. IPCC. Summary for policymakers. In: Stocker TF, Qin D, Plattner G-K, Tignor M, Allen SK, Boschung J, Nauels A, Xia Y, Bex V, Midgley PM, editors. Climate change 2013: the physical science basis contribution of working group I to the fifth assessment report of the Intergovernmental Panel on Climate Change. Cambridge, New York: Cambridge University Press; 2013.
2. Le Tertre A, Lefranc A, Eilstein D, Declercq C, Medina S, Blanchard M, Chardon B, Fabre P, Filleul L, Jusot JF, Pascal L, Prouvost H, Cassadou S, Ledrans M. Impact of the 2003 heatwave on all-cause mortality in 9 French cities. Epidemiology. 2006;17(1):75–9.
3. Knowlton K, Rotkin-Ellman M, King G, Margolis HG, Smith D, Solomon G, Trent R, English P. The 2006 California heat wave: impacts on hospitalizations and emergency department visits. Environ Health Perspect. 2009;117(1):61–7.
4. Kysely J, Pokorna L, Kyncl J, Kriz B. Excess cardiovascular mortality associated with cold spells in the Czech Republic. BMC Public Health. 2009;9(1):19.
5. Revich B, Shaposhnikov D. Temperature-induced excess mortality in Moscow, Russia. Int J Biometeorol. 2008;52(5):367–74.
6. Qin D, Zhang J, Shan C, Song L. China national assessment report on risk management and adaptation of climate extremes and disasters. Beijing: Science Press; 2015.
7. Dian-Xiu Y, Ji-Fu Y, Zheng-Hong C, You-Fei Z, Rong-Jun W. Spatial and temporal variations of heat waves in China from 1961 to 2010. Adv Clim Chang Res. 2014;5(2):66–73.
8. Lan L, Lin L, Yang C, Liang W. Assessment on heat wave and health risks early warning system in Harbin. Chin J Public Health Manage. 2016;4:441–3.
9. Zhou B, Gu L, Ding Y, Shao L, Wu Z, Yang X, Li C, Li Z, Wang X, Cao Y. The great 2008 Chinese ice storm: its socioeconomic–ecological impact and sustainability lessons learned. Bull Am Meteorol Soc. 2011;92(1):47–60.
10. Xia Y, Li Y, Guan D, Tinoco DM, Xia J, Yan Z, Yang J, Liu Q, Huo H. Assessment of the economic impacts of heat waves: a case study of Nanjing, China. J Clean Prod. 2018;171:811–9.
11. Bai L, Ding G, Gu S, Bi P, Su B, Qin D, Xu G, Liu Q. The effects of summer temperature and heat waves on heat-related illness in a coastal city of China, 2011-2013. Environ Res. 2014;132:212–9.

12. Chen K, Bi J, Chen J, Chen X, Huang L, Zhou L. Influence of heat wave definitions to the added effect of heat waves on daily mortality in Nanjing, China. Sci Total Environ. 2015;506-507:18–25.
13. Chen K, Huang L, Zhou L, Ma ZW, Bi J, Li TT. Spatial analysis of the effect of the 2010 heat wave on stroke mortality in Nanjing, China. Sci Rep. 2015;5:10816.
14. Cui L, Zhou J, Geng X, Zhang J. Epidemiological character and risk analysis of heat stroke cases during 2011-2014 in Ji'nan city. J Enivron Health. 2015;9:809–12.
15. Ding Y, Yang J, Ou C, Liu H, Lin G, Liu L. Impact of cold wave on mortality in Guangzhou. J Environ Health. 2013;30(11):981–3.
16. Du Z, Mo Y, Li T. Heat wave-related excess mortality assessment in Shanghai, in summer 2013. J Enivron Health. 2014;31(9):757–60.
17. Gao JH, Sun YZ, Liu QY, Zhou MG, Lu YG, Li LP. Impact of extreme high temperature on mortality and regional level definition of heat wave: a multi-city study in China. Sci Total Environ. 2015;505:535–44.
18. Guo Y, Jiang F, Peng L, Zhang J, Geng F, Xu J, Zhen C, Shen X, Tong S. The association between cold spells and pediatric outpatient visits for asthma in Shanghai, China. PLoS One. 2012;7(7):e42232.
19. Han J, Liu S, Zhang J, Zhou L, Fang Q, Zhang J, Zhang Y. The impact of temperature extremes on mortality: a time-series study in Jinan, China. BMJ Open. 2017;7(4):e014741.
20. Lin YK, Chang CK, Wang YC, Ho TJ. Acute and prolonged adverse effects of temperature on mortality from cardiovascular diseases. PLoS One. 2013;8(12).
21. Lin Y-K, Ho T-J, Wang Y-C. Mortality risk associated with temperature and prolonged temperature extremes in elderly populations in Taiwan. Environ Res. 2011;111(8):1156–63.
22. Ma W, Zeng W, Zhou M, Wang L, Rutherford S, Lin H, Liu T, Zhang Y, Xiao J, Zhang Y, Wang X, Gu X, Chu C. The short-term effect of heat waves on mortality and its modifiers in China: an analysis from 66 communities. Environ Int. 2015;75:103–9.
23. Wang L, Liu T, Hu M, Zeng W, Zhang Y, Rutherford S, Lin H, Xiao J, Yin P, Liu J, Chu C, Tong S, Ma W, Zhou M. The impact of cold spells on mortality and effect modification by cold spell characteristics. Sci Rep. 2016;6:38380.
24. Xie H, Yao Z, Zhang Y, Xu Y, Xu X, Liu T, Lin H, Lao X, Rutherford S, Chu C, Huang C, Baum S, Ma W. Short-term effects of the 2008 cold spell on mortality in three subtropical cities in Guangdong Province, China. Environ Health Perspect. 2013;121(2):210–6.
25. Yang J, Liu Hua Z, Chun QO, Lin Guo Z, Ding Y, Zhou Q, Shen Ji C, Chen Ping Y. Impact of heat wave in 2005 on mortality in Guangzhou, China. Biomed Environ Sci. 2013;26(8):647–54.
26. Luan G, Li T, Yin P, Zhou M. Heat wave impact on mortality in Beijing in 2010. J Environ Hyg. 2015;(06):525–9.
27. Zhang Y, Feng R, Wu R, Zhong P, Tan X, Wu K, Ma L. Global climate change: impact of heat waves under different definitions on daily mortality in Wuhan, China. Glob Health Res Policy. 2017;2:10.
28. Lan L, Cui G, Yang C, Wang J, Sui C, Xu G, Zhou D, Cheng Y, Guo Y, Li T. Increased mortality during the 2010 heat wave in Harbin, China. Ecohealth. 2012;9(3):310–4.
29. Huang W, Kan H, Kovats S. The impact of the 2003 heat wave on mortality in Shanghai, China. Sci Total Environ. 2010;408(11):2418–20.
30. Tian Z, Li S, Zhang J, Guo Y. The characteristic of heat wave effects on coronary heart disease mortality in Beijing, China: a time series study. PLoS One. 2013;8(9):e77321.
31. Wang C, Chen R, Kuang X, Duan X, Kan H. Temperature and daily mortality in Suzhou, China: a time series analysis. Sci Total Environ. 2014;466-467:985–90.
32. Ma W, Yang C, Chu C, Li T, Tan J, Kan H. The impact of the 2008 cold spell on mortality in Shanghai, China. Int J Biometeorol. 2013;57(1):179–84.
33. Zhou MG, Wang LJ, Liu T, Zhang YH, Lin HL, Luo Y, Xiao JP, Zeng WL, Zhang YW, Wang XF, Gu X, Rutherford S, Chu C, Ma WJ. Health impact of the 2008 cold spell on mortality in subtropical China: the climate and health impact national assessment study (CHINAs). Environ Health. 2014;13:60.
34. Zhang Y, Zhong P, Wu R, Ye B, Tian X, Zhu C, Ma L. Acute impact of cold spells on mortality during 2001-2011 in Jiang'an district of Wuhan, China. Chin J Prev Med. 2016;(7):634–9.
35. Zhong K, Liu L, Zhang J. Impact of cold wave on mortality of Cerebra-cardiovascular diseases in Beijing: a case-crossover study. J Enivron Health. 2010;(02):100–5.
36. Liu Y, Du Z, Wang Y, Zhang W, Fei T, Li T. Impacts of heat waves on emergency department visits in Beijing, 2010. South China J Prev Med. 2014;(04):322–6.
37. Wang Y-C, Lin Y-K, Chuang C-Y, Li M-H, Chou C-H, Liao C-H, Sung F-C. Associating emergency room visits with first and prolonged extreme temperature event in Taiwan: a population-based cohort study. Sci Total Environ. 2012;416:97–104.
38. Sun X, Sun Q, Yang M, Zhou X, Li X, Yu A, Geng F, Guo Y. Effects of temperature and heat waves on emergency department visits and emergency ambulance dispatches in Pudong new area, China: a time series analysis. Environ Health. 2014;13:76.
39. Ma W, Xu X, Peng L, Kan H. Impact of extreme temperature on hospital admission in Shanghai, China. Sci Total Environ. 2011;409(19):3634–7.
40. Li Y, Li C, Luo S, He J, Cheng Y, Jin Y. Impacts of extremely high temperature and heatwave on heatstroke in Chongqing, China. Environ Sci Pollut Res Int. 2017;24(9):8534–40.
41. Zheng S, Wang M, Shang K, He S, Yi L, Li T, Wang S. A case-crossover analysis of heat wave and hospital emergency department visits for cardiovascular diseases in 3 hospitals in Beijing. J Hyg Res. 2016;(02):246–51.

42. Liu Y, Hu M, Zeng W, Yang Y, Lin H, Liu T, Xiao J, Li X, Ma W, Ouyang Y. Short-term effect of heat wave on daily hospital admission in Guangzhou and Xingning. South China J Prev Med. 2015;(06):512–6.
43. Song X, Wang S, Li T, Tian J, Ding G, Wang J, Wang J, Shang K. The impact of heat waves and cold spells on respiratory emergency department visits in Beijing, China. Sci Total Environ. 2018;615:1499–505.
44. Cheng J, Xu Z, Zhao D, Xie M, Zhang H, Wang S, Su H. The burden of extreme heat and heatwave on emergency ambulance dispatches: a time-series study in Huainan, China. Sci Total Environ. 2016;571:27–33.
45. Wang YC, Lin YK. Temperature effects on outpatient visits of respiratory diseases, asthma, and chronic airway obstruction in Taiwan. Int J Biometeorol. 2015;59(7):815–25.
46. China W. What is cold spell? The Public Weather Service Center of China Meteorological Administration; 2009.
47. China W. Hot temperature and heat wave: The Public Weather Service Center of China Meteorological Administration; 2014.
48. Zeng W, Lao X, Rutherford S, Xu Y, Xu X, Lin H, Liu T, Luo Y, Xiao J, Hu M, Chu C, Ma W. The effect of heat waves on mortality and effect modifiers in four communities of Guangdong Province, China. Sci Total Environ. 2014;482–483:214–21.
49. Anderson GB, Bell ML. Heat waves in the United States: mortality risk during heat waves and effect modification by heat wave characteristics in 43 U.S. communities. Environ Health Perspect. 2011;119:210–8.
50. Barnett AG, Hajat S, Gasparrini A, Rocklov J. Cold and heat waves in the United States. Environ Res. 2012;112:218–24.
51. Huedo-Medina TB, Sanchez-Meca J, Marin-Martinez F, Botella J. Assessing heterogeneity in meta-analysis: Q statistic or I2 index? Psychol Methods. 2006;11(2):193–206.
52. Guo Y, Gasparrini A, Armstrong BG, Tawatsupa B, Tobias A, Lavigne E, Zanotti Stagliorio S, Coelho X, Pan H, Kim M, Hashizume Y, Honda Y-LL, Guo C-FW, Zanobetti A, Schwartz JD, Bell ML, Scortichini M, Michelozzi P, Punnasiri K, Li S, Tian L, Osorio Garcia SD, Seposo X, Overcenco A, Zeka A, Goodman P, Tran Ngoc D, Do Van D, Mayvaneh F, Nascimento Saldiva PH, Williams G, Tong S. Heat wave and mortality: a multicountry, multicommunity study. Environ Health Perspect. 2017;125(8):087006.
53. WHO. World health statistics 2018: monitoring health for the SDGs sustainable development goals. Geneva: World Health Organization; 2018.
54. Yang J, Yin P, Zhou MG, Ou CQ, Guo YM, Gasparrini A, Liu YN, Yue YJ, Gu SH, Sang SW, Luan GJ, Sun QH, Liu QY. Cardiovascular mortality risk attributable to ambient temperature in China. Heart. 2015;101(24):1966–72.
55. Yang J, Yin P, Zhou MG, Ou CQ, Li MM, Li J, Liu XB, Gao JH, Liu YN, Qin RN, Xu L, Huang CR, Liu QY. The burden of stroke mortality attributable to cold and hot ambient temperatures: epidemiological evidence from China. Environ Int. 2016;92-93:232–8.
56. Keatinge WR, Coleshaw SR, Cotter F, Mattock M, Murphy M, Chelliah R. Increases in platelet and red cell counts, blood viscosity, and arterial pressure during mild surface cooling: factors in mortality from coronary and cerebral thrombosis in winter. Br Med J (Clin Res Ed). 1984;289(6456):1405–8.
57. Keatinge WR, Coleshaw SRK, Easton JC, Cotter F, Mattock MB, Chelliah R. Increased platelet and red cell counts, blood viscosity, and plasma cholesterol levels during heat stress, and mortality from coronary and cerebral thrombosis. Am J Med. 1986;81(5):795–800.
58. Zhang X, Zhou M, Huang J, Lin H, Liu Q. Impact of heat wave on non-accidental mortality of local residents in Jinan. South China J Prev Med. 2014;(04):327–32.
59. Koskela HO. Cold air-provoked respiratory symptoms: the mechanisms and management. Int J Circumpolar Health. 2007;66(2):91–100.
60. Mäkinen TM, Juvonen R, Jokelainen J, Harju TH, Peitso A, Bloigu A, Silvennoinen-Kassinen S, Leinonen M, Hassi J. Cold temperature and low humidity are associated with increased occurrence of respiratory tract infections. Respir Med. 2009;103(3):456–62.
61. Li M, Gu S, Bi P, Yang J, Liu Q. Heat waves and morbidity: current knowledge and further direction-a comprehensive literature review. Int J Environ Res Public Health. 2015;12(5):5256.
62. Ryti NRI, Guo Y, Jaakkola JJK. Global Association of cold spells and adverse health effects: a systematic review and meta-analysis. Environ Health Perspect. 2016;124(1):12–22.
63. Zhang J, Liu S, Han J, Zhou L, Liu Y, Yang L, Zhang J, Zhang Y. Impact of heat waves on nonaccidental deaths in Jinan, China, and associated risk factors. Int J Biometeorol. 2016;60(9):1367–75.
64. Yang J, Yin P, Sun J, Wang B, Zhou M, Li M, Tong S, Meng B, Guo Y, Liu Q. Heatwave and mortality in 31 major Chinese cities: definition, vulnerability and implications. Sci Total Environ. 2018;649:695–702.
65. Ebi KL, Teisberg TJ, Kalkstein LS, Robinson L, Weiher RF. Heat watch/warning systems save lives: estimated costs and benefits for Philadelphia 1995-98. Bull Am Meteorol Soc. 2003;14(8).
66. Chau PH, Chan KC, Woo J. Hot weather warning might help to reduce elderly mortality in Hong Kong. Int J Biometeorol. 2009;53(5):461–8.
67. Tan J, Kalkstein LS, Huang J, Lin S, Yin H, Shao D. An operational heat/health warning system in shanghai. Int J Biometeorol. 2004;48(3):157–62.
68. Sun Q, Ban J, Chen C, Li T. Heat waves health risk early warning system: a review of recent studies. J Enivron Health. 2015;32(11):1026–30.
69. Wang Q, Li Y, Ding Z, Zhou L, Chen X, Jin Y. Assessment on heat-wave and health risks early warning system in Nanjing. J Enivron Health. 2014;31(5):382–4.

4 Health Impacts Due to Major Climate and Weather Extremes

Wei Ma and Baofa Jiang

Abstract

China is one of the countries which suffer the most serious climate extremes and disasters in the world. Climate extremes in China feature various types of extremes with high frequency, strong seasonal and regional differences, and a wide range of effects. This chapter summarizes studies about three major climate and weather extremes' health impacts conducted in China. Rainstorm and flood disasters directly or indirectly threaten the living environment of human beings and the health of the people, such as the deterioration of the ecological environment, the loss of huge property, death and related diseases, psychological trauma, and other immediate and delayed adverse effects. Tropical cyclone has multiple effects on human being's health. In addition to death and injury caused by direct winds, heavy rains, and storm surges, it can also indirectly affect the health of the population through the destruction of shelter and health services, population migration, water pollution, and food reduction (resulting in hunger and malnutrition), resulting in an increase in mortality, disability, and incidence of infectious diseases and noncommunicable diseases. During the drought period, water sources are more likely to be contaminated by feces and pathogens, causing outbreaks of digestive tract diseases. Drought can also increase risk of noncommunicable diseases such as gynecologic diseases, esophageal cancer, renal damage, etc. With the global climate change, the frequency and intensity of extreme weather events such as heat waves, rainstorms, floods, and droughts have increased and will continue to increase. Although many literatures have studied the health effects of extreme weather events, there are still many problems to be solved.

Keywords

Climate and weather extremes · Flood · Drought · Tropical cyclone · Health impacts

W. Ma (✉) · B. Jiang
Department of Epidemiology, School of Public Health, Shandong University Climate Change and Health Center, Shandong University, Jinan, Shandong, China
e-mail: weima@sdu.edu.cn; bjiang@sdu.edu.cn

4.1 Introduction

Climate and weather extremes, or climate- and weather-related disasters, generally refer to natural disasters induced by specific climate and weather conditions or changes. Because of its vast territory, complex geographical and ecological environment, and various climatic conditions, China is one of the countries that suffer from frequent climate and weather extremes. Climate extremes in China feature various types of extremes with high frequency, strong seasonal

H. Lin et al. (eds.), *Ambient Temperature and Health in China*,
https://doi.org/10.1007/978-981-13-2583-0_4

and regional differences, and a wide range of effects (high confidence) [1, 2].

Based on the *China National Assessment Report on Risk Management and Adaptation of Climate Extremes and Disasters,* areas with a high incidence of extremely high temperature are concentrated; drought are distributed in a wide pattern; extreme precipitation events occur mostly in southern China; typhoons are concentrated seasonally; sandstorms show apparent seasonal variation; frosts and cold waves are strong in northern China while weak in southern China; and gales vary significantly depending on regions. During the past 60 years, climate extremes have changed significantly in China. The numbers of high-temperature days and rainstorm days have increased, and the frequency of extreme low-temperature events has decreased. The tendency toward aridification has strengthened in northern and southwestern China. The intensity of landing typhoons has increased, and the number of haze days has increased (high confidence). The frequency and scope of regional or group-occurring climate extremes have increased in China (high confidence) [1].

Climate extremes and disasters pose multiple threats to populations, especially for those in developing countries where the disaster relief resources are limited [3, 4]. For example, Sri Lanka, Indonesia, Pakistan, China, Haiti, and Japan have all experienced climate extremes and disasters that caused high mortality during the last decade [5].

Since the 1980s, China has gone through great changes in its population size, economic conditions, socioeconomic status, and development patterns. An increase in the extent and magnitude of areas affected by weather- or climate-related disasters has been witnessed in China, with direct economic losses increasing, while death tolls declined steadily (high confidence). The nature of the aging, high-density, and highly mobile population, along with the rapid accumulation of social wealth and poor infrastructure, resulted in an increase in the vulnerability of disaster-bearing bodies (high confidence) [1].

Using data from the Emergency Events Database (EM-DAT), Han et al. analyzed the characteristics of natural disasters and losses associated with natural disasters in China from 1985 to 2014 [6]. Over 500 natural disasters occurred in China during this period, including 235 storms, 216 floods, 59 landslides, 30 droughts, 13 extreme temperature events (ETEs), and 5 wildfires. The annual average frequencies of storms, floods, landslides, droughts, ETEs, and wildfires were: 7.8, 7.2, 2.0, 1.0, 0.4, and 0.2, respectively. Data also showed that there was an increasing trend in the occurrence of total natural disasters, particularly for floods, landslides, and storms (Fig. 4.1).

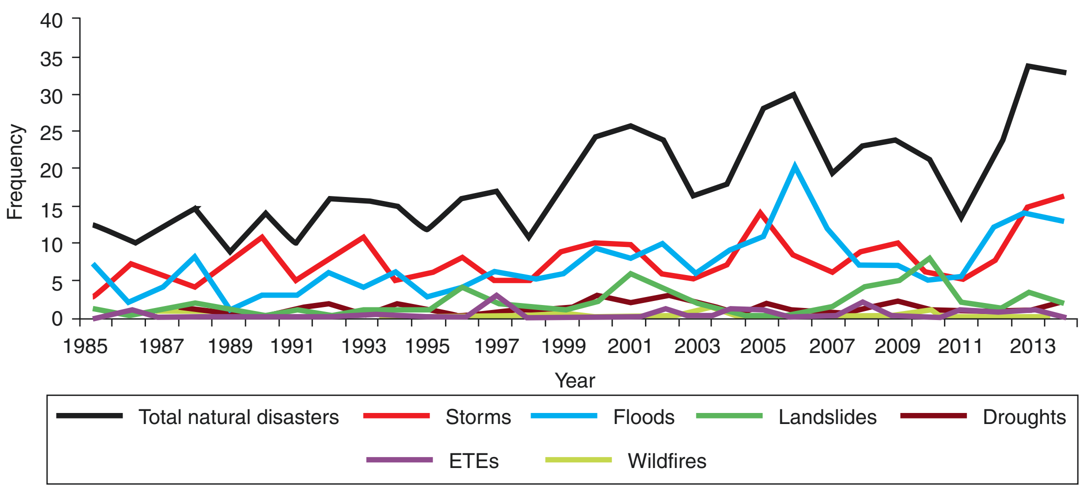


Fig. 4.1 Frequency of different natural disasters in China, 1985–2014. Reproduced with permission from Han et al. [6] (https://www.mdpi.com/1660-4601/13/11/1118/htm)

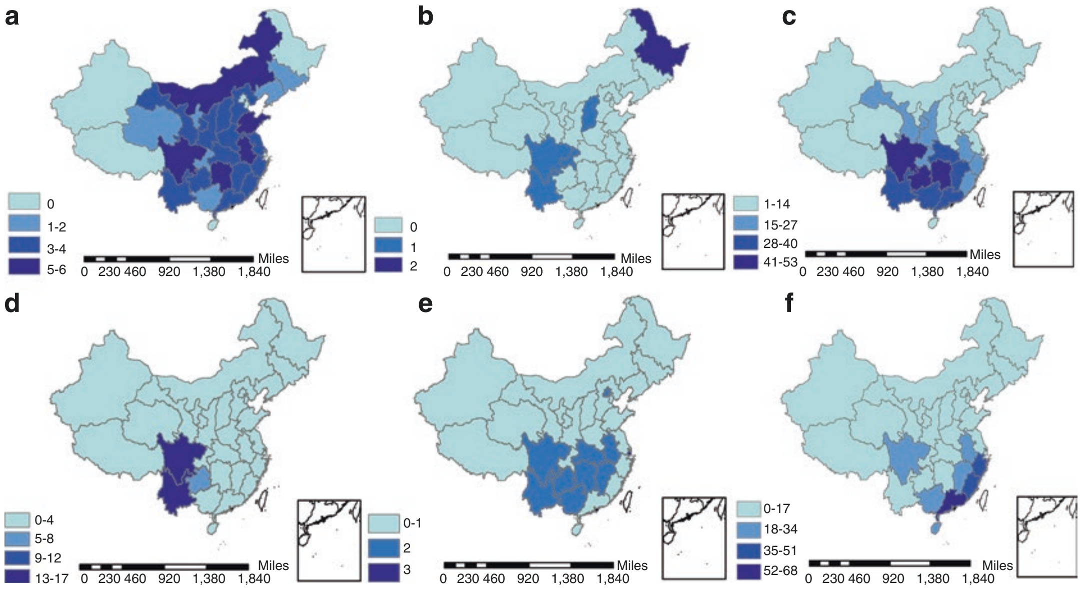


Fig. 4.2 The spatial patterns of natural disasters by types in China, 1985–2014. (**a**) Droughts; (**b**) wildfires; (**c**) floods; (**d**) landslides; (**e**) ETEs; and (**f**) storms (Publisher's note: Springer Nature remains neutral with regard to jurisdictional claims in published maps). Reproduced with permission from Han et al. [6] (https://www.mdpi.com/1660-4601/13/11/1118/htm)

According to Han's study, southern coastal provinces in China were influenced by storms most frequently, among which Guangdong ranked the first. Sichuan, Hunan, and Guangxi suffered most frequently from floods, with over 40 floods in each province. Most landslides occurred in southwestern China and droughts affected the provinces in central China such as Shandong, Anhui, and Hunan. Wildfires and ETEs were seldom reported, with most wildfires occurring in Northeast China and more ETEs occurring in South inland, Beijing and Shanghai were relatively more affected than others by ETEs. (Fig. 4.2) [6].

From 1985 to 2014, natural disasters caused more than 50,000 deaths in China, among which 61.0% were caused by floods, 22.5% by storms, 8.7% by landslides, 6.5% by droughts, 0.7% by ETEs, and 0.5% by wildfires. Deaths from total natural disasters decreased over the study period, but no significant trend was observed. However, a significant decreasing trend in annual deaths caused by storms was detected (Fig. 4.3) [6].

4.2 Health Impacts Due to Floods

Flood is the most common natural disaster in the world. For example, in 2011, 60% of the biggest natural disasters were floods globally in terms of affected population and number of deaths. Due to the expansion of population and property in flood plains, the frequency of river floods and economic losses caused by floods have been increasing. Little is known about health trends attributable to flooding, except for mortality. There are large differences in mortality in different countries [7, 8].

Rainstorm and flood disasters directly or indirectly threaten the living environment and the health of human beings, such as the deterioration of the ecological environment, the loss of huge property, death and related diseases, psychological trauma, and other immediate and delayed adverse effects. In the studies of the relationship between rainstorm and flood and human health, with the gradual deepening of human awareness of the environment and health, the research on the health hazards caused by the flood is also in depth.

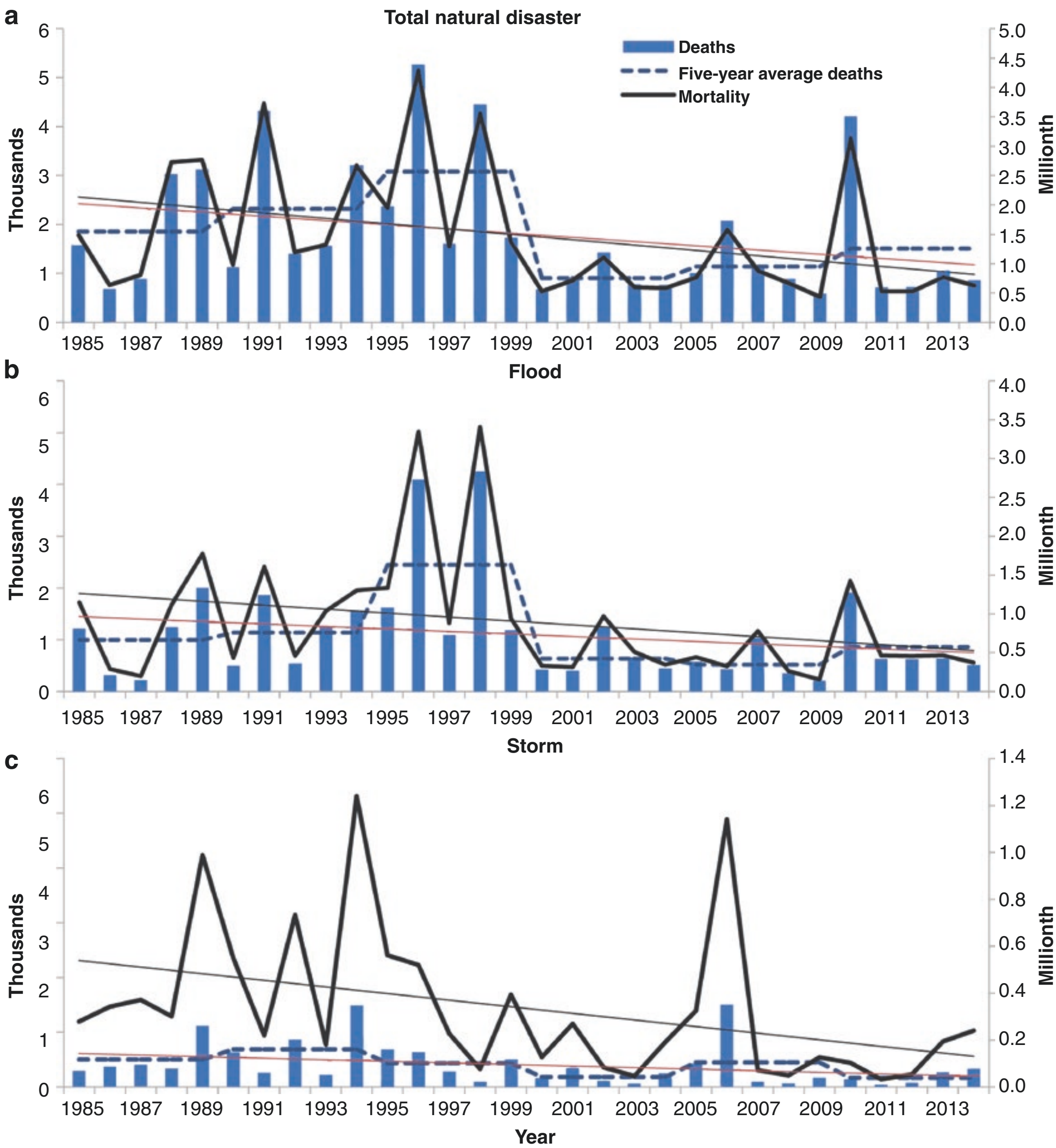


Fig. 4.3 Deaths caused by floods, storms, and total natural disasters in China, 1985–2014. Note: the line in red denotes the changing trend of deaths, while the line in black denotes that of mortality; the *y*-axes on the left correspond to deaths; the *y*-axes on the right correspond to mortality (Publisher's note: Springer Nature remains neutral with regard to jurisdictional claims in published maps). Reproduced with permission from Han et al. [6] (https://www.mdpi.com/1660-4601/13/11/1118/htm)

4.2.1 Deaths Caused by Floods

The impact of rainstorm and flood on people's health is multifaceted, so the measurement of its damage effect is extremely complicated. Death means the end of life. It is the result of multiple factors. Therefore, the change of the death rate of the residents in the disaster area can be used as a comprehensive index to evaluate the impact of flood on the health of the people.

Rainstorm and flood disasters cause heavy casualties worldwide and in China. According to the statistics of the *China Flood and Drought Disaster Bulletin (2016)*, the average annual death of flood victims in China was 4212 from 1950 to 2006 [9]. The Emergency Events Database (EM-DAT) showed that, during the period from 2000 to 2009, 5401 people died of floods in the river in China. This number was even higher (8119) in 2010. If the floods caused by other reasons are taken into consideration, the number of casualties will be more [10]. A study on the impact of flood disasters on the daily deaths of cardiovascular and cerebrovascular diseases in Hunan Province shows that floods can lead to increased risk of cardiovascular disease, especially ischemic heart disease [11]. The survey data of the catastrophic floods in Hunan Province in 1996 and 1998 in China showed that the total mortality (939/100000) in the flood area was significantly higher than that in the non-disaster area (726/100000, $P < 0.01$) and the RRs were 1.61 and 1.44, respectively [12]. In addition, studies have shown that the intensity and frequency of precipitation may increase as a result of climate change, thus the possibility of local heavy rainfall increases, and the loss of the population associated with the flood will rise [13]. The higher mortality rate in the disaster area may be related to the deterioration of the living environment and the increase of mental and material pressure.

4.2.2 Floods and Infectious Diseases

After natural disasters, people often suffer from the deterioration of ecological and residential environment, water pollution, water and food scarcity, mental and psychological trauma, resulting in the decline of resistance, and then the outbreak of infectious diseases.

In recent years, the epidemic of infectious diseases caused by rainstorm and flood has attracted more and more attention from relevant scholars and departments. The main infectious diseases are different in different stages of flood. In the early period of the flood, drinking water facilities and disinfection facilities were damaged in varying degrees, and drinking water sources and food were extremely vulnerable to pollution, so in this stage, intestinal infectious diseases often became the main type of infectious disease that threatened the health of the victims [14]. In the middle of the flood, the victims were transferred to the embankments or high places, the living conditions were poor and overcrowded, people who sleep in the open increased, and the opportunities and frequency of exposure to the infected water were greatly increased in the process of flood resistance and rescue; some respiratory diseases and natural-focus diseases would become the main threat. In the later period of the flood, the flood subsided, and the wild animals, such as rodents, oncomelania, and mosquitoes, were easily propagated because of the suitable climate conditions, resulting in the increase of the incidence of natural-focus diseases [15, 16].

4.2.2.1 Floods and Intestinal Infectious Diseases

After the storm and flood disaster, drinking water and food are very vulnerable to the pollution of the infected water, but it is often lack of decontamination and disinfection measures. These polluted water and food are consumed and eaten by the victims, thus causing the epidemic of many kinds of intestinal infectious diseases. Studies have shown that the types of infectious diseases after the flood are mainly intestinal infectious diseases, accounting for more than 70% of the total number of infectious diseases [17]. Therefore, intestinal infectious diseases are the major threat and should be the focus of disease control in the early stage after the flood [18].

Ding et al. studied the relationship between rainstorm flood and infectious diarrhea in Fuyang city in Anhui Province and showed that the risk of infectious diarrhea was increased by rainstorm and flood [19]. From 2004 to 2010, there were eight rainstorm and flood disasters in Nanning city of Guangxi, and the incidence of bacillary dysentery is positively correlated with the rainstorm and flood, as well as the duration of rainstorm and flood. After adjusting the meteorological factors and other confounding factors, the RR (relative risk) value of the influence of rainstorm and flood to the bacillary dysentery was 1.44. The incidence of bacillary dysentery will increase by 8% with every one additional day of rainstorm and flood [20]. A survey conducted in Qingdao showed that heavy rain and flooding will increase the risk of hand, foot, and mouth disease in the total population [21]. However, currently the results of the study on the incidence of intestinal infectious diseases during rainstorm and flood are different. For example, a study carried out in Bangladesh in 2010 showed that the incidence of cholera in residents of rainstorm and flood protection areas was higher than that in non-protected areas [22]. Therefore, the research on the relationship between rainstorm flood and digestive tract infectious diseases is not thorough enough. Further research and discussion should be carried out in the future.

4.2.2.2 Floods and Respiratory Infectious Diseases

During the rainstorm and flood, the immunity of population (especially children) was decreased by the sudden climate change, the heavy rain, the poor living environment, and the interruption of the planned immunization; thus the incidence of respiratory infectious diseases will rise. A study about the prevalence of infectious diseases caused by severe rainstorm and flood disasters in Hubei Province in 1998 showed that in 1999, the number of intestinal infectious diseases and natural-focus diseases continued to increase in the disaster area compared to the non-affected areas, the Province, and the whole country. The incidence of respiratory infectious diseases was also increasing significantly [23]. Studies in the Huaihe River Basin of China in 2003 showed that many patients in the disaster area had mainly tonsillitis, heatstroke, diarrhea, upper respiratory tract infection, and skin infection [24].

4.2.2.3 Floods and Zoonoses and Vector-Borne Diseases (Natural-Focus Diseases)

Natural-focal diseases refer to diseases whose infection sources are wild animals, which are often transmitted among wild animals. However, under certain conditions, they can infect human beings [25]. In the period of flood, the flood inundated the breeding ground of the rodent and some domestic animals. A large number of excreta such as urine and feces were scoured, which caused a variety of pathogens to spread with the epidemic water. The migration of the rodent and livestock with the migration of the victims would greatly expand the scope of the epidemic. In addition, post-disaster climatic conditions are suitable for breeding of mosquito and other vectors. Therefore, various natural-focus diseases are prone to occur after the disaster [18]. An investigation by Zhou et al. in Hunan Province showed that the rate of rostral *Leptospira* (4.63%) in the flood area was significantly higher than that in the non-flood area (1.35%), indicating that the flood would have a certain influence on the rate of the *Leptospira* [26]. Through the analysis of the incidence of infectious diseases after the flood in Beijing in July 21, 2012, Gao et al. also found that the natural-focus disease should be one of the types of infectious diseases which are the key prevention and control after the disaster [27].

4.2.3 Floods and Chronic Diseases

There are few studies and reports about the impact of rainstorm and flood on the chronic noncommunicable diseases of the victims in China. Through a retrospective survey of the areas suffering from catastrophic floods, Li et al. found that among the residents in the disaster area, the mental and behavioral disorders and the incidence of major chronic diseases in the nervous system, circulation system, respiratory system, digestive system, musculoskeletal and connective tissue, urogenital system and other major chronic diseases were higher than those in non-disaster areas [30]. Studies have also shown that floods and waterlogging events can lead to the risk of cardiovascular and cerebrovascular diseases or increased risk of death [11]. Attention should be paid to the monitoring and prevention of such diseases after the disaster [11, 28].

Because of the slow onset of chronic diseases and long course of disease, the health damage to the victims is often fully revealed for a period of time after the disaster. This is also the difficult point to assess the impact of the flood on chronic diseases. However, the current related research has suggested that the rainstorm and flood will affect the incidence and death of chronic diseases, so the prevention and control of chronic diseases should not be neglected during flood period.

4.2.4 Floods and Other Diseases

4.2.4.1 Floods and Dermatosis

After the rainstorm and flood disaster, it is very easy to cause skin diseases because of the humid living environment. A field survey in the Huaihe basin in 2003 showed that 1025 patients were found in the flood area. The survey showed that most of them were mosquito bites, diarrhea, heatstroke, tonsillitis, upper respiratory infection, and skin infection [24].

4.2.4.2 Floods and Mental Health

Floods and waterlogging disasters not only threaten the property and personal safety of the residents in the disaster area, but when the severity and scale of the floods are beyond the capacity of the residents, they will have different effects on their mental health.

The recent and long-term traumatic psychological reactions to flood victims are very serious and common, mainly including post-traumatic stress disorder (PTSD), depression, anxiety, fear, and so on [29, 30]. By investigating 36,481 people aged 7–96 years old in the 1995 Dongting Lake flood disaster area in 1999, Liu et al. found that 11,273 of the patients (30.9%) were PTSD patients, suggesting that PTSD is one of the psychological diseases that often occur after the flood and cannot be ignored [31]. A survey of Songhua River flood victims by the SCL-90 scale and the Self-Rating Anxiety Scale showed that the positive rate of anxiety (63.93%) and the positive rate of anxiety and depression (53.51%) were significantly higher than those of the control group (41.12% and 25.95%, respectively) [32]. The stress levels of hundreds of people affected by the flood after the flood were tested by Luo et al. The results showed that compared with the control group, the anxiety of the disaster group was obviously serious [33]. Seventeen years after the floods in the Dongting Lake in 1998, Dai et al. conducted a cross-sectional survey of 325 survivors of the disaster. The results showed that their prevalence of PTSD and anxiety was 9.5% and 9.2%, respectively [34]. In addition, studies in China also found that the incidence of PTSD in the disaster area was negatively correlated with social support and children, women, and elderly people were vulnerable groups [35, 36].

The above studies all suggest that the impact of rainstorm and flood disaster on the mental health of the residents in the affected areas cannot be ignored. It is necessary to establish psychological intervention mechanism or timely provide mental health service after disaster occurs as a necessary measure to reduce the incidence of psychological diseases.

4.3 Health Impacts Due to Tropical Cyclones

Tropical cyclone is one of the extreme weather events that seriously threaten human health. It has multiple effects on people's health, but it is mainly caused by negative effects. In addition to its direct winds, heavy rains, and storm surges, it can also indirectly affect the health of the population through the destruction of shelter and health services, population migration, water pollution, and food reduction (resulting in hunger and malnutrition), resulting in an increase in mortality, disability, and incidence of infectious diseases.

4.3.1 Injury and Death Caused by Tropical Cyclones

Typhoons cause house collapse, glass debris, collision of floating objects, and falling down at high altitude, which can cause various injuries, with high disability rate and high mortality rate. Gong et al. investigated on the 2004 "Rananim" typhoon injury situation and showed that the occurrence of injury is closely related to wind speed and rainfall. Among the direct casualties caused by typhoons, the fatality rate of hard objects was the highest, reaching 31%, and the impact injury was 19% [37]. Shen's research on typhoon Saomai in 2006 also found that injury reached its peak when the wind speed reached its maximum [38].

The death of tropical cyclones can be divided into the following categories: the direct death caused by the destruction of the houses, the outbreak of the flood, the accidental death or death of the disease in evacuation and restoration and reconstruction, the suicide, and other deaths caused by various factors after the disaster. The study of the effect of typhoon on the mortality of residents from 2008 to 2011 in Yuexiu District, Guangzhou, by Wang Xin, found that the occurrence of typhoon events will lead to the mortality of all death causes and the mortality of malignant tumor in the residents, women, infants, and the elderly and the resulting disease burden in women, children, and the elderly is higher than the rest of the population [39].

4.3.2 Tropical Cyclones and Infectious Diseases

Tropical cyclones often cause storm floods and destroy the underground drainage, water supply systems, and health infrastructure in affected areas. The deterioration of the ecological environment in the affected areas, the interruption of water supply and health services, and population aggregation and migration have created conditions for the occurrence and prevalence of infectious diseases, causing the pathogen to spread rapidly in the susceptible population. Tropical cyclones also have different effects on different types of infectious diseases, which mainly contribute to the occurrence of infectious diseases transmitted through the digestive tract and contacts.

Zheng et al. examined the impacts of tropical cyclones on notifiable infectious diseases in four coastal provinces in China from 2005 to 2011. They found that tropical cyclones have mixed effects on the risk of infectious diseases. For example, tropical cyclones are more likely to increase the risks of infectious diseases transmitted through intestinal tracts such as bacillary dysentery and paratyphoid fever. They are also more likely to increase the risks of infectious diseases transmitted through contact such as acute hemorrhagic conjunctivitis. However, tropical cyclones are more likely to decrease the risk of respiratory infectious diseases such as measles, mumps, and varicella (Table 4.1) [40].

4.3.2.1 Cholera

Tropical cyclone causes water quality deterioration and drinking water shortage in the affected areas. Marine zooplankton is a natural storage of *Vibrio cholerae*. With global warming, the water temperature in the coastal and river estuary increases, causing a large number of algae to propagate and promote the epidemic of cholera. Chen et al. found that the average corrected risk and the maximum risk (0.4433 and 0.5372) of the cholera epidemic were higher after the typhoon disaster in Wenzhou, second only to other infectious diarrhea [41].

4.3.2.2 Bacterial Dysentery

The research on the effect of tropical cyclone on bacillary dysentery in China is mainly concentrated in Guangdong and Zhejiang Provinces, which are seriously affected by tropical cyclones, but there are regional differences in the results. Kang et al. showed that during 2005–2011 in the region affected by tropical cyclone in Guangdong Province, bacillary dysentery is not a sensitive infectious disease associated with the landing of tropical cyclones in Guangdong [42]. However, in Deng's study in Zhejiang, both typhoons and tropical storms could contribute to an increase in risk of bacillary dysentery and other infectious diarrhea in Zhejiang. Tropical cyclone precipitation may also be a risk factor for these diseases when it reaches 25 mm and 50 mm, respectively [43].

4.3.2.3 Other Infectious Diarrhea

Tropical cyclones can increase the risk of other infectious diarrhea in the whole population and high-risk groups, but the lag effect may be

Table 4.1 Effects of TCs[a] on infectious diseases in China, 2005–2011 (total TCs = 675). Reproduced with permission from Zheng et al. [40] (https://www.mdpi.com/1660-4601/14/5/494/htm)

Disease	Number of TCs increasing the risk (%)	Number of TCs increasing the risk with statistical significance (%)	Number of TCs decreasing the risk (%)	Number of TCs decreasing the risk with statistical significance (%)	Direction[b] of the effect and P^c	Range of RR
Air transmitted						
Influenza	40 (5.93)	8 (1.19)	30 (4.44)	11 (1.63)	↑0.232	0.01–144.38
Influenza A (H1N1)	10 (1.48)	5 (0.74)	8 (1.19)	6 (0.89)	↑0.637	0–10.75
HFMD[d]	134 (19.85)	26 (3.85)	144 (21.33)	28 (4.15)	↓0.549	0.10–6.73
Measles	18 (2.67)	1 (0.15)	39 (5.78)	4 (0.59)	↓0.005	0.19–3.74
Mumps	84 (12.44)	4 (0.59)	136 (20.15)	21 (3.11)	↓<0.001	0.25–8.17
Rubella	0 (0)	0 (0)	3 (0.44)	2 (0.3)	↓0.083	0.13–0.43
Varicella[e]	28 (4.15)	2 (0.3)	50 (7.41)	6 (0.89)	↓0.013	0.12–14.24
Water-food transmitted						
Bacillary dysentery	69 (10.22)	4 (0.59)	36 (5.33)	1 (0.15)	↑0.001	0.47–5.63
Typhoid fever	1 (0.15)	0 (0)	0 (0)	0 (0)	↑0.317	2.38
Paratyphoid fever	4 (0.59)	0 (0)	0 (0)	0 (0)	↑0.046	1.04–6.81
Other infectious diarrhea	246 (36.44)	26 (3.85)	206 (30.52)	19 (2.81)	↑0.060	0.23–14.33
Hepatitis A	4 (0.59)	0 (0)	3 (0.44)	0 (0)	↑0.705	0.75–2.26
Contact transmitted						
Acute hemorrhagic conjunctivitis	32 (4.74)	22 (3.26)	16 (2.37)	13 (1.93)	↑0.021	0.18–60.00
Mosquito transmitted						
Vivax malaria	0 (0)	0 (0)	8 (1.19)	0 (0)	↓0.005	0.47–0.98
Nontypeable malaria	2 (0.3)	0 (0)	7 (1.04)	1 (0.15)	↓0.096	0.33–1.38
Dengue fever	4 (0.59)	1 (0.15)	0 (0)	0 (0)	↑0.046	1.11–34.38

[a]Tropical cyclones
[b]↑, more likely to increase the risk than to decrease the risk; ↓, more likely to decrease the risk than to increase the risk
[c]The numbers of TCs that increased the risk of analyzed diseases were compared with the numbers of TCs that decreased the risk using χ^2 tests
[d]Hand, foot, and mouth disease also transmitted through water-food
[e]Also transmitted through contact

different. Some studies have found that the risk of other infectious diarrhea is the first of six kinds of intestinal infectious diseases in Wenzhou after the typhoon disaster [41]. Wang et al. showed that tropical cyclones increase the risk of other infectious diarrhea, and the largest effect was in lag 5d [44]. Deng's study showed that the maximum effect of tropical storm and typhoon on other infectious diarrhea in Zhejiang Province was in lag 6d and 5d, respectively [43].

4.3.2.4 Vector-Borne Infectious Diseases

The heavy rainfall accompanied by tropical cyclone is easy to cause the inverted sewage and the garbage accumulation. The unclean environmental sanitation provides a good breeding ground for the mosquitoes. At the same time, the crowds and the environmental exposure of the population increase after the typhoon, creating favorable conditions for the spread of the vector-borne infectious diseases. Studies have confirmed that vector-borne diseases such as malaria and dengue fever are prone to increase or even outbreaks after typhoons [40].

4.3.2.5 Hand, Foot, and Mouth Disease

Hand, foot, and mouth disease (HFMD) is infantile infectious disease caused by a variety of enteroviruses. It can be transmitted through the respiratory tract, digestive tract, and contact. Relatively few studies were conducted. Some studies have shown that different grades of tropical cyclones have an impact on the occurrence of hand, foot, and mouth disease, and the effects of tropical cyclones at all levels on high-risk groups are higher than those of the whole population, and there is a certain lag effect [45]. The maximum effects of tropical storm and strong tropical storm and above on the risk of HFMD among high-risk population aged 0–5 were 7d and 3d, respectively. The reason may be that the landing of tropical cyclone is often accompanied by heavy wind and rain and the weather system has the characteristics of low pressure, low temperature, little sunshine, large humidity, and large wind speed, which can increase the risk of hand, foot, and mouth disease [46].

4.3.2.6 Respiratory Infectious Diseases

Tropical cyclone-related respiratory infectious diseases include measles, rubella, mumps, and chickenpox. The impact of tropical cyclones on mumps is regionally different. Studies have shown that there is no significant difference in the number of mumps before and after the landing of the tropical cyclone during 2006–2010 in the landing area of the tropical cyclone in Zhejiang Province, but the incidence of mumps in the 5 weeks after landing is less than before the landing, which may be related to the intensity of the typhoon and the concentration of the virus in the air diluted [47].

4.3.3 Tropical Cyclones and Other Diseases

Studies have shown that the cases of diarrhea, gastrointestinal dysfunction, skin infection, and insomnia caused by the typhoon Fitow increased by 1.24, 1.11, 1.28, and 2.48 times more than before the typhoon, which may be associated with increased exposure to environmental risk factors [48]. The short-term and long-term traumatic psychological reactions caused by disaster events to the affected population are very serious and widespread. Studies in China and other countries showed that stressful events can cause anxiety, depression, somatization, reactive mental symptoms, and other mental disorders [30]. Tropical cyclone as a natural disaster can also bring serious psychological harm to the victims. Post-traumatic stress disorder (PTSD) is a mental disorder caused by unusually threatening and disastrous psychological trauma, leading to delayed occurrence and long-term persistent mental disorders. PTSD is the most important influence of tropical cyclones on human psychological and mental health [49, 50]. After months of tropical cyclones, PTSD symptoms and other mental health problems emerge gradually, and the weakening of mental symptoms is based on the time and degree of exposure to tropical cyclones.

4.4 Health Impacts Due to Droughts

4.4.1 Droughts and Infectious Diseases

4.4.1.1 Digestive Tract Diseases

In the drought areas, the supply of water resources in the arid areas is insufficient, the discharge and level of water are reduced, the dilution ability of water is reduced [51]. The continuous drought makes the proportion of the secondary water supply and self-contained water supply not in line with the standard of drinking water increase, and the free residual chlorine, the total number of bacteria, and the excess of coliform bacteria in the water are higher [52]. Therefore, during the drought period, water sources are more likely to be contaminated by feces and pathogens, causing outbreaks of digestive tract diseases [53].

In the autumn and winter of 1998, due to drought and little rain in Dejiang County, six wells in the town were in short supply, and there was no public water intake equipment. The pollution was serious, causing the outbreak and epidemic of typhoid fever [54]. Xue et al. studied the relationship between drought events and infectious diseases in Shandong Province and screened sensitive infectious diseases in drought events. They found that the risk of amoebic dysentery, rubella, and epidemic encephalitis B (EB) increased in drought and its OR value and 95% CI were 2.457 (1.609–3.752), 2.206 (1.436–3.388), and 1.192 (1.058–1.344), respectively, and the corresponding lag period was 3, 0, and 1 months, respectively. The risk of bacillary dysentery, HFMD (hand, foot, and mouth disease), measles, and tsutsugamushi disease decreased after the drought (OR < 1), corresponding lag periods were 2, 2, 0, and 3 months, respectively [55].

Due to the lack of water resources during the drought, it is easy to cause pollution of the water source, so that the pathogenic microbes of drinking water and living water are propagated in a large amount, which leads to the epidemic of infectious diseases in the digestive tract. From 2009 to 2010, there was a severe drought in Qiannan, Guizhou Province, and there was a serious shortage of drinking water. The water samples of 129 public wells in Dushan County of this area were measured by Meng. The results showed that the total number of bacteria and coliform in most of the wells in Chengguan Town exceeded the national standard [56]. Yang also found the outbreak of dysentery during the severe drought in Xi'an in 1995 [52]. The outbreak of hepatitis A occurred in some areas of Xixia County, Henan Province, from May to August 2007. Through epidemiological investigation, Cao et al. found that the outbreak was caused by the drought, the decrease of surface water, the pollution of domestic water, the increase of the content of pathogens in the living water, and the poor perception of health prevention in the residents [57].

Qu et al. studied the relationship between meteorological factors and infectious diseases in the digestive tract and found that the average evaporation was positively correlated with the incidence of bacillary dysentery and typhoid paratyphoid, the average precipitation was negatively correlated with the incidence of bacillary dysentery and typhoid fever, and the average pressure was negatively correlated with the incidence of bacillary dysentery, viral hepatitis, and typhoid fever [58].

4.4.1.2 Other Infectious Diseases

Chen et al. showed that no water and food can be found in the field during the severe drought and the rodent could migrate to the residential area, which makes the density of the indoor rat increase and is beneficial to the transmission of hantavirus in the rat, causing the outbreak of the hemorrhagic fever in the renal syndrome [59].

Epidemic encephalitis B is mainly transmitted by mosquito vectors, and its incidence has obvious peak in summer and autumn. Its epidemic is closely related to air temperature and precipitation [60]. Increasing temperature not only accelerates the growth and propagation of vector insects but also enhances the pathogenicity of pathogens in insects. Qu et al. found that the incidence of encephalitis B was positively correlated with the average evaporation [61]. However, the study by Yang showed that the incidence of vector-borne diseases such as encephalitis B, hemorrhagic fever, and typhus in Xi'an was decreased during the severe drought, which may be due to the impact of drought on the living environment of media insects [52].

Under the conditions of dry climate, the amount of precipitation is less, the amount of evaporation is large, and the air is dry. It is not only conducive to the spread of infectious diseases but also reduces the resistance of respiratory tract mucosa. Shi et al. found that the average pressure of the drought area was negatively correlated with the incidence of epidemic meningitis, measles, and pertussis the average evaporation was positively correlated with epidemic meningitis, measles, and pertussis and the average precipitation was negatively correlated with the incidence of epidemic meningitis and measles [62].

4.4.2 Droughts and Other Diseases

Under drought climate, the incidence of various gynecologic diseases may increase significantly. Guo et al. studied the relationship between gynecopathy and annual precipitation in Qingyang County of Gansu Province from 1991 to 2000. The results showed that the incidences of simple vaginitis, trichomonas vaginitis, cervical cancer, cervical erosion, cervical polyps, uterine myoma, ovarian cysts, adnexitis, pelvic inflammation, prolapse of uterus, etc. were high in drought year or the next year [63]. Studies on the effects of drought on other reproductive system diseases are still lacking.

Wu et al. studied the correlation between annual mean precipitation, annual average evaporation and desiccation, and esophageal cancer mortality from 1961 to 1990 in mainland China. The results showed that the region with high mortality of esophageal cancer is the same as the region with high dryness, and correlation and regression analysis also showed that annual average precipitation is negatively related to the mortality of esophageal cancer. There was a positive correlation between the degree of dryness and the mortality of esophageal cancer [64]. At present, there are few studies on drought in cancer, and subsequent studies need to prove whether drought has an impact on other types of cancer.

Wupuer et al. investigated the early renal damage in the Taklamakan "desert people" in Xinjiang. The study found that the detection rate of microalbuminuria in this population was 10.5% and the detection rate of renal dysfunction was 3.88%, which was obviously higher than that in the nondesert areas, which may be related to the extreme drought and heat in this area [65].

Drought events are also associated with respiratory diseases. Liu et al. studied the relationship between asthma attacks and the meteorological factors in 445 children in Qingdao from 2000 to 2004. The results showed that the asthma attack in children was positively related to the pressure of the air and was negatively related to the temperature and humidity [66].

Zhou et al. studied the effects of drought and water shortage on the health of rural schools and primary school students in five rural primary schools in Gansu Province. They found that in the water-deficient schools, the main water source was collecting precipitation in cellar; because of the limitation of precipitation water, water supply could not meet the requirements of the school, and extra expenses were used to buy water; water supply per capita was low; the schools lacked basic sanitation facilities; due to poor sanitation, long storage time, irregular disinfection, or no disinfection, water in cellars was easily contaminated by surface debris and feces, leading to the cellar water quality unqualified, the water turbidity, oxygen consumption, and microbial indicators to exceed standard; most students brought their own drinking water to school; students in water-deficient schools drank less water, and many students did not drink water during school or often drank raw water; lack of water has a more obvious effect on male students, leading to poor physical development; as the study county is a water shortage area, the overall economic and health conditions are poor, and the growth and development level of primary school students lags behind the national average; school children were more likely to develop blepharoconjunctival lesions, dental caries, parasitic infections, and skin disorders; and students who did not drink water in school had high prevalence of eye and mouth diseases and low accuracy of hygienic behaviors [67].

4.5 Summary

To sum up, extreme weather events affect multiple human systems. With the global climate change, the frequency and intensity of extreme weather events such as heat waves, rainstorms, floods, and droughts have increased and will continue to increase. Although many literatures have studied the health effects of extreme weather events, there are still many problems to be solved:

1. Existing studies are based on a single city or a small number of cities or limited to individual diseases, and there is a lack of large-scale studies in China to analyze the effects of extreme weather events on the occurrence of infectious and chronic noncommunicable diseases at the national level.
2. The health effects of extreme weather events are affected by a variety of factors, resulting in

differences in gender, age, and region; thus there is a need to screen sensitive diseases in different regions and vulnerable populations of different diseases.

3. There are few studies on the mechanism of extreme weather events affecting health. At present, most studies use cross-sectional and case-control methods. There may be a variety of extreme weather events at the same time, and there are many confounding factors. Therefore, subsequent research needs to combine field research with laboratory research, and the interference of other meteorological factors should be excluded in order to increase the strength of the argument.
4. At present, there are not many researches on extreme weather events and human health in China. Therefore, good baseline data need to be collected in order to better study the impact of extreme weather events in China.
5. Research on adaptation to extreme weather events is still relatively rare. The adaptability of different regions and different populations in dealing with extreme weather events is different, so it is necessary to adapt to local conditions, to study the adaptation mechanism of sensitive diseases, and to formulate strategies and measures for the adaptation of government, community, and individuals to extreme weather events.

References

1. Qin D. China national assessment report on risk management and adaptation of climate extremes and disasters. Beijing: Science Press; 2015.
2. Zhou Y, Liu Y, Wu W, Li N. Integrated risk assessment of multi-hazards in China. Nat Hazards. 2015;78(1):257–80.
3. Du Y, Ding Y, Li Z, Cao G. The role of hazard vulnerability assessments in disaster preparedness and prevention in China. Mil Med Res. 2015;2:27.
4. Ekanayake S, Prince M, Sumathipala A, Siribaddana S, Morgan C. "We lost all we had in a second": coping with grief and loss after a natural disaster. World Psychiatry. 2013;12(1):69–75.
5. Frankenberg E, Sikoki B, Sumantri C, Suriastini W, Thomas D. Education, vulnerability, and resilience after a natural disaster. Ecol Soc. 2013;18(2):16.
6. Han W, Liang C, Jiang B, Ma W, Zhang Y. Major natural disasters in China, 1985-2014: occurrence and damages. Int J Environ Res Public Health. 2016;13(11):E1118.
7. IPCC. Climate change 2014: impacts, adaptation, and vulnerability. 2014.
8. UNISDR. 2011 global assessment report on disaster risk reduction: revealing risk, redefining development. Geneva: UNISDR; 2011.
9. State Flood Control and Drought Relief Headquarters, M. o. W. R. China flood and drought disaster bulletin. Beijing: SinoMaps Press; 2017. p. 2016.
10. Liu C, Wan J, Ma J, Wang L. Research progress on human mortality due to flood. South North Water Divers Water Sci Technol. 2012;10(4):97–101.
11. Li Y, Wang H, Ni W, Ding G, Gao L, Jiang B. Impact of floods on cardiovascular disease mortality in Hunan province. J Environ Health. 2015;32(4):287–90.
12. Li X, Tan H, Li S, Zhou J, Liu A, Yang T, Wen SW, Sun Z. Years of potential life lost in residents affected by floods in Hunan, China. Trans R Soc Trop Med Hyg. 2007;101(3):299–304.
13. Ge Q, Zou M, Zheng J. Integrated assessment of natural disaster risks in China. Beijing: Science Press; 2008.
14. Ban H, Zhang L. Epidemiological characteristics of drinking water pollution and intestinal infectious diseases in flood and waterlogging in China. China Health Stand Manage. 2012;3(4):61–3.
15. Chen W, Zeng G. Flood and infectious diseases. Chin J Public Health. 2003;19(8):899–900.
16. Li Y, Ni W, Ding G, Gao L, Jiang B. Temporal and spatial distribution of floods and its relationship with human health in the last 50 years in China. J Environ Health. 2014;31(4):367–71.
17. Wang M. Distribution and main characteristics of related diseases after flood—literature review on disaster prevention and disease prevention in the Yangtze river basin. Disaster Reduction China. 2000;10(3):38–42.
18. Chen W, Jin L, Jiao M, Zhang X. Epidemic situation of notifiable infectious diseases in Hubei Province and analysis of important infectious diseases related to flood disasters, 1990-2002. Dis Surveil. 2004;19(5):186–90.
19. Ding G, Zhang Y, Gao L, Ma W, Li X, Liu J, Liu Q, Jiang B. Quantitative analysis of burden of infectious diarrhea associated with floods in northwest of Anhui province, China: a mixed method evaluation. PLoS One. 2013;8(6):e65112.
20. Liu Z, Ding G, Zhang Y, Xu X, Liu Q, Jiang B. Analysis of risk and burden of dysentery associated with floods from 2004 to 2010 in Nanning, China. Am J Trop Med Hyg. 2015;93(5):925–30.
21. Hu X, Jiang F, Ni W. Floods increase the risks of hand-foot-mouth disease in Qingdao, China, 2009-2013: a quantitative analysis. Disaster Med Public Health Prep. 2018;12:723–9.
22. Carrel M, Voss P, Streatfield PK, Yunus M, Emch M. Protection from annual flooding is correlated with increased cholera prevalence in Bangladesh: a zero-inflated regression analysis. Environ Health. 2010;9:13.

23. Zeng G, Chen W, Zhang X. The influence of 1998 flooding on infectious diseases epidemiology in Hubei Province. Pract Prev Med. 2005;12(2):249–52.
24. Shi Q. Investigation of diseases distribution of flood victims in a township in 2003. Anhui J Prev Med. 2004;10(3):159–60.
25. Lin J, Guo Z. Impact of climate change on the incidence of infectious disease. J Dis Monit Control. 2013;7(7):414–6.
26. Zhou J, Huang X, He H, Liu A, Yang T, Li S, Tang X, Tan H. Epidemiological study on leptospirosis infection of host animals and healthy population in flood areas. J Cent South Univ (MedSci). 2009;34(2):99–103.
27. Gao T, Su N. Risk assessment and coping strategies of infectious diseases after rain and flood in Beijing, 2012. Chin J PHM. 2013;29(6):713–6.
28. Chen X, Peng H, Chen H, Sun C, Zhu M. A study of the relationship between mental stress, social support and angiocardiopathy after disaster. Health Psychol J. 2000;8(2):176–9.
29. Li X, Hua Q. The influence of major stress events on the physical and mental health of the population. J Capital Univ Med Sci. 2003;24(4):487–8.
30. Liu T, Ding G, Gao L, Zhang W, Jiang B. Mental health caused by floods in China: a review of recent researches. J Environ Health. 2012;29(12):1136–9.
31. Liu A, Tan H, Zhou J, Li S, Yang T, Sun Z, Wang J, Tang X, Xiang L, Zhang X, He H, Li L, Tang S. A study of PTSD and its risk factors after flood. J Chin Phys. 2003;5(12):1630–2.
32. Zhu Z, Wu H, Guo H, Li S. Investigation of mental and physical health of flood victims. Chin Ment Health J. 2000;14(6):373.
33. Luo Y, Hu W, Wu H, Cao H, Xu Y, Lu P, Wang X, Gao L. Investigation report on stress level of 610 disaster victims after flood in Jiujiang. Jiujiang Med J. 1999;14(2):93–4.
34. Dai W, Kaminga AC, Tan H, Wang J, Lai Z, Wu X, Liu A. Long-term psychological outcomes of flood survivors of hard-hit areas of the 1998 Dongting Lake flood in China: prevalence and risk factors. PLoS One. 2017;12(2):e0171557.
35. Li X, Huang X, Tan H, Liu A, Zhou J, Yang T. A study on the relationship between posttraumatic stress disorder in flood victim parents and children in Hunan, China. Aust N Z J Psychiatry. 2010;44(6):543–50.
36. Peng M, Liu A, Zhou J, Wen S, Li S, Yang T, Li X, Huang X, Abuaku B, Tan H. Association between posttraumatic stress disorder and preflood behavioral characteristics among children aged 7-15 years in Hunan, China. Med Princ Pract. 2011;20(4):336–40.
37. Gong Z, Chai C, Tu C, Lin J, Qiu Y, Gao Y, Zeng G, Fontaine R, Lee C, Chen K. An epidemiological study on serious injuries caused by typhoon Ranamim. National Med J Chin. 2005;85(42):3007–9.
38. Shen J, Feng Z, Zeng G, Zhu BP. Risk factors for injury during Typhoon Saomai. Epidemiology. 2009;20(6):892–5.
39. Wang X, Xun H, Kang R, Wang W, Ma W. Effects of typhoon on mortality and burden of disease of residents in Yuexiu district of Guangzhou from 2008 to 2011. J Environ Health. 2015;32(4):315–8.
40. Zheng J, Han W, Jiang B, Ma W, Zhang Y. Infectious diseases and tropical cyclones in Southeast China. Int J Environ Res Public Health. 2017;14(5):494.
41. Chen T, Xie H, Ni C, Wei J, Zhu S, Lin S, Li Q, Chi H, Wang J, Chen G, Zhang J, He F. Risk assessment on intestinal infectious diseases caused by typhoon in Wenzhou. Chin Prev Med. 2016;17(10):727–32.
42. Kang R, Xun H, Zhang Y, Wang W, Wang X, Jiang B, Ma W. Impacts of different grades of tropical cyclones on infectious diarrhea in Guangdong, 2005-2011. PLoS One. 2015;10(6):e0131423.
43. Deng Z, Xun H, Zhou M, Jiang B, Wang S, Guo Q, Wang W, Kang R, Wang X, Marley G. Impacts of tropical cyclones and accompanying precipitation on infectious diarrhea in cyclone landing areas of Zhejiang Province, China. Int J Environ Res Public Health. 2015;12(2):1054.
44. Wang W, Xun HM, Zhou MG, Jiang BF, Wang SW, Guo Q, Kang RH, Wang X, Marley G, Ma W. Impacts of typhoon 'Koppu' on infectious diarrhea in Guangdong Province, China. Biomed Environ Sci. 2015;28(12):920–3.
45. Kang R. Impacts of tropical cyclones on hand, foot and mouth disease in Guangdong, Fujian and Hainan provinces, 2008–2013. Shandong: Shandong University; 2016.
46. Xun H. Impacts of tropical cyclones on infectious diseases in Guangdong Province, 2005-2011. Shandong: Shandong University; 2015.
47. Kang R, Jiang B, Xun H, Wang X, Wang W, Ma W. Relationship between tropical cyclone and incidence of mumps in Zhejiang, China, 2005-2010. J Environ Health. 2015;32(4):307–11.
48. Li X, Wang H. Analysis of monitoring results of related diseases before and after typhoon Fitow floods. Zhejiang Prev Med. 2014;26(10):1005–6.
49. Kinney PL, Matte T, Knowlton K, Madrigano J, Petkova E, Weinberger K, Quinn A, Arend M, Pullen J. New York City panel on climate change 2015 report chapter 5: public health impacts and resiliency. Ann N Y Acad Sci. 2015;1336(1):67–88.
50. Xun H, Jiang B, Ma W. Research progress in impact of tropical cyclone to human health. Chin J Epidemiol. 2014;35(4):462–5.
51. Moran P, Nhandara C, Hove I, Charimari L, Katito C, Bradley M, Williams MA. Contamination of traditional drinking water sources during a period of extreme drought in the Zvimba communal lands, Zimbabwe. Cent Afr J Med. 1997;43(11):316–21.
52. Yang H. The effect of extreme drought on epidemic trend of infectious diseases. Occup Health. 2001;17(2):15–6.
53. Shehane SD, Harwood VJ, Whitlock JE, Rose JB. The influence of rainfall on the incidence of microbial faecal indicators and the dominant sources of fae-

cal pollution in a Florida river. J Appl Microbiol. 2005;98(5):1127–36.
54. Zhou L, Fu Y. Research progress on the influence of drought on human health and hygienic behavior. J Environ Hyg. 2013;3(3):264–7.
55. Xue X, Li X, Li X, Ding G, Liu Q. Study on effects of drought events on infectious diseases in Shandong province. Chin J Vector Biol Control. 2017;28(6):538–42.
56. Meng X. Analysis of microbial detection results of public water wells in Dushan County town in 2009~2010. J Qiannan Med Coll Nationalities. 2010;23(4):262–3.
57. Cao Z, Cao Q, Feng J. A survey of hepatitis A outbreak in local areas of Xixia County. Chin J Urban Rural Enterprise Hyg. 2011;(06):98–9.
58. Qu B, Guo H, Guan P, Zhou B. Influence and prediction of meteorological factors on epidemic situation of digestive system infectious diseases in drought area. World Chin J Digestol. 2009;17(14):1443–7.
59. Chen H. Influence of flood and drought on epidemic of hemorrhagic fever with renal syndrome and preventive measures. Chin J Public Health. 1999;15(7):665.
60. Guo H, Qu B, Ding H, Sun G. Seasonal distribution of morbidity and mortality of Japanese encephalitis in China from 2004 to 2010. Chin J Vector Biol Control. 2011;22(3):243–4.
61. Qu B, Guo H, Guan P, Zhou B, Huang D. Study on the influence of meteorological factors on the incidence of epidemic encephalitis B. Chin J Epidemiol. 2006;27(2):179.
62. Shi H, Qu B, Guo H, Guan P, Zhou B. Effect of meteorological factors on epidemic situation of aspiratory infectious diseases in drought area. Chin J Public Health. 2006;22(4):417–8.
63. Guo Y, Li Q. Analysis of correlation between annual precipitation and gynecological diseases in arid and semi-arid regions. Maternal Child Health Care China. 2002;17(3):164–6.
64. Wu K, Li K. Association between esophageal cancer and drought in China by using geographic information system. Environ Int. 2007;33(5):603–8.
65. Wupuer M, Chen F, Cheng Z, Zhu P, QIu C, Maimaitiyiming D. Preliminary investigation of early renal damage in Taklimakan “desert man”. Beijing Med J. 2011;33(7):533–6.
66. Liu X, Zhou X, Liang S, Lin R. Study on the relationship between asthmatic attack in children and meteorological factors in Qingdao urban area. Med J Qilu. 2007;22(2):109–10.
67. Zhou L. Study of the rural school sanitation and rural pupil's health status associated with water shortage in drought area master. Beijing: Chinese Center for Disease Control and Prevention; 2013.

5 Ambient Temperature and Major Infectious Diseases in China

Xiaobo Liu, Jimin Sun, Xiaodong Liu, Jingchun Fan, Yanlin Niu, Lingling Lang, and Qiyong Liu

Abstract

Infectious diseases are a group of diseases which have complex transmission ways and various influencing factors. Clarifying the correlation between ambient temperature and major infectious diseases in China is a crucial step toward the successful control of infectious diseases including vector-borne diseases, water-borne diseases, food-borne diseases, respiratory infectious diseases, etc. and the implementations of climate change adaption strategy and measures in China. However, no study has systematically reviewed the available evidences on the impact of ambient temperature on the incidence of major infectious diseases, and such information is essential for policymakers and stakeholders to take specific actions to control infectious diseases and protect the vulnerable population in the future. In order to fill this gap, we systematically review

X. Liu · Q. Liu (✉)
State Key Laboratory of Infectious Disease Prevention and Control, National Institute for Communicable Disease Control and Prevention, Chinese Center for Disease Control and Prevention, Collaborative Innovation Center for Diagnosis and Treatment of Infectious Diseases, WHO Collaborating Centre for Vector Surveillance and Management, Beijing, China
e-mail: liuxiaobo@icdc.cn; liuqiyong@icdc.cn

J. Sun
Zhejiang Provincial Center for Disease Control and Prevention, Hangzhou, China
e-mail: jmsun@cdc.zj.cn

X. Liu
Shandong Provincial Center for Disease Control and Prevention, Jinan, China

J. Fan
State Key Laboratory of Infectious Disease Prevention and Control, National Institute for Communicable Disease Control and Prevention, Chinese Center for Disease Control and Prevention, Collaborative Innovation Center for Diagnosis and Treatment of Infectious Diseases, WHO Collaborating Centre for Vector Surveillance and Management, Beijing, China

School of Public Health, Gansu University of Chinese Medicine, Lanzhou, China

Y. Niu
State Key Laboratory of Infectious Disease Prevention and Control, National Institute for Communicable Disease Control and Prevention, Chinese Center for Disease Control and Prevention, Collaborative Innovation Center for Diagnosis and Treatment of Infectious Diseases, WHO Collaborating Centre for Vector Surveillance and Management, Beijing, China

Beijing Centers for Disease Prevention and Control, Beijing Centers for Disease Preventive Medical Research, Beijing, China

L. Lang
Guangdong Provincial Institute of Public Health, Guangdong Provincial Center for Disease Control and Prevention, Guangzhou, China
e-mail: langll@gdiph.org.cn

H. Lin et al. (eds.), *Ambient Temperature and Health in China*,
https://doi.org/10.1007/978-981-13-2583-0_5

the current evidence for the effect of ambient temperature on major infectious diseases in China. The findings could provide explicit information for the scientific prevention and control of infectious diseases in China.

Keywords

Ambient temperature · Climate change · Infectious diseases · China

5.1 Introduction

Infectious diseases continue to be the major health threats in most regions globally. As one type of important infectious diseases, vector-borne diseases (VBDs) are expected to affect about 80% of the world's population. According to WHO's report, 17% of the global burden of communicable diseases was due to vector-borne diseases.

In China, 10 of the 39 notifiable infectious diseases are vector-borne diseases. Great achievements have been made in the control of infectious diseases in the past decades, and five notifiable infectious diseases were eradicated or nearly eradicated at present, including polio, filariasis, severe acute respiratory syndrome (SARS), plague, and diphtheria [1]. The incidences of some notifiable infectious diseases were reduced, including cholera, hepatitis A, bacterial dysentery, amoebic dysentery, typhoid, paratyphoid, gonorrhea, pertussis, epidemic cerebrospinal meningitis, epidemic hemorrhagic fever, rabies, leptospirosis, anthrax, typhus, encephalitis, malaria, tuberculosis, and tetanus. By contrast, an increasing trend was observed for 11 notifiable infectious diseases, including human immunodeficiency virus (HIV), brucellosis, hepatitis C, hepatitis E, syphilis, scarlet fever, dengue, influenza, infectious diarrhea, hydatid disease, leishmaniasis, and schistosomiasis.

Among these diseases, dengue fever (DF), malaria, hemorrhagic fever with renal syndrome (HFRS), plague, and severe fever with thrombocytopenia syndrome (SFTS) were the most prevalent vector-borne diseases in China. According to literature review, these diseases mentioned above are all sensitive to the variations of meteorological factors, especially for ambient temperature [2, 3]. Water-borne diseases are conditions caused by pathogenic microorganisms that are transmitted in water. The infection would occur when people ingested contaminated water or contacted with infected water containing various forms of intestinal pathogens during bathing or swimming. As a type of old diseases, the occurrence of schistosomiasis and its vector could also be impacted by ambient temperature [4]. At present, the epidemic of hand-foot-mouth disease (HFMD) is very serious in China, and it is believed that heat could facilitate the spread of HFMD [5]. Regarding respiratory infectious diseases, influenza is surely a representative infectious diseases sensitive to ambient temperature in China [6]. Therefore, to better understand the relationship between meteorological factors and infectious diseases in China, it is essential to carry out prediction and projection of important infectious diseases under the context of climate change which will be of great significance to the prevention and control of infectious diseases in future.

However, little information was available regarding the effect of ambient temperature on infectious diseases in China. In this chapter, we extensively reviewed the available evidence on the effect of ambient temperature on major infectious diseases in China, in order to make up this gap, and provide scientific guidance for policymakers to implement corresponding actions to reduce the incidence of major infectious diseases.

5.2 Ambient Temperature and Vector-Borne Diseases

5.2.1 Ambient Temperature and Mosquito-Borne Diseases

In this chapter, some representative mosquito-borne diseases with the biggest diseases burden or public health significance were selected.

Literatures concerning these themes are reviewed to clarify the relationship between ambient temperature and mosquito-borne diseases.

5.2.1.1 Dengue

DF is the most rapidly spreading mosquito-borne viral disease, showing a 30-fold increase in global incidence over the past 50 years. Three quarters of the population exposed to dengue are in the Asia-Pacific region. Since the first recorded outbreak of dengue in Foshan, Guangdong, in 1978, DF occurs frequently in southern China and becomes a major public health threat in China [7]. In 2017, 5893 DF cases occurred in China with two of these dead. In recent years, indigenous cases of DF occurred in Yunnan, Guangxi, Guangdong, Hainan, Fujian, Zhejiang, Anhui, Shanghai, Henan, and Shandong, while imported cases happened in all provinces except for Tianjin and Tibet in 2017. In China, the principal vectors for DF, including *Aedes aegypti* and *Ae. albopictus*, are all sensitive to climate. *Ae. albopictus* is the most important mosquito in DF transmission in Guangdong and Zhejiang, while *Ae. aegypti* is the major DF vector in Yunnan.

The means by which ambient temperature affects DF are via the following bioecological aspects: dengue virus, *Aedes* mosquitoes, human population, and its transmission environment [2]. The ambient temperature could not only impact the reproductive of dengue virus in *Aedes* mosquitoes but also the distribution of *Aedes* mosquitoes. In China, regarding the impact of ambient temperature on dengue vector distribution, Wu et al. found that *Ae. albopictus* have expanded their geographic range to areas with an annual mean temperature below 11 °C and a January mean temperature below −5 °C using CLIMEX model [8]. Temperature plays an important role in vector competence. Liu et al. found that temperature increase enhances the competence of *Ae. albopictus* to transmit dengue virus [9]. Most studies in China believed that temperature can drive dengue transmission [10, 11], showing a nonlinear effect [11, 12]. Among those studies, different models are employed such as generalized additive model (GAM), autoregressive integrated moving average (ARIMAX) model, ecologically based model, etc. In recent years, most studies were carried out in Guangdong and Yunnan provinces considering the higher frequency of DF outbreak. Local DF cases were positively associated with temperature with different time lags in Guangzhou [13]. The minimum temperature at a lag of 1 month was positively associated with dengue incidence in Guangzhou [14]. The mean and minimum temperatures were positively associated with increased DF risk, while the maximum temperature was negatively associated with DF transmission [15]. Xiang et al. demonstrated that a reversed U-shaped nonlinear association was found between ambient temperature and DF in Guangzhou. The optimal maximum temperature (Tmax) range for dengue transmission was 21.6–32.9 °C and 11.2–23.7 °C for minimum temperature (Tmin) [16].

In Guangzhou, a negative binomial regression model was adopted, and the results showed that average temperature (Tave) and previous month's minimum temperature (Tmin) were positively associated with DF incidence. A threshold of 18.25 °C was found in the relationship between the current month's Tmin and DF incidence [17].

Regarding the comparative studies of the influence of ambient temperature on DF in the domestic and abroad, the current studies in China mainly focus on the influence of ambient temperature on the distribution and spread of DF and its vectors via the application of different models. And this is consistent with the international researches. However, at present, very little information is available regarding the impact mechanism of the ambient temperature on dengue virus, vectors, and ultimately dengue transmission mechanism, and limited literatures could be found regarding the impact of social and economic factors on DF, and these field should be the focus in future study.

5.2.1.2 Malaria

As a representative vector-borne disease, malaria is due to parasites of the genus *Plasmodium* and transmitted by four species of female *Anopheles* mosquitoes in China, including *An. sinensis*, *An. lesteri*, *An. minimus*, and *An. dirus*, respectively.

Despite dramatical reductions in the incidence of malaria observed at present, imported cases still constitute a threat to the malaria elimination commitment of the Chinese government to WHO.

Most studies found that temperature was a fundamental meteorological factor related to malaria incidence in China [18]. Extreme high temperature restricts the development of mosquitoes and reduces the transmission of malaria since higher temperature increases mosquito growth, virus replication, and biting frequency of vectors. Generally speaking, temperatures lower than 16 °C or higher than 30 °C are not conductive to mosquitoes development [19]. Daily variations on temperature could impact necessary mosquito and parasite characteristics that help to malaria transmission intensity [20]. In Jinan, maximum temperature with a 1 °C rise may be relevant to a 7.7–12.7% increase in malaria cases, while minimum temperature with a 1 °C rise might lead to about 11.8–12.7% increase in malaria cases [21]. Li et al. reported that each 1 °C rise in temperature amounts to an increase of 0.90% in the monthly malaria cases in Guangzhou [3]. However, the correlation between temperature indexes and incidence of malaria may not be throughout the year. Tian et al. found an increased risk of transmission due to a high temperature in warmer winters [22]. The effect of ambient temperature concerning malaria frequently leads to a lag-time effect because of the life cycle of *Anopheles* and the parasite [23]. Zhou et al. revealed that a 75.3% variation on monthly malaria incidence was related to the average temperature in last 2 months in central China [18]. In four counties of Yunnan, an increasing temperature resulted in increased malaria risk the varied lag periods for these associations [24].

Almost all studies mentioned above identified an association between ambient temperature indicators and transmission of malaria in different sites and periods lag in China. This is coherent to the similar studies abroad. However, very few studies focus on the impact mechanism of the ambient temperature on malaria parasites, vectors, and its transmission.

5.2.2 Rodent-Borne Diseases

5.2.2.1 Ambient Temperature and Plague

Plague, caused by *Yersinia pestis*, is one of the most devastating infectious diseases in human history. The three plague pandemics have caused numerous deaths worldwide and changed human civilization [25, 26]. In China, plague is belonging to category A of 39 notifiable infectious diseases and once constituted a great burden during the initial stage of new China. At present, the disease was well controlled, and the incidence of plague keeps very low level.

Climate affects the plague intensity through its effect on maintenance and replication of the pathogen, host, and vector populations by affecting temperature and precipitation in some studies [27–29]. Suitable climate could increase the reproductive rate of pathogenic microbes [30] and contribute to form stable plague foci [31]. Rodent populations and flea survival respond rapidly to climate variations [30]. Epizootics are likely to occur when rodent and flea number excess a certain threshold [32–34]. The high abundance of rodents and fleas would also increase the human plague risk [35]. Temperature seems to determine the distribution of *Yersinia pestis*. Nearly 95% of human plague occur in regions with an average annual temperature greater than 13 °C, and most large plague outbreaks occur within areas with an annual temperature of 24–27 °C [36]. Additionally, outbreaks of historical plague pandemics also seemed to be driven by climate change. The introduction of the Black Death is associated with climate fluctuations in Central Asia, with an approximate delay of 15 years [37]. The above-normal warmer and wetter climate during 1855 and 1870 may be responsible for extensive plague outbreaks in China during the Third Pandemic [36]. The associations between climate and plague can vary by regions [38, 39].

Regarding the comparative studies, most studies have focused on the individual effect of precipitation or temperature, or the mixed effect of two climate variables. As for the high temperature, plague would increase under this condition in western United States [38, 40]. In Arizona and New Mexico, plague would increase if the number of days above a certain temperature threshold increased, with 80 °F for New Mexico and 85 °F for Arizona, respectively [38]. However, the transmission between fleas and mammalian hosts was significantly reduced when temperature excess 27.5 °C [41]. The mixed effect of precipitation and temperature also revealed a regional difference. *Yersinia pestis* prevalence was shown to increase with warmer springs and wetter summers in gerbils in Kazakhstan [42]. Similarly, the rodent and flea densities, as well as the presence of plague in Mongolian gerbils, are positively correlated with the precipitation and temperature in China [43]. High risk of human plague tends to follow the plague outbreaks in hosts [33]. However, an increased plague incidence can be expected in Vietnam during the hot, dry seasons [41]. Besides, plague outbreaks in preindustrial period were more frequent in cold and arid climate in Europe [44]. Plague is also associated with large-scale weather events [28]. El Nino Southern Oscillation (ENSO) and the Pacific Decadal Oscillation (PDO) are related to precipitation and temperature which could in turn affect plague dynamics [45, 46]. The increasing rate of human plague was closely associated with Southern Oscillation Index (SOI) and Sea Surface Temperature of east Pacific equator (SST) in China. Ari et al. found PDO explained much of the human plague variation in western United States. However, as the association between large-scale climate and plague was nonstationary and nonlinear in Madagascar and Europe [45, 47], we should pay more attention to the scale of the climate and the complexity of the interaction in the ecosystem when analyzing large-scale climate and plague systems.

5.2.2.2 Ambient Temperature and HFRS

HFRS caused by the Hanta virus and results in about 200,000 hospitalized cases yearly. It is generally thought that ambient temperature is one of the most key meteorological factors exerting the impact of endemic intensity of HFRS [48], because warm temperature is in ideal condition for the growth of crops and increase of rodent. Furthermore, it is probably that surface air temperature can increase more obviously in winter and spring than in other seasons, particularly in the northern China [49]. As the temperature increases, areas with relatively lower temperature could become beneficial to rodent breeding then extend the breeding seasons, which have a potential impact on the number, scale, and emergence of new natural foci of HFRS. In China, most studies showed that HFRS is sensitive to ambient temperature. Temperatures from 10 to 25 °C are most beneficial to rodent growth, and breeding rates for both *A. agrarius* and *R. norvegicus* would decrease when temperatures were out of this range [48]. Temperature of 17 °C as a threshold was identified in a study, below which there was a positive association, while above the threshold there was an inverse association [50]. Likewise, it is reported that the highest incidence of HFRS is with temperatures about 17.5 °C [51]. Temperature above 23.7 °C and below 6 °C revealed positive effects on the HFRS incidence of 3 months later; in contrast, temperature between 6.0 °C to 23.7 °C was negative with the incidence of HFRS [52].

However, it is difficult to compare findings across different studies given the range of metrics and methodologies used. A recent comprehensive review suggested that many studies that quantified HFRS-ambient temperature associations have drawn different conclusions (either positive [53–59] or negative [49, 60, 61]), possibly because of the use of different statistical methods and climate characteristics of the study regions. Variables from different studies included mean, minimum, maximum ambient temperature and land surface temperature. Land surface temperature mainly impacts the distribution and abundance of populations of *A. agrarius* [62], while ambient temperature mainly affects the behavior of rodent and human.

5.2.3 Tick-Borne Diseases

SFTS is an emerging infectious disease which was firstly identified in 2009. Although SFTS is considered to be transmitted by air or direct contact with secretion or blood of SFTS patients, the current evidences reveal that the majority of SFTS cases were infected via tick bites. The majority of cases were happened from April to October. Meteorological factors may exert some impact on ecology of SFTSV directly or indirectly by affecting tick in itself, tick-human interactions, and virus replication.

Table 5.1 listed the related studies of climatic factors and SFTS in China. Sun et al. conducted an analysis concerning ambient temperature and SFTS in 21 counties in Henan and Hubei via distributed lag nonlinear models (DLNMs). They reported that the effects of temperature on incidence of SFTS were nonlinear, with larger relative risk (RR) at the higher temperature on lag 0. The high temperatures had acute and short-term effects, while the effects in low-temperature ranges were persistent over longer lag periods. Higher temperatures such as 23.97 °C and 29.30 °C had the maximum RR for SFTS cases on the current week, which decreased quickly in the next weeks. Low temperatures including 1.62 °C and 6.97 °C had the minimum RR on the current week and had the maximum RR at lag 13 weeks, which decreased slowly in the next weeks. The effects of lower temperatures could last 24 weeks, but the effect of 29.30 °C was not significant at lag 8 weeks [63].

A negative binomial regression model (NBM) established by Sun et al. revealed that the occurrence of SFTS would increase by 25.68% and 10.31%, respectively, if monthly maximum temperature and mean relative humidity increase one unit [64]. Du et al. studied geographic distribution and related factors of SFTS and found that temperature is one of the key environmental factors affecting the occurrence of SFTS [65]. Similarity, cattle density, rain-fed cropland, built-up land, temperature, and relative humidity were independent risk factors for the distribution of SFTS [66]. The risk of SFTS increased when reached a threshold with monthly average temperature higher than 19.65 °C, or monthly average relative humidity higher than 74.5%, or (95% CI) were 12.889 (2.307, 72.016) and 13.417 (3.042, 59.171), respectively [67].

5.3 Ambient Temperature and Water-Borne Diseases

Schistosomiasis, caused by a trematode worms belonging to the genus Schistosoma [68], is a kind of water-borne diseases, bringing a heavy burden on the residents of the endemic areas [69]. The parasite species which can infect human

Table 5.1 Summary of included studies on ambient temperature and SFTS in China

Source	Location	Time period	Key findings
Sun et al. [64]	Henan, Hubei	2011–2015	A nonlinear effect existed between weekly temperature and SFTS. The exposure-response curve was a reversed U-shape
Sun et al. [64]	Henan, Hubei	2011–2015	Temperature and relative humidity were significantly correlate to the occurrence of SFTS
Du et al. [65]	Shandong	2010–2013	Temperature, precipitation, land cover, normalized difference vegetation index (NDVI), and duration of sunshine were the key environmental factors affecting SFTS occurrence
Wang et al. [66]	Hubei	2011–2016	Temperature, relative humidity, cattle density, rain-fed cropland, and built-up land were independent risk factors for the distribution of SFTS
Zhai et al. [67]	Zhejiang	2011–2014	Monthly average temperature, atmospheric pressure, and relative humidity were associated with incidence of SFTS

include *Schistosomiasis haematobium*, *Schistosomiasis japonicum*, *Schistosomiasis mansoni*, *Schistosomiasis intercalatum*, *Schistosomiasis mekongi*, and *Schistosomiasis malayensis* [70]. *Schistosomiasis japonica* that caused by *S. japonicum* is widely spread in China since 2000, particularly in areas along the Yangtze River and further south [71]. *Oncomelania hupensis*, the sole intermediate host of *S. japonicum*, plays an important role in the transmission of *S. japonicum* in China and correlates closely with the distribution of this disease [72, 73]. *S. japonicum* completes its life cycle through a sexual generation in the vascular system of the definitive host (i.e., mammals) and an asexual generation in *O. hupensis*.

Ambient temperature is an important ecological factor for growth and development of *S. japonicum* and the presence of *O. hupensis*, which can influence the prevalence and distribution of schistosomiasis in China [74–79]. In the process of transmission of schistosomiasis, ambient temperature plays a vital role in the biological activity of *O. hupensis* and the development of *S. japonicum* within the intermediate host. The optimal temperature range for miracidia infecting *O. hupensis* is between 10 °C and 20 °C. There is no significance in infection rates when temperature ranges between 21 °C and 31 °C and low infection rates under 10 °C. However, miracidia can never infect *O. hupensis* when temperature drops to 3.2 °C [4, 80]. After the invasion, *S. japonicum* arrested their development in snails when temperature was kept at about 15.3 °C or above 37 °C, while the optimum development occurred at 25 °C–30 °C, which means within a temperature range of 15.3 °C–30 °C, the higher the temperature is, the shorter the pre-patent period of *S. japonicum* within *O. hupensis* will be [79, 81]. Temperature could also influence the cercaria effusion, where 25 °C–30 °C were the optimal range [82]. The optimal temperature for *O. hupensis* ranges between 20 °C and 25 °C, which means any temperature out of this range would result in delayed or arrested development and reproduction of *O. hupensis* [74, 83, 84]. Physiological functions of *O. hupensis* declines as environmental temperature drops [74]. When the temperature drops to 5.8 °C–6.4 °C, half of the snails were in hibernation (ET_{50}) [79, 81]. In Yunnan, it is concluded that the optimal LST for *O. hupensis* was ≥22.7 °C after considering land surface temperature (LST) as the most suitable environmental factor for snail habitat prediction [85]. In Dongting Lake Region, the mean snail density increased gradually when the temperature was between 24.30 and 25.70 °C, while mean snail density decreased gradually when the temperature was from 24.15 to 22.40 °C in the GWR (Geographically Weighted Regression) model. A possible suitable range of temperature was from 22.73 to 24.23 °C estimated by interquartile range in high-high clustered areas. [86]. The accumulated degree-days (ADD) are considered to be similar to growing degree-days (GDD), which both reflects the heat accumulation during the development of the organism. It was estimated that the mean ADD for the development of *S. japonicum* in its intermediate host snail was 842.9–852.6 degree-days, and the same index for the development of a generation of *O. hupensis* was 3846.3 degree-days [79, 87]. Several studies conducted in Yunnan, Jiangxi, Anhui, and Hunan have drawn the similar conclusion that the mean LST, the median night-time LST, the maximum LST at daytime, the maximum and minimum LST at night, and average temperature in June were positively associated with the prevalence of *S. japonicum*, which showed the importance of LST [5, 88–93]. From another perspective, a spatio-temporal kriging model suggested seasonal variation of LST at daytime were negatively associated with the risk of schistosomiasis [94], for the possible reason that large seasonal temperature differences would impede the development of *S. japonicum* [79]. The January temperature is a significant determinant to the distribution of schistosomiasis. When the January mean minimum temperature is below −4 °C or the annual extreme low temperature drops under −7.6 °C, it is not suitable for *O. hupensis* to survive, which is the main reason that restricts transmission of *S. japonicum* shifting toward to north [79, 95]. However, the northern limit of the schistosome- endemic zone has shifted due to climate change. Yang et al. [96] found that the distribution limits of *O. hupensis* have shifted from 33°15'N to 33°41'N due to an increase of 0.96 °C of January temperature in the past 30 years. In other words, the potential transmission area have expanded by more than 40,000 km^2, which resulted in an additional 20.7 million people at risk of schistosomiasis [90]. The average minimum temperature in January and in winter had predominant influence on *Oncomelania* density and frame occurrence rate of living *Oncomelania*, respectively. The variation of average minimum temperature in January by 1 °C would lead to the change of *Oncomelania* density by 5.08–6.71%. The variation of average minimum temperature in winter by 1 °C would lead to the change of frame occurrence rate by 15.521–15.928% [97]. What's more, *O. hupensis* can only exist in areas with an annual mean temperature of 16–20 °C [98]. Yang et al. found that the lowest air temperature in a year was one of the factors that significantly affect the occurrence of snails in Hunan, China. When the lowest air temperature in a year ranges from −2.88 to −2.10 °C, the snails could exist, while no snail can survive when the range was between −2.88 and – 2.34 °C [99]. A predictive model based on distribution of schistosomiasis in eastern China has been constructed to estimate the probability that schistosomiasis occurs in a target area, which showed a mean temperature of coldest quarter was of significance in model [100]. However, air temperature is less suitable for predicting snail density compared to soil temperature [101].

Having realized the ambient temperature is one of the most principal elements affecting distribution and transmission of schistosomiasis, researchers in China focused on related studies from different perspectives. Generally, the conclusions that we had drawn are in line with those of other countries, while the subtle difference is probably due to geographic variation of the temperature. Though large number of studies that involving different temperature-related variables have been conducted, the question that which one is the most closely related to the schistosomiasis is still unknown. In addition, widespread use of GIS/RS promotes the multiscale studies in China, but there is not many studies carried out on national level yet where the trend of temperature variation is more stable. That's the direction we should focus on in future.

5.4 Ambient Temperature and Intestinal Infectious Diseases

Hand-foot-mouth disease (HFMD) is an infectious disease of infants and children [102] caused by viruses from the group called enteroviruses. According to WHO's report, outbreaks of HFMD occur every few years in different parts of the world, but in recent years these have occurred more in Asia. Countries with recent large increases in the number of reported HFMD cases in Asia include China, Japan, Hong Kong (China), Republic of Korea, Malaysia, Singapore, Thailand, and Vietnam. In China, HFMD is one of the most common infectious diseases [103]. It tends to occur in outbreaks during spring, summer, and autumn seasons. There has been a substantial increase of HFMD in many parts of the country in recent years [104].

Most of literatures reported that HFMD is a climate-sensitive disease, and it positively correlates with temperature with some days lag. A study in Beijing revealed that mean temperature was positively associated with HFMD [102]. In Jiangsu, average temperature was positively correlated to HFMD incidence, while low temperature or high temperature was negatively related [105]. In Zhengzhou, average atmospheric temperature with 2 or 3 weeks lagged were identified as significant predictors for the number of HFMD and the pathogens [106]. Using meta-analysis, Cheng et al. analyzed the relationship between ambient temperature and HFMD in East and Southeast Asia and found that ambient temperature could increase the incidence of HFMD in Asia-Pacific regions. It was revealed that 1 °C increase in the temperature was significantly correlated to the increasing of the incidence of HFMD [107]. As to the specific threshold, when the temperature was above 24.85 °C and the relative humidity was between 80.59 and 82.55%, the RR of HFMD was 3.49 relative to monthly average incidence [108].

Regarding the relationship between HFMD and ambient temperature, most studies in other countries focus on the temperature threshold for the risk of HFMD and the quantitative relationship between temperature increase and HFMD. And this is consistent to China's study. In Japan, Sumi A revealed that the average temperature data indicated a lower threshold at 12 °C and a higher threshold at 30 °C for risk of HFMD infection. Maximum and minimum temperature data indicated a lower threshold at 6 °C and a higher threshold at 35 °C [109], and the threshold is higher than that in Du et al.'s study in China in 2016. In South Korea, at an average temperature below 18 °C, the HFMD rate increased by 10.3% for every 1 °C rise in average temperature (95% confidence interval (CI), 8.4, 12.3%) [110]. In Vietnam, a 1 °C increase in average temperature was associated with 5.6% increase in HFMD rate at lag 5 days (95% CI 0.3–10.9) [111]. However, very little information is available regarding the relationship between HFMD and socioeconomic factors and demographic features. Therefore, more studies are needed to clarify the relationship between ambient temperature and incidence of HFMD in various settings with distinct climate, socioeconomic, and demographic features.

5.5 Ambient Temperature and Respiratory Infectious Diseases

Respiratory infectious diseases are a group of commonly and frequently occurring diseases, the lesion mainly in the trachea, bronchus, lungs, and thoracic cavity. Climatic conditions may have affected the incidence of respiratory infectious diseases. Influenza, commonly known as "the flu," is a representative respiratory infectious disease caused by some influenza virus. Regarding the virus classification, influenza viruses belong to RNA viruses that include three of the five genera of the family *Orthomyxoviridae*, that is, influenza A virus, influenza B virus, and influenza C virus. A fourth family of influenza viruses has been proposed – influenza D. The type species for this family is bovine influenza D virus which was first isolated in 2012. The influenza A virus can be subdivided into some serotypes on the basis of the antibody response to these viruses. The serotypes confirmed in humans and ordered by the number of known human pandemic deaths include H1N1, H2N2, H3N2, H5N1, H7N7, H1N2, H9N2, H7N2, H7N3, H10N7, H7N9, and H6N1, respectively.

Climate change may alter the incidence and severity of respiratory infections by affecting vectors and host immune responses [112]. Most literatures revealed that influenza is a climate-sensitive disease [113]. Climate change may affect the distribution and migration of the host of influenza virus and will eventually affect the transmission cycle, prevalence, and intensity of influenza. Most of studies revealed that ambient temperature was correlated to influenza risks with possible nonlinear, interactive, and lagged effects [114]. In China, the majority of studies focus on the influenza A virus, and studying the relationship between ambient temperature and H1N1, H7N9, few studies focus on avian influenza virus (AIV) and influenza B virus. Lower temperature was the climatic factor facilitating local transmission of 2009 pandemic influenza A (H1N1) in mainland China after correction for the effects of school summer vacation and public holidays, as well as population density and the density of medical facilities [115]. In Changsha, the sensitive climatic factors did have a "driving effect" on the incidence of influenza A (H1N1). In the initial stage of the disease, a 6-day lag was found between the incidence and the daily minimum temperature. In the peak period of the disease, the daily minimum temperature was negatively relevant to the incidence [116].

The outbreak of human infections with an emerging avian influenza A (H7N9) virus occurred in China in early 2013. A boosted regression tree (BRT) models revealed that temperature significantly contributed to the occurrence of human infection with H7N9 virus [117, 118]. In Shanghai, H7N9 incidence rate was significantly associated with fortnightly mean temperature (relative risk (RR), 1.54; 95% credible interval (CI), 1.22–1.94) [119]. Mean monthly temperature was significantly associated with the occurrence of human H7N9 infection [120]. Zhang et al. found that both daily minimum and daily maximum temperature contributed significantly to human infection with the influenza A H7N9 virus [121]. Models incorporating the nonlinear effect of minimum or maximum temperature on day 13 prior to disease onset were considered to have the best predictive effect. Liu et al. investigate the independent and interactive effects of ambient temperature (TM) and absolute humidity (AH) on H7N9 risks in China. Significantly nonlinear negative associations of TM and VP with H7N9 risks were observed in all cases, and in cases from northern and southern regions. Different risky windows of H7N9 infection exist in the northern (TM, 0–18 °C; VP, 313 mb) and southern areas (TM, 7–21 °C; VP, 3–17 mb) [122]. Temperature was correlated to the avian influenza virus (AIV) invasion in the destination to some degree [123]. Since the end of 2003, highly pathogenic avian influenza viruses (HPAI) H5N1 have caused lots of outbreaks in poultries and wild birds from East Asia and have spread to at least 48 countries. Liu et al. developed a new climatic approach for early predicting future HPAI outbreaks and preventing pandemic disasters. The results demonstrate a temperature drop shortly before these outbreaks in birds in each of the Eurasian regions stricken in 2005 and 2006. Dust storms, like those that struck near China's Lake Qinghai around May 4, 2005, exacerbated the spread of HPAI H5N1 virus, causing the deaths of a record number of wild birds and triggering the subsequent spread of H5N1 [124]. Climate factors were the strongest predictors of influenza B seasonality, including minimum temperature [125]. In comparison with the incidence of influenza to climatic factors during 2000–2007 in five countries, Tang et al. found that the mean temperature was the key climate variable associated with the incidence of influenza B in Hong Kong, Brisbane, Melbourne, and Vancouver [126]. Furthermore, Internet search metrics in conjunction with temperature [127] could be adopted to predict influenza outbreaks, which can be regarded as a prerequisite for establishing early-warning systems using search and temperature data.

Currently, most studies focus on influenza A virus, and very few studies are available regarding the correlation between ambient temperature and influenza B, C, and D virus. There is still lack of enough evidences concerning the independent and interactive effects of ambient temperature and other complicated climatic factors on the risk of influenza in China and comparative studies in different countries [128]. In addition, most studies in China consider the effect of specific temperature on influenza rather than a decrease of temperature; this is also important. Jaakkola K et al. found that a decrease rather than low temperature increases the risk of influenza epidemic in a cold climate [129].

5.6 Ambient Temperature and Other Infectious Diseases

In China, there are 39 notifiable infectious diseases including 2 from category A, 26 from category B, and 11 from category C. Besides the major infectious diseases mentioned above, there are still some other infectious diseases that correlate to ambient temperature such as Japanese encephalitis (JE) and Chikungunya.

5.6.1 JE

JE is an important mosquito-borne disease and is commonly transmitted via the bite of *Culex tritaeniorhynchus* with pig as a reservoir host and source of infection. At present, the morbidity and mortality of JE has declined gradually year by year. However, JE is still one of the threats to the public, and it has recently spread to new territories.

In China, some studies revealed the positive relationships between ambient temperature and JE when controlling for non-climatic factors. Using ARIMA models, monthly average temperature was positively associated with incidence of JE in Linyi, Shandong after adjusting for mass vaccination in this area [130]. Correlation analysis and back propagation artificial neural work were applied; the annual JE incidence was considered to be positively correlated with maximum temperature and extreme maximum temperature [131]. In areas close to the three gorges dam, a significant positive association between temperature with a lag of 1 and 3 months and JE incidence was found [132]. Few studies believed that temperature has a threshold effect on JE cases. In 2007, Bi et al. have clarified positive relationships between monthly maximum temperature, minimum temperature, and JE transmission in a rural region of Anhui and a metropolitan area of Shandong with no rice plating and the uncertain role of pigs in JE transmission [133]. In Jinan, an obvious increase in JE cases occurred when the monthly mean maximum temperature was higher than 25.2 °C or the minimum temperature was over 21.0 °C [133]. These findings mentioned above are consistent with the threshold temperature detection in Linyi [130].

5.6.2 Chikungunya Fever

Chikungunya fever is an emerging infection of Chikungunya virus (CHIKV), constituting a serious public health problem. It is transmitted mainly by mosquitoes of the genus *Aedes* although other ways of transmission by blood transfusions and vertical transmission have also been reported [134]. It is a climate-sensitive mosquito-transmitted viral disease which was first identified in Africa; now its distribution spread to Asia. In China, the first outbreak of Chikungunya happened in Dongguan, Guangdong, 2010. After that, the outbreak happened in Zhejiang in 2016. However, few studies are available at present concerning the correlation between ambient temperature and Chikungunya fever in China.

5.7 Projection of Important Infectious Diseases Under Different Climate Scenarios

Projection of important infectious diseases under the context of climate change is beneficial to the prevention and control of infectious disease in the future. In this section, we summarized the projection of representative vector-borne diseases including rodent-borne diseases, water-borne diseases, intestinal infectious diseases, and respiratory infectious diseases.

5.7.1 Mosquito-Borne Diseases

5.7.1.1 DF

Ambient temperature could impact the distribution of dengue vectors in China in the future. Fan et al. adopted CLIMEX model to project the changes of suitable habitat range of *Ae. albopictus* in the current climatic situation and under different climatic scenarios (RCP 2.6, RCP4.5, RCP6.0, and RCP8.5) under different times (2020s, 2030s, 2050s, and 2100s). It is revealed that future climate change will lead to the distribution of *A. albopictus* suitable area expanding to high latitude. Compared with dengue distribution of the current climatic situation (1981–2010), ambient temperature could also impact dengue transmission under RCP 2.6, RCP4.5, RCP6.0, and RCP8.5 scenarios under 2020s, 2030s, 2050s, and 2100s, respectively. Based on the findings from Fan et al., 168 million people of 142 counties (districts) in China are in the high-risk area of DF at present. Under RCP8.5 scenario, the high-risk area of DF will further expand, and it will increase to 456 counties (districts) (490 million population) in 2100.

5.7.1.2 Malaria

In China, very little literatures are available regarding the distribution of malaria in the future. Using Maxent species distribution model, the environmentally suitable area (ESA) of *A. dirus* and *A. minimus* will increase by 49 and 16% in the context of three climatic scenarios (RCP2.6, RCP4.5, and RCP8.5) in the 2030s. In the 2050s, the ESA of *A. lesteri* and *A. sinensis* under two scenarios (RCP4.5 and PCP8.5) will increase 36% and 11%, respectively. Meanwhile, considering the level of land use and urbanization, the population of exposed to four *Anopheles* mosquitoes in the 2030s and the 2050s showed a significant net increase [135].

Regarding the trend of malaria incidence in different scenarios in the future, it will show the similar trend with *Anopheles* mosquitoes [136]. In 205 counties in Henan and Anhui from 2004 to 2010, B_1 low emission scenario, A_1B intermidiate scenario, and A_2 high emission scenario, that are nearly consistent to the scenarios RCP2.6, RCP4.5, RCP6.0, and RCP8.5, respectively, were used, and GP-based model was adopted to describe the nonlinear relationship among incidence, temperature, and humidity and then project the change of incidence under different years. It is demonstrated that malaria incidence will increase markedly, and the distribution area of malaria will expand markedly in the future under the scenario of no malaria control. Specifically, the malaria incidence in North China will increase 19–29% in 2020s.

5.7.2 Rodent-Borne Diseases

Based on literature review, at present, no information is available regarding the projection of rodent-borne diseases such as HFRS, plague under different climatic scenarios. In future, the research in this field should be strengthened.

5.7.3 Schistosomiasis

With the development of new technologies and methods, accurate and stable prediction of ambient temperature-based schistosomiasis transmission becomes possible. Based on the historical data, some researchers applied the future temperature data into the transmission model for schistosomiasis projection [137].

According to historical data of temperature from 1960 to 2000 in China, a prediction that the mean January temperature will increase by 0.9 °C in 2030 and by 1.6 °C in 2050. Based on biologic model, for these temperature increases, potential risk areas for schistosomiasis transmission will increase an additional 662,373 km^2 and 783,883 km^2 by 2030 and 2050, respectively. Disease transmission is thus likely to occur in previously non-endemic areas, such as the southern parts of Shandong and Henan. Under the circumstances, the transmission intensity is possible to increase in areas already endemic for schistosomiasis [79]. To some extents, the predictions might explain the recent observations of reemergence of this disease in areas where up to the criteria for transmission control, or even interruption [71, 138, 139].

Based on the data of mean temperature and monthly minimum temperature in January in China, the impact of warming climate in winter to the scale of schistosomiasis spreading was assessed using the indexes of 0 °C mean temperature and −4 °C monthly minimum temperature in January. Results showed the possibility that *O. hupensis* moves northward [140]. Through comparison in January average temperature 0 °C, January average minimum temperature −4 °C, and January average temperature 0.9 °C, Peng et al. found the last one fitted the schistosomiasis endemic areas best. By this standard, the potential epidemic areas moved toward north, and endemic areas would significantly increase in 2100 compared to that in 2050 [141].

Zhu et al. utilized fine-tuned Maxent (fMaxent) and ensemble models to anticipate potential distributions of *O. hupensis* under future climate change scenarios on the background of SNWDP in China. Results indicated increased suitability and range expansion in *O. hupensis* in the future. The southern Central Route of SNWDP will coincide with suitable areas for *O. hupensis* in 2050–2060. Its suitable areas will also expand northward along the southern Eastern Route in 2080–2090 [142]. Modeling with application of GIS and RS that integrated ambient temperature (i.e., LST) resulted in a good predictive accuracy for the presence of *O. hupensis* in recent years [143]. Zhou et al. applied the mean monthly temperature and other environment variables in GIS model to predict the transmission of schistosomiasis in the southern part of China. *S. japonicum*-endemic areas were restricted to settings with a transmission risk index exceeding 900, which is mostly consistent with the −4 °C average minimum temperature isotherm in China, while an improved model conducted by Zhao et al. supposed isotherm was at −2 °C [144–146].

After that, an improved GIS forecast model combined with mean minimum temperature in January revealed hotspots of high transmission intensities in Jiangsu and adjacent areas in different transmission seasons, which showed a high sensitivity of 88.9% [146].

By using the results from PRECIS on reference years (1991–2005), more than 20 meteorological indexes including the highest and lowest temperature of the day in 2050s (2046–2050) and 2070s (2066–2070) were estimated under A_2 and B_2 scenario, which were developed in the IPCC (Intergovernmental Panel on Climate Change) Special Report on Emissions Scenarios (SRES) to reflect the extent of climate change. The biology-based model is used to calculate the corresponding risk areas and potential transmission index in China in response to different climate scenarios. The transmission areas of schistosomiasis are supposed to extend to north both in 2050s and 2070s under A_2 and B_2 scenario, especially in Jiangsu and Anhui, and the extended areas in 2070s are larger than that in 2050s. North boundary of the transmission areas will extend further north under A_2 than that under B_2 in 2070s, which has reached Shandong. Compared with the year of 2005, the high-risk areas with potential transmission index>1500 increased by 89.6% and 81.3% under A_2 and B_2 in 2050s, respectively, which further increased in the 2070s [147].

5.7.4 HFMD

Based on literature review, the association between temperature and HFMD varies across China and that the future impact of climate change on HFMD incidence will vary as well. Zhao et al. projected the change in HFMD cases due to projected temperature change by the 2090s [148]. They found that the projected incidence of HFMD increased by 3.2% and 5.3% by the 2090s under the RCP 4.5 and 8.5 scenarios, respectively. However, regional projections suggest that HFMD may decrease with climate change in temperate areas of central and eastern China.

Wang et al. adopted the spatial regression model to project the incidence of HFMD according to projected climatic factors and population under different emission scenarios. There was not significant variation of the average incidence of HFMD from 2030s to 2080s under RCP 2.6 scenario. The incidence of the disease was also increased under RCP 4.5 and RCP 6.0 scenarios. However, the average incidence of HFMD would increase linearly under RCP 8.5 scenario with the fastest growth rate (unpublished). Regarding the trend of HFMD in various major administrative regions under different climate scenarios, the incidence of HFMD in the northeast and northwest regions declined continuously in the future, while the increase of the incidence of the southwest region was under RCP 2.6 scenario. Under the scenario of RCP4.5, the incidence of HFMD in North China, East China, Central China, southern China, and southwest increased continuously. In the context of RCP6.0, the incidence of the disease in north China, East China, Central China, and southern China increased continuously. And in the context of RCP 8.5, the incidence of the disease in other regions, except in the northeast, increased. According to the trend of HFMD in various climate zone under different climate scenarios, the trend of the incidence of HFMD is increased in the Qinghai Tibet plateau and the middle subtropical region while that decreased in the middle temperate zone under the scenario of RCP 2.6. Under the RCP 4.5 scenario, the incidence of HFMD in the warm temperate zone, the northern subtropical zone, the middle subtropical, and the south subtropical regions is increased continuously while that decreased in the moderate temperate zone and the cold temperate zone; and the incidence of HFMD in warm temperate, northern subtropical, south subtropical, and marginal tropics is increased continuously while that decreased in middle temperate zone and cold temperate zone under RCP 6.0 scenario; and the incidence of HFMD in other regions increased except that in the middle temperate zone and cold temperate zone under RCP 8.5 scenario.

5.7.5 Respiratory Infectious Diseases

Regarding the projection of influenza in China, at present, very little information is available. Take H5N1 avian influenza for example, based on 20 global climate projection models under the future scenarios, Chen et al. obtained seasonal distribution of migratory birds in the context of different climate models and the seasonal distribution of H5N1 avian influenza in migratory birds. The results show that Japan and southern China will become high-risk areas of H5N1 highly pathogenic avian influenza in January and February. Northern Africa, Western Asia, and Central Asia entered a high-risk period from April to June. The west coast of Africa, West Asia, India, and southern China become areas high risk of outbreak after October. Compared with the current situation in high-risk areas, high-risk areas in Africa will move northward from the central part of the continent. In addition, the high-risk area of H5N1 avian influenza in winter in future will spread from low latitudes to high latitudes.

5.8 Summary

In this chapter, the relationship between ambient temperature and infectious diseases were systematically summarized in China. We focused on not only the impact of temperature on the current situation of infectious diseases including vector-borne diseases, rodent-borne diseases, water-borne diseases, HFMD, and respiratory diseases but also future trend of these diseases mentioned above. The findings may provide scientific evidence for the prevention and control of infectious diseases in China. The summary information of infectious diseases due to ambient temperature may provide a valuable knowledge for the policy-maker to develop the climate-based intervention strategies and adapted measures to protect public health from ambient temperature.

Acknowledgments This study were supported by the National Key Research and Development Project "Biological Security Key Technology Research and Development" Special Funds (No. 2016YFC1200802), National Natural Science Foundation of China (No. 81703280), and National Science and Technology Major Project (No. 2017ZX10303404-005).

References

1. Liu Q, Xu W, et al. Landscape of emerging and re-emerging infectious diseases in China: impact of ecology, climate, and behavior. Front Med. 2018a;12(1):3–22.
2. Li C, Lu Y, et al. Climate change and dengue fever transmission in China: evidences and challenges. Sci Total Environ. 2018;622-623:493–501.
3. Li T, Yang Z, et al. Temperature, relative humidity and sunshine may be the effective predictors for occurrence of malaria in Guangzhou, southern China, 2006-2012. Parasit Vectors. 2013b;6:155.
4. Sun Leping ZX, Qingbiao H, Yang G, Yixin H, Weiping X, Yuji J. Impact of global warming on the transmission of schistosomiasis in China V. Effectively growing degree days of schistosoma japonicum developing in different snail populations. Chin J Schisto Control. 2003;15(5):342–5.
5. Yi H, Xia C, et al. Assessing environmental factors associated with regional schistosomiasis prevalence in Anhui Province, Peoples' Republic of China using a geographical detector method. Infect Dis Poverty. 2017;6(1):87.
6. Li J, Rao Y, et al. Identification of climate factors related to human infection with avian influenza A H7N9 and H5N1 viruses in China. Sci Rep. 2015a;5:18094.
7. Chen B, Liu Q. Dengue fever in China. Lancet. 2015;385(9978):1621–2.
8. Wu F, Liu Q, et al. Distribution of Aedes albopictus (Diptera: Culicidae) in northwestern China. Vector Borne Zoonotic Dis. 2011;11(8):1181–6.
9. Liu Z, Zhang Z, et al. Temperature increase enhances Aedes albopictus competence to transmit dengue virus. Front Microbiol. 2017;8:2337.
10. Jing QL, Cheng Q, et al. Imported cases and minimum temperature drive dengue transmission in Guangzhou, China: evidence from ARIMAX model. Epidemiol Infect. 2018;146:1226–35.
11. Xu L, Stige LC, et al. Climate variation drives dengue dynamics. Proc Natl Acad Sci U S A. 2017;114(1):113–8.
12. Wu X, Lang L, et al. Non-linear effects of mean temperature and relative humidity on dengue incidence in Guangzhou, China. Sci Total Environ. 2018;628-629:766–71.
13. Sang S, Yin W, et al. Predicting local dengue transmission in Guangzhou, China, through the influence of imported cases, mosquito density and climate variability. PLoS One. 2014;9(7):e102755.
14. Lu L, Lin H, et al. Time series analysis of dengue fever and weather in Guangzhou, China. BMC Public Health. 2009;9:395.

15. Fan J, Lin H, et al. Identifying the high-risk areas and associated meteorological factors of dengue transmission in Guangdong Province, China from 2005 to 2011. Epidemiol Infect. 2014;142(3):634–43.
16. Xiang J, Hansen A, et al. Association between dengue fever incidence and meteorological factors in Guangzhou, China, 2005-2014. Environ Res. 2017;153:17–26.
17. Shen JC, Luo L, et al. The impacts of mosquito density and meteorological factors on dengue fever epidemics in Guangzhou, China, 2006-2014: a time-series analysis. Biomed Environ Sci. 2015;28(5):321–9.
18. Zhou SS, Huang F, et al. Geographical, meteorological and vectorial factors related to malaria re-emergence in Huang-Huai River of Central China. Malar J. 2010;9:337.
19. Bi P, Tong S, et al. Climatic variables and transmission of malaria: a 12-year data analysis in Shuchen County, China. Public Health Rep. 2003;118(1):65–71.
20. Zhao X, Chen F, et al. Characterizing the effect of temperature fluctuation on the incidence of malaria: an epidemiological study in south-west China using the varying coefficient distributed lag non-linear model. Malar J. 2014;13:192.
21. Zhang Y, Bi P, et al. Meteorological variables and malaria in a Chinese temperate city: a twenty-year time-series data analysis. Environ Int. 2010b;36(5):439–45.
22. Tian L, Bi Y, et al. One-year delayed effect of fog on malaria transmission: a time-series analysis in the rain forest area of Mengla County, south-west China. Malar J. 2008;7:110.
23. Huang F, Zhang S, Wang H, Tang L. Temporal correlation analysis between malaria and meteorological factors in Motuo County, Tibet. Malar J. 2011;10:54.
24. Wardrop NA, Barnett AG, et al. Plasmodium vivax malaria incidence over time and its association with temperature and rainfall in four counties of Yunnan Province, China. Malar J. 2013;12:452.
25. Bramanti B, Stenseth NC, et al. In: Yang R, Anisimov A, editors. Plague: a disease which changed the path of human civilization. Yersinia pestis: retrospective and perspective. Berlin: Springer; 2016. p. 1–26.
26. Perry RD, Fetherston JD. Yersinia pestis—etiologic agent of plague. Clin Microbiol Rev. 1997;10(1):35–66.
27. Ari TB, Gershunov A, et al. Human plague in the USA: the importance of regional and local climate. Biol Lett. 2008;4(6):737–40.
28. Ari TB, Neerinckx S, et al. Plague and climate: scales matter. PLoS Pathog. 2011;7(9):e1002160.
29. Holt AC, Salkeld DJ, et al. Spatial analysis of plague in California: niche modeling predictions of the current distribution and potential response to climate change. Int J Health Geogr. 2009;8(1):38.
30. Parmenter RR, Yadav EP, et al. Incidence of plague associated with increased winter-spring precipitation in New Mexico. Am J Trop Med Hyg. 1999;61(5):814–21.
31. Xu L, Fang X, et al. The evolutionary dynamics and the ecological niche of natural plague foci in China. Chin J Vector Biol Control. 2015a;3:228–32.
32. Davis S, Begon M, et al. Predictive thresholds for plague in Kazakhstan. Science. 2004;304(5671):736–8.
33. Kausrud KL, Begon M, et al. Modeling the epidemiological history of plague in Central Asia: palaeoclimatic forcing on a disease system over the past millennium. BMC Biol. 2010;8(1):112.
34. Reijniers J, Davis S, et al. A curve of thresholds governs plague epizootics in Central Asia. Ecol Lett. 2012;15(6):554–60.
35. Davis S, Calvet E, et al. Fluctuating rodent populations and risk to humans from rodent-borne zoonoses. Vector Borne Zoonotic Dis. 2005;5(4):305–14.
36. Gage KL, Burkot TR, et al. Climate and vectorborne diseases. Am J Prev Med. 2008;35(5):436–50.
37. Schmid BV, Büntgen U, et al. Climate-driven introduction of the black death and successive plague reintroductions into Europe. Proc Natl Acad Sci U S A. 2015;112(10):3020–5.
38. Enscore RE, Biggerstaff BJ, et al. Modeling relationships between climate and the frequency of human plague cases in the southwestern United States, 1960-1997. Am J Trop Med Hyg. 2002;66(2):186–96.
39. Xu L, Liu Q, et al. Nonlinear effect of climate on plague during the third pandemic in China. Proc Natl Acad Sci U S A. 2011;108(25):10214–9.
40. Brown HE, Ettestad P, et al. Climatic predictors of the intra- and inter-annual distributions of plague cases in New Mexico based on 29 years of animal-based surveillance data. Am J Trop Med Hyg. 2010;82(1):95–102.
41. Cavanaugh DC, Marshall JD Jr. The influence of climate on the seasonal prevalence of plague in the Republic of Vietnam. J Wildl Dis. 1972;8(1):85–94.
42. Stenseth NC, Samia NI, et al. Plague dynamics are driven by climate variation. Proc Natl Acad Sci U S A. 2006;103(35):13110–5.
43. Xu L, Schmid BV, et al. The trophic responses of two different rodent–vector–plague systems to climate change. Proc R Soc Lond B Biol Sci. 2015b;282(1800):20141846.
44. Yue RPH, Lee HF. Pre-industrial plague transmission is mediated by the synergistic effect of temperature and aridity index. BMC Infect Dis. 2018a;18(1):134.
45. Kreppel KS, Caminade C, et al. A non-stationary relationship between global climate phenomena and human plague incidence in Madagascar. PLoS Negl Trop Dis. 2014;8(10):e3155.
46. Zhang Z, Li Z, et al. Relationship between increase rate of human plague in China and global climate index as revealed by cross-spectral and cross-wavelet analyses. Integr Zool. 2007;2(3):144–53.
47. Yue RPH, Lee HF. The relationship between climate change and plague in European history. Sci Sin Terrae. 2018b;48(2):165–80.
48. Liu J, Xue FZ, et al. Association of haemorrhagic fever with renal syndrome and weather factors

in Junan County, China: a case-crossover study. Epidemiol Infect. 2013;141(4):697–705.
49. Hansen A, Cameron S, et al. Transmission of haemorrhagic fever with renal syndrome in China and the role of climate factors: a review. Int J Infect Dis. 2015;33:212–8.
50. Lin H, Zhang Z, et al. Meteorological factors are associated with hemorrhagic fever with renal syndrome in Jiaonan County, China, 2006-2011. Int J Biometeorol. 2014;58(6):1031–7.
51. Xiao H, Lin X, et al. Ecology and geography of hemorrhagic fever with renal syndrome in Changsha, China. BMC Infect Dis. 2013b;13:305.
52. Jiang F, Wang L, et al. Meteorological factors affect the epidemiology of hemorrhagic fever with renal syndrome via altering the breeding and hantavirus-carrying states of rodents and mites: a 9 years' longitudinal study. Emerg Microbes Infect. 2017;6(11):e104.
53. Bi P, Tong S, et al. Climatic, reservoir and occupational variables and the transmission of haemorrhagic fever with renal syndrome in China. Int J Epidemiol. 2002;31(1):189–93.
54. Guan P, Huang D, et al. Investigating the effects of climatic variables and reservoir on the incidence of hemorrhagic fever with renal syndrome in Huludao City, China: a 17-year data analysis based on structure equation model. BMC Infect Dis. 2009;9:109.
55. Joshi YP, Kim EH, et al. The influence of climatic factors on the development of hemorrhagic fever with renal syndrome and leptospirosis during the peak season in Korea: an ecologic study. BMC Infect Dis. 2017;17(1):406.
56. Li CP, Cui Z, Li SL, Magalhaes RJ, Wang BL, Zhang C, Sun HL, Li CY, Huang LY, Ma J, Zhang WY. Association between hemorrhagic fever with renal syndrome epidemic and climate factors in Heilongjiang Province, China. Am J Trop Med Hyg. 2013a;89(5):1006–12.
57. Liu X, Jiang B, et al. Temporal trend and climate factors of hemorrhagic fever with renal syndrome epidemic in Shenyang City, China. BMC Infect Dis. 2011;11:331.
58. Xiang J, Hansen A, et al. Impact of meteorological factors on hemorrhagic fever with renal syndrome in 19 cities in China, 2005-2014. Sci Total Environ. 2018;636:1249–56.
59. Xiao H, Gao LD, et al. Environmental variability and the transmission of haemorrhagic fever with renal syndrome in Changsha, People's Republic of China. Epidemiol Infect. 2013a;141(9):1867–75.
60. Fang LQ, Wang XJ, et al. Spatiotemporal trends and climatic factors of hemorrhagic fever with renal syndrome epidemic in Shandong Province, China. PLoS Negl Trop Dis. 2010;4(8):e789.
61. Wei Y, Wang Y, et al. Meteorological factors and risk of hemorrhagic fever with renal syndrome in Guangzhou, southern China, 2006-2015. PLoS Negl Trop Dis. 2018;12(6):e0006604.
62. Zhang WY, Guo WD, et al. Climate variability and hemorrhagic fever with renal syndrome transmission in northeastern China. Environ Health Perspect. 2010a;118(7):915–20.
63. Jimin Sun LL, Yang J, Liu K, Wu H, Liu Q. Association between severe fever with thrombocytopenia syndrome incidence and ambient temperature. Am J Trop Med Hyg. 2018;98(5):1478–83.
64. Sun JM, Lu L, et al. Forecast of severe fever with thrombocytopenia syndrome incidence with meteorological factors. Sci Total Environ. 2018;626:1188–92.
65. Du Z, Wang Z, et al. Ecological niche modeling for predicting the potential risk areas of severe fever with thrombocytopenia syndrome. Int J Infect Dis. 2014;26:1–8.
66. Wang T, Li XL, et al. Epidemiological characteristics and environmental risk factors of severe fever with thrombocytopenia syndrome in Hubei Province, China, from 2011 to 2016. Front Microbiol. 2017;8:387.
67. Zhai Yujia LF, Xiaopeng S, He F, Lin J. A study on the association between meteorological factors and severe fever with thrombocytopenia syndrome. Zhejiang Prev Med. 2016;28(2):117–20. (in Chinese).
68. Utzinger J, Keiser J. Schistosomiasis and soil-transmitted helminthiasis: common drugs for treatment and control. Expert Opin Pharmacother. 2004;5(2):263–85.
69. King CH, Dickman K, et al. Reassessment of the cost of chronic helmintic infection: a meta-analysis of disability-related outcomes in endemic schistosomiasis. Lancet. 2015;365(9470):1561–9.
70. Wang W, Liang YS, et al. African schistosomiasis in mainland China: risk of transmission and countermeasures to tackle the risk. Parasit Vectors. 2013b;6(1):249.
71. Zhou XN, Wang LY, et al. The public health significance and control of schistosomiasis in China—then and now. Acta Trop. 2005;96(2):97–105.
72. Guo D, Zhang Y, et al. Functional properties of hemocyanin from Oncomelania hupensis, the intermediate host of Schistosoma japonicum. Exp Parasitol. 2009;123(3):277–81.
73. Wei MA, Liao WG, et al. Study on response of suitable environment for Oncomelania breeding grounds to variation of flow regime. J Yangtze River Sci Res Inst. 2010;27(10):65–9.
74. Mao CP. Biology of schistosome and control of schistosomiasis. Beijing: People's Health Press; 1990.
75. Ross AGP, Sleigh AC, et al. Schistosomiasis in the People's Republic of China: prospects and challenges for the 21st century. Clin Microbiol Rev. 2001;14(2):270.
76. Stensgaard AS, Utzinger J, et al. Large-scale determinants of intestinal schistosomiasis and intermediate host snail distribution across Africa: does climate matter? Acta Trop. 2013;128(2):378–90.

77. Yang GJ, Utzinger J, et al. The regional network for Asian Schistosomiasis and other Helminth Zoonoses (RNAS+): target diseases in face of climate change. Adv Parasitol. 2010a;73:101.
78. Yang GJ, Vounatsou P, et al. A Bayesian-based approach for spatio-temporal modeling of county level prevalence of Schistosoma japonicum infection in Jiangsu province, China. Int J Parasitol. 2005a;35(2):155–62.
79. Zhou XN, Yang GJ, et al. Potential impact of climate change on schistosomiasis transmission in China. Am J Trop Med Hyg. 2008;78(2):188–94.
80. Leping ZX, Qingbiao H, Yang G, Yixing H, Weiping X, Yuji J. Impact of global warming on transmission of schistosomiasis in china III relationship between snail infections rate and environmental temperature. Chin J Schisto Control. 2003;15(3):161–3.
81. Yang GJ, Utzinger J, et al. Effect of temperature on the development of Schistosoma japonicum within Oncomelania hupensis, and hibernation of O. hupensis. Parasitol Res. 2007;100(4):695–700.
82. Zhou Xiaonong YG, Leping S, Qingbiao H, Yang K, Wang R, Zhenghui H. The potential impact of global warming on schistosomiasis transmission. Chin J Epidemiol. 2002;23(2):83–6.
83. Xu Y, Zhang S. The influence of environmental factors on snail growth and distribution. Int J Med Parasit Dis. 2011;38(4):218–22.
84. Liu YY, Zhang WZ, Wang YX. Medical malacology. Beijing: Ocean Press; 1993.
85. Zhu HR, Liu L, et al. Ecological model to predict potential habitats of Oncomelania hupensis, the intermediate host of Schistosoma japonicum in the mountainous regions, China. PLoS Negl Trop Dis. 2015;9(8):e0004028.
86. Wu JY, Zhou YB, et al. Identification of optimum scopes of environmental factors for snails using spatial analysis techniques in Dongting Lake region, China. Parasit Vectors. 2014;7(1):216.
87. Sun LP, Zhou XN, et al. Investigation on effectively growing degree days of cercaria of Schistosoma japonicum developing in snail. Chin J Zoonoses. 2003;19(06):59–61.
88. Gong C, Dan L, et al. The influence of natural factors on the spatio-temporal distribution of Oncomelania hupensis. Acta Trop. 2016;164:194–207.
89. Wang XH, Zhou XN, et al. Bayesian Spatio-temporal modeling of Schistosoma japonicum prevalence data in the absence of a diagnostic 'gold' standard. PLoS Negl Trop Dis. 2008;2(6):e250.
90. Yang GJ, Vounatsou P, et al. A potential impact of climate change and water resource development on the transmission of Schistosoma japonicum in China. Parassitologia. 2005b;47(1):127.
91. Yang J, Zhao Z, et al. A multi-level analysis of risk factors for Schistosoma japonicum infection in China. Int J Infect Dis. 2009;13(6):e407–12.
92. Yi H, Zhang Z, et al. Spatial pattern of schistosomiasis in Xingzi, Jiangxi Province, China: the effects of environmental factors. Part Fibre Toxicol. 2013;6(1):214.
93. Yong W, Zhuang D. A rapid monitoring and evaluation method of schistosomiasis based on spatial information technology. Int J Environ Res Public Health. 2015;12(12):15843–59.
94. Hu Y, Li R, et al. Spatio-temporal transmission and environmental determinants of Schistosomiasis japonica in Anhui Province, China. PLoS Negl Trop Dis. 2015b;9(2):e0003470.
95. Zhang Zhijie PW, Jianlin Z, Yibiao Z, Genming Z, Qingwu J. Relationships between distribution of Oncomelania hupensis and extreme air temperature in a year. Chin J Schisto Control. 2005;17(5):341–3.
96. Yang GJ, Vounatsou P, et al. A review of geographic information system and remote sensing with applications to the epidemiology and control of schistosomiasis in China. Acta Trop. 2005c;96(2):117–29.
97. Liu Kequn XX, Yuxia C, Rendong L, Yang T, Fenghua W. Analysis on influence of meteorological factors on Oncomelania density. Chin J Epidemiol. 2015;36(11):1274–8.
98. Zheng Y, Qang Q, et al. The function of the overlaying climate data in analysis of Oncomelania snail distribution. Chin Publ Health. 1998;14:724–5.
99. Yang Y, Zheng SB, et al. The three gorges dam: does the flooding time determine the distribution of Schistosome-transmitting snails in the middle and lower reaches of the Yangtze River, China? Int J Environ Res Public Health. 2018;15(7):1304.
100. Schrader M, Hauffe T, et al. Spatially explicit modeling of schistosomiasis risk in eastern China based on a synthesis of epidemiological, environmental and intermediate host genetic data. PLoS Negl Trop Dis. 2013;7(7):e2327.
101. Zhang Z, Ong S, et al. A model for the prediction of Oncomelania hupensis in the lake and marshland regions, China. Parasitol Int. 2008;57(2):121–31.
102. Tian L, Liang F, et al. Spatio-temporal analysis of the relationship between meteorological factors and hand-foot-mouth disease in Beijing, China. BMC Infect Dis. 2018;18(1):158.
103. Shi RX, Wang JF, et al. Spatiotemporal pattern of hand-foot-mouth disease in China: an analysis of empirical orthogonal functions. Public Health. 2014;128(4):367–75.
104. Wang JF, Xu CD, et al. Spatial dynamic patterns of hand-foot-mouth disease in the People's Republic of China. Geospat Health. 2013a;7(2):381–90.
105. Liu W, Ji H, et al. Spatiotemporal dynamics of hand-foot-mouth disease and its relationship with meteorological factors in Jiangsu Province, China. PLoS One. 2015;10(6):e0131311.
106. Feng H, Duan G, et al. Time series analysis of hand-foot-mouth disease hospitalization in Zhengzhou: establishment of forecasting models using climate variables as predictors. PLoS One. 2014;9(1):e87916.
107. Cheng Q, Bai L, et al. Ambient temperature, humidity and hand, foot, and mouth disease: a system-

atic review and meta-analysis. Sci Total Environ. 2018;625:828–36.
108. Du Z, Zhang W, et al. The threshold effects of meteorological factors on hand, foot, and mouth disease (HFMD) in China, 2011. Sci Rep. 2016;6:36351.
109. Sumi A, Toyoda S, Kanou K, Fujimoto T, Mise K, Kohei Y, Koyama A, Kobayashi N. Association between meteorological factors and reported cases of hand, foot, and mouth disease from 2000 to 2015 in Japan. Epidemiol Infect. 2017;145(14):2896–911.
110. Kim BI, Ki H, et al. Effect of climatic factors on hand, foot, and mouth disease in South Korea, 2010-2013. PLoS One. 2016;11(6):e0157500.
111. Nguyen HX, Chu C, et al. Temporal and spatial analysis of hand, foot, and mouth disease in relation to climate factors: a study in the Mekong Delta region, Vietnam. Sci Total Environ. 2017;581-582:766–72.
112. Mirsaeidi M, Motahari H, et al. Climate change and respiratory infections. Ann Am Thorac Soc. 2016;13(8):1223–30.
113. Chen G, Zhang W, et al. The impact of ambient fine particles on influenza transmission and the modification effects of temperature in China: a multi-city study. Environ Int. 2017;98:82–8.
114. Lau SY, Wang X, et al. Identification of meteorological factors associated with human infection with avian influenza A H7N9 virus in Zhejiang Province, China. Sci Total Environ. 2018;644:696–709.
115. Fang LQ, Wang LP, et al. Distribution and risk factors of 2009 pandemic influenza A (H1N1) in mainland China. Am J Epidemiol. 2012;175(9):890–7.
116. Xiao H, Lin XL, et al. Study on sensitivity of climatic factors on influenza A (H1N1) based on classification and regression tree and wavelet analysis. Zhonghua Yu Fang Yi Xue Za Zhi. 2012;46(5):430–5.
117. Fang LQ, Li XL, et al. Mapping spread and risk of avian influenza a (H7N9) in China. Sci Rep. 2013;3:2722.
118. Li XL, Yang Y, et al. Risk distribution of human infections with avian influenza H7N9 and H5N1 virus in China. Sci Rep. 2015b;5:18610.
119. Hu W, Zhang W, et al. Weather variability and influenza a (H7N9) transmission in Shanghai, China: a Bayesian spatial analysis. Environ Res. 2015a;136:405–12.
120. Qiu J, Li R, et al. Spatiotemporal pattern and risk factors of the reported novel avian-origin influenza A (H7N9) cases in China. Prev Vet Med. 2014;115(3–4):229–37.
121. Zhang Y, Feng C, et al. The impact of temperature and humidity measures on influenza A (H7N9) outbreaks-evidence from China. Int J Infect Dis. 2015;30:122–4.
122. Liu T, Kang M, et al. Independent and interactive effects of ambient temperature and absolute humidity on the risks of avian influenza A (H7N9) infection in China. Sci Total Environ. 2018b;619-620:1358–65.
123. Lu L, Leigh Brown AJ, et al. Quantifying predictors for the spatial diffusion of avian influenza virus in China. BMC Evol Biol. 2017;17(1):16.
124. Liu CM, Lin SH, et al. Temperature drops and the onset of severe avian influenza A H5N1 virus outbreaks. PLoS One. 2007;2(2):e191.
125. Yu H, Alonso WJ, et al. Characterization of regional influenza seasonality patterns in China and implications for vaccination strategies: spatio-temporal modeling of surveillance data. PLoS Med. 2013;10(11):e1001552.
126. Tang JW, Lai FY, et al. Comparison of the incidence of influenza in relation to climate factors during 2000-2007 in five countries. J Med Virol. 2010;82(11):1958–65.
127. Zhang Y, Bambrick H, et al. Using Google trends and ambient temperature to predict seasonal influenza outbreaks. Environ Int. 2018;117:284–91.
128. Iha Y, Higa F, et al. Effect of climatic conditions on epidemic patterns of influenza in Okinawa, Japan, during the pandemic of 2009: surveillance of rapid antigen test results. Jpn J Infect Dis. 2012;65(4):295–300.
129. Jaakkola K, Saukkoriipi A, et al. Decline in temperature and humidity increases the occurrence of influenza in cold climate. Environ Health. 2014;13(1):22.
130. Lin H, Yang L, et al. Time series analysis of Japanese encephalitis and weather in Linyi City, China. Int J Public Health. 2012;57(2):289–96.
131. Qu B, Guan P, Zhou BS, Huang DS. Study on the impact of meteorological factors on Japanese encephalitis incidence. Chin J Epidemiol Infect. 2006;27:179.
132. Bai Y, Xu Z, et al. Regional impact of climate on Japanese encephalitis in areas located near the three gorges dam. PLoS One. 2014;9(1):e84326.
133. Bi P, Zhang Y, et al. Weather variables and Japanese encephalitis in the metropolitan area of Jinan city, China. J Infect. 2007;55(6):551–6.
134. Moizeis RNC, Fernandes T, et al. Chikungunya fever: a threat to global public health. Pathog Glob Health. 2018:1–13.
135. Ren Z, Wang D, et al. Predicting malaria vector distribution under climate change scenarios in China: challenges for malaria elimination. Sci Rep. 2016;6:20604.
136. Hundessa S, Li S, et al. Projecting environmental suitable areas for malaria transmission in China under climate change scenarios. Environ Res. 2018;162:203–10.
137. Zhou Xiaonong YK, Qingbiao H, Leping S, Yang G, Liang Y, Yixin H. Prediction of the impact of climate warming on transmission of Schistosomiasis in China. Chin J Parasitol Parasit Dis. 2004;22(5):2–265.
138. Liang S, Yang C, et al. Re-emerging schistosomiasis in hilly and mountainous areas of Sichuan, China. Bull World Health Organ. 2006;84(2):139.
139. Utzinger J, Zhou XN, et al. Conquering schistosomiasis in China: the long march. Acta Trop. 2005;96(2–3):69–96.
140. Yu Xianshan TW, Shen J, Jian C. Assessment on the impact of warming climate in winter on schistosomiasis epidemIcs. Chin J Epidemiol. 2004;25(7):575–7.

141. Peng WX, Zhang ZJ, Zhuang JL, Zhou YB, Jang QW. Potential impact of climate changes on spatial distribution of Schistosomiasis in China. Sci Technol Rev. 2006;24(7):58–60.
142. Zhu G, Fan J, et al. Schistosoma japonicum transmission risk maps at present and under climate change in mainland China. PLoS Negl Trop Dis. 2017;11(10):e0006021.
143. Zhang ZY, Xu DZ, et al. Remote sensing and spatial statistical analysis to predict the distribution of Oncomelania hupensis in the marshlands of China. Acta Trop. 2005;96(2):205–12.
144. Zhao A, Wang TJ. A re-adapted Malone Schistosome transmission index model and its application. Geogr Res. 2008;27(2):250–6.
145. Zhou XN, Hu XS, et al. Application of geographic information systems on schistosomiasis surveillance I. Application possibility of prediction model. Chin J Schistosomiasis Control. 1998.
146. Zhou XN, Hu XS, et al. Application of geographical information systems on schistosomiasis surveillance II. Predicting transmission intensity. Chin J Schi Contl. 1999;2:66–70.
147. Yang K, Pan J, et al. Projection of the transmission scale and intensity of Schistosomiasis in China under A2 and B2 climate change scenarios. Adv Clim Chang Res. 2010b;6(04):248–53.
148. Zhao Q, Li S, et al. Modeling the present and future incidence of pediatric hand, foot, and mouth disease associated with ambient temperature in mainland China. Environ Health Perspect. 2018;126(4):047010.

Ambient Temperature and Reproductive Health Outcomes

6

Minshan Lu, Xuan Zhao, Dongmei Wei,
Jiaying Zhang, Yusi Li, Jianrong He, Huimin Xia,
and Xiu Qiu

Abstract

Increasing evidence shows that ambient temperature has extensive effects on reproductive health outcomes, including hypertensive disorders, preterm birth, and childhood health. In this chapter, related studies published in Chinese or in English were searched from electronic sources and references lists of identified sources, to obtain a whole picture on the updated association between ambient temperature exposure and reproductive health outcomes in Chinese population.

Keywords

Ambient temperature · Hypertensive disorders · Preterm birth · Childhood health

6.1 Blood Pressure-Related Diseases

Hypertensive disorders during pregnancy, including gestational hypertension, preeclampsia, and eclampsia, contribute to perinatal morbidity and mortality both for mothers and their children. According to tenth revision of the International Classification of Diseases [ICD-10], gestational hypertension (O13) was regarded as new onset of hypertension (higher than 140 mmHg in systolic blood pressure and/or higher than 90 mmHg in diastolic blood pressure) after 20 gestational weeks; preeclampsia (O14) was defined as proteinuria or organ dysfunction in the patient with new onset of hypertension; eclampsia (O15) was seizures in a diagnosed preeclampsia patient that could not be ascribed to other causational factors [1].

There might be a relationship between seasons, ambient temperature, and hypertensive disorders. A study conducted in Hong Kong showed that conception in hot seasons and being exposed in high ambient temperature for a long time increased the risks of preeclampsia. Hong Kong, located in the south of China and characterized by subtropical climate, has four different seasons. While winter is cold and dry, summer is identified by high temperature and humidity. Spring and autumn are the transitional seasons. In the study, the risk of occurrence of preeclampsia for women conceived during summer was significantly increased when compared to autumn (OR 1.7, 95% CI: 1.2–2.5). Women who conceived in winter and spring were not with higher risk. The highest incidence of preeclampsia was found in women who conceived in June (3.0%), while lowest incidence was found in

M. Lu · X. Zhao · D. Wei · J. Zhang · Y. Li · J. He
H. Xia · X. Qiu (✉)
Division of Birth Cohort Study, Guangzhou Women and Children's Medical Center, Guangzhou Medical University, Guangzhou, China
e-mail: xiu.qiu@bigcs.org

H. Lin et al. (eds.), *Ambient Temperature and Health in China*,
https://doi.org/10.1007/978-981-13-2583-0_6

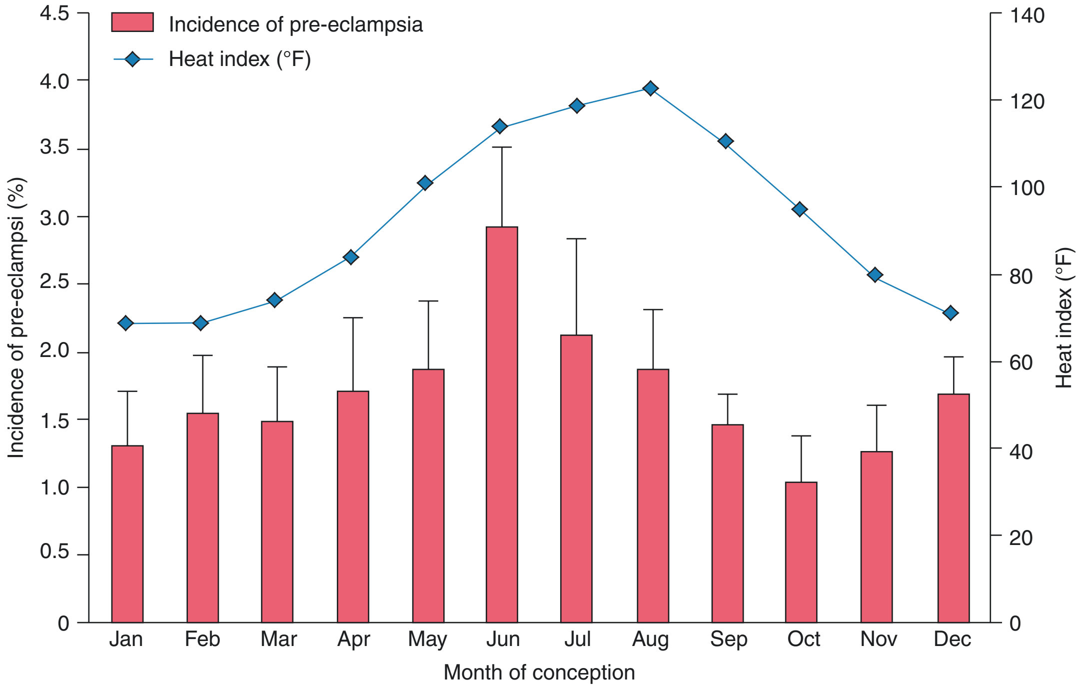


Fig. 6.1 Incidence of preeclampsia by months of conception (12 months) and the mean heat indices of the corresponding months. Error bars represent the standard errors of the means of the monthly incidences of preeclampsia [2]

women conceived in October (1.1%) (as shown in Fig. 6.1) [2]. Higher ambient temperature in the early stage of pregnancy might have a detrimental influence on development and remodeling of placental vascular, though the mechanism has to be studied in the future. The process of placental impairment and dysfunction has been thought to be the pathology of preeclampsia.

However, some possible confounders like the time intervals between conception and onset of clinical symptoms of hypertensive disorders may affect the seasonal effect on the risk of preeclampsia. When considering the incidence of hypertensive disorders only based on the time of diagnosis, researchers found that the rate of hypertensive disorders, particularly preeclampsia, in winter was higher than other three seasons among Chinese pregnant women in Nanchang (as shown in Fig. 6.2), a city with lowest temperature in January and December (2–21 °C) and highest temperature in July (19–38 °C) [3]. In addition, there was a negative relationship between ambient temperature and incidence of hypertensive disorders during pregnancy ($r = -0.787$, $P = 0.002$) [3]. However, Li et al. reported that in Liuyang, a county-level city in Hunan Province of China, compared with summer delivery, delivery in winter or spring was associated with a higher probability of gestational hypertension (winter, adjusted OR = 1.40, 95% CI: 1.01–1.95; spring, 1.47, 1.06–2.04), but not preeclampsia [4].

Although the biological mechanisms of the effect of ambient temperature on hypertensive disorders complicating pregnancy are not fully known, several possible underlying mechanisms have been proposed. Firstly, low ambient temperature can activate sympathetic nervous system and the renin vasoactive system, increase the level of catecholamine secretion, reduce the production of nitric oxide, lead to peripheral vascular contraction, and increase heart rate and cardiac output. As a result, pressure of blood on the vascular wall and resistance of periphery blood vessels are increased, and high blood pressure occurs [5, 6]. Under

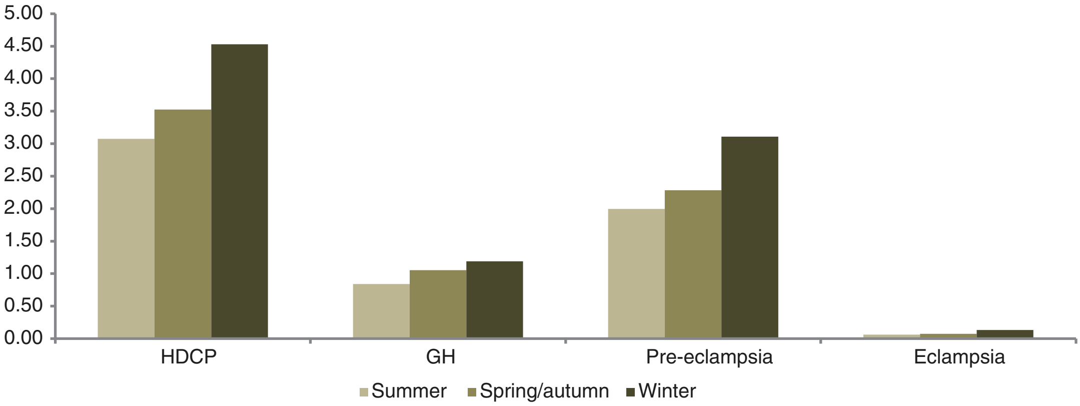


Fig. 6.2 The rate of hypertensive disorders complicating pregnancy across the seasons in Nanchang, from July 2008 to Jun 2010. *HDCP* hypertensive disorders complicating pregnancy; *GH* gestational hypertension. Data from the study by Huang et al. [3]

high ambient temperature, maternal blood vessels are less subject to severe stress contractions; thus the risk of hypertensive disorders is reduced [7]. Secondly, increasing angiotensin sensitivity might be another explanation of the relation between ambient temperature and hypertensive disorders. One established pathogenesis of gestational hypertension is maternal ischemia, which could enhance vascular sensitivity to angiotensin II and then prevent formation of vasodilators [8]. Sun et al. reported that the upregulation of angiotensin has a certain role in the cold-induced high blood pressure [9]. Thirdly, inflammation, oxidative stress, and activated L-type calcium channels might be potential pathways in the relation between longer exposure to low temperature and elevated high blood pressure [6]. Fourthly, low ambient temperature can also lead the blood to be highly viscous and hypercoagulable, causing higher levels of hematocrit and whole-blood viscosity in pregnant women in the cold seasons than other seasons [10]. One explanation for this phenomenon is that with the increasing gestational age, the levels of clotting factors and fibrinogen in circulating system increase and coagulation function gradually enhances to prevent postpartum hemorrhage [11]. Hypertensive disorders can cause dysfunctional activities of maternal coagulation system including the increment of platelet count and concentration of various clotting factors [12], so low temperature will exacerbate hypertensive disorders in pregnant women.

6.2 Preterm Birth

Preterm birth, defined as birth before 37 completed weeks of gestation [ICD-10], is a complex syndrome and an important global health problem. Several studies explored the association between ambient temperatures and preterm birth in China. Guangzhou, the largest city located in Southern China with 13 million permanent residents, has a subtropical climate with mild to chilly winters and hot and humid summers. He JR et al. used birth data of 838,146 singleton vaginal births and also daily meteorological data from the Guangzhou Meteorological Bureau, to estimate associations between average temperature during pregnancy and preterm birth. The researchers modeled weekly temperature as a time-varying exposure in different time windows: the last week of the pregnancy, the last 4 weeks of the pregnancy, late pregnancy (gestational week 20 onward), and the entire pregnancy. They found that high mean temperatures in the last 4 weeks of the pregnancy, late pregnancy, and the entire pregnancy time windows were associated with increased risks of preterm birth. Compared with the median temperature, exposures to extreme

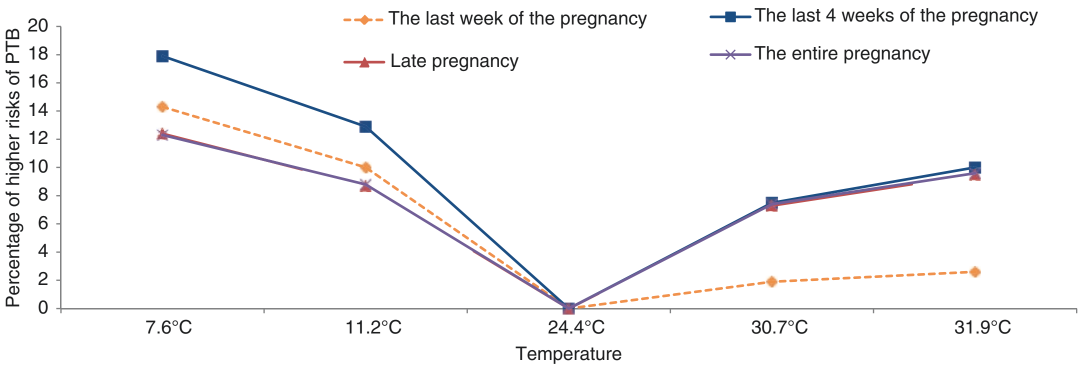


Fig. 6.3 Percentage of higher risks of preterm birth in association with low and high temperatures during different time windows of pregnancy. 7.6 °C, 11.2 °C, 24.4 °C, 30.7 °C, and 31.9 °C represent the local 1st, 5th, 50th, 95th, and 99th percentile temperature over an 11-year period (2001–2011), respectively [13]

cold and extreme heat in the last 4 weeks of the pregnancy were associated with 17.9% and 10.0% increased risks of preterm birth, respectively (as shown in Fig. 6.3). In the stratified analyses, they also found that the association between extreme heat and preterm birth was stronger for preterm births during weeks 20–31 and 32–34 than those during 35–36 weeks [13].

Another big city in southeastern China, Shenzhen, has subtropical oceanic monsoon climate. The average daily temperature in Shenzhen is 23.0 °C; the average temperature in January, the coldest month of the year, is 15.4 °C; and the average temperature in July, the hottest month of the year, is 28.9 °C. According to a recent study conducted in Shenzhen, low ambient temperature might be a risk factor of PTB, and high temperature appeared to be a protective factor of PTB [14] (as shown in Fig. 6.4).

But the largest study focused on the relationship between temperature and preterm birth in China which included more than one million pregnant women got different conclusion. The researchers found that both acute and chronic extreme temperatures exposure may affect preterm birth risk. Extreme high temperature is a risk factor, while extreme low temperature is a protective factor of preterm birth [15].

The mechanism that account for the association between ambient temperature and preterm birth is unclear. Several possible mechanisms are proposed in previous studies. Dehydration on account of high temperature in the pregnant women with poor thermoregulation can decrease uterine blood flow and induce uterine contractions and thus induce labor onset [16, 17]. Maternal heat stress may induce cortisol release, which may also induce onset of labor [18]. Explanations regarding the association between cold temperature and preterm birth are also proposed. Previous studies showed that low temperature could cause vascular constriction and high blood viscosity and thus might induce labor [16].

6.3 Early Childhood Health

The global climate is going through a huge change, in which the temperature rising as the main characteristic. Temperature change has a global and universal impact on individual health [19]. Over the past century, the average temperature of mainland China increased from 0.9 to 1.5 °C. During the last 15 years, the trend of temperature rising was stepped down. It is expected by the end of the twenty-first century, the temperature will increase by 1.3–5.0 °C [20]. Global warming also produced the corresponding effect on children, which are a special group of the population (Fig. 6.5).

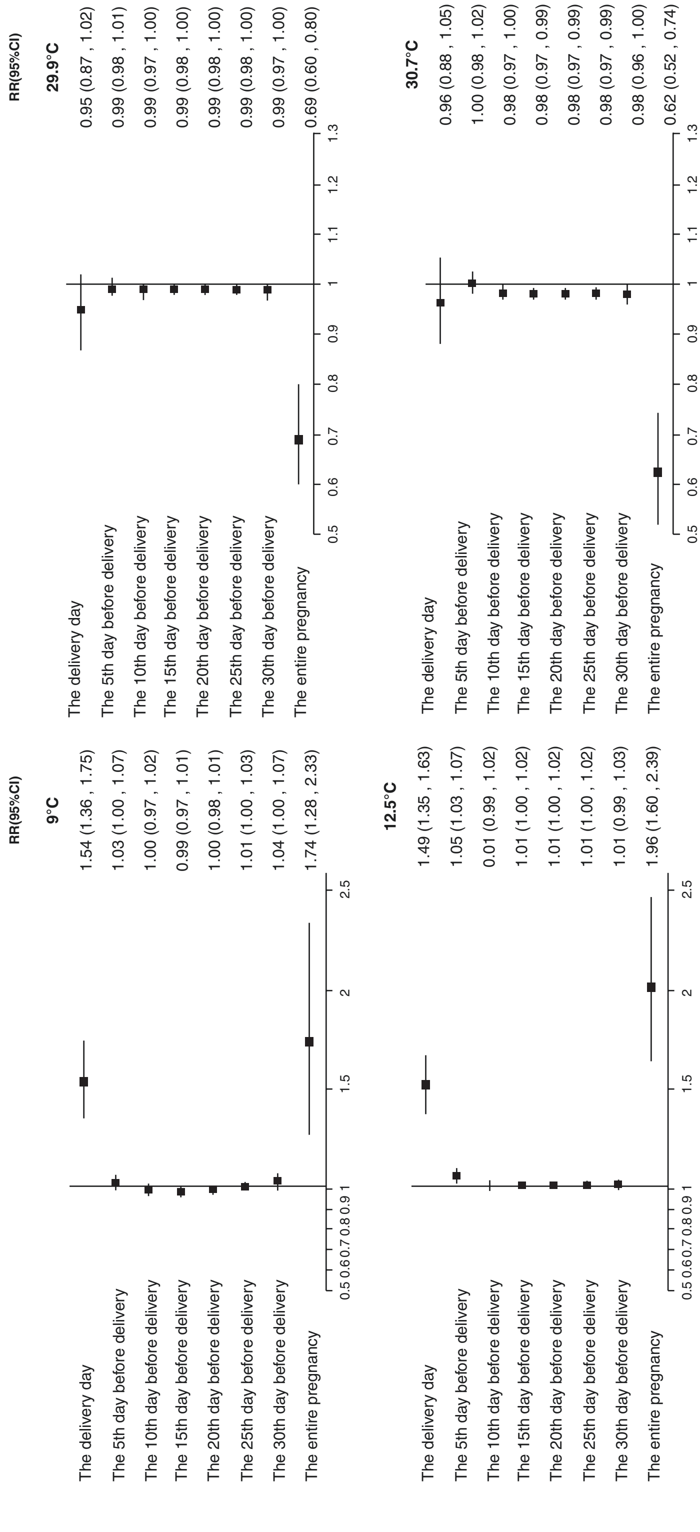


Fig. 6.4 Relative risk (RR) and 95% confidence intervals (CI) for total PTBs for temperature (1st, 5th, 95th, and 99th percentiles) at different days before delivery with reference at 24.5 °C

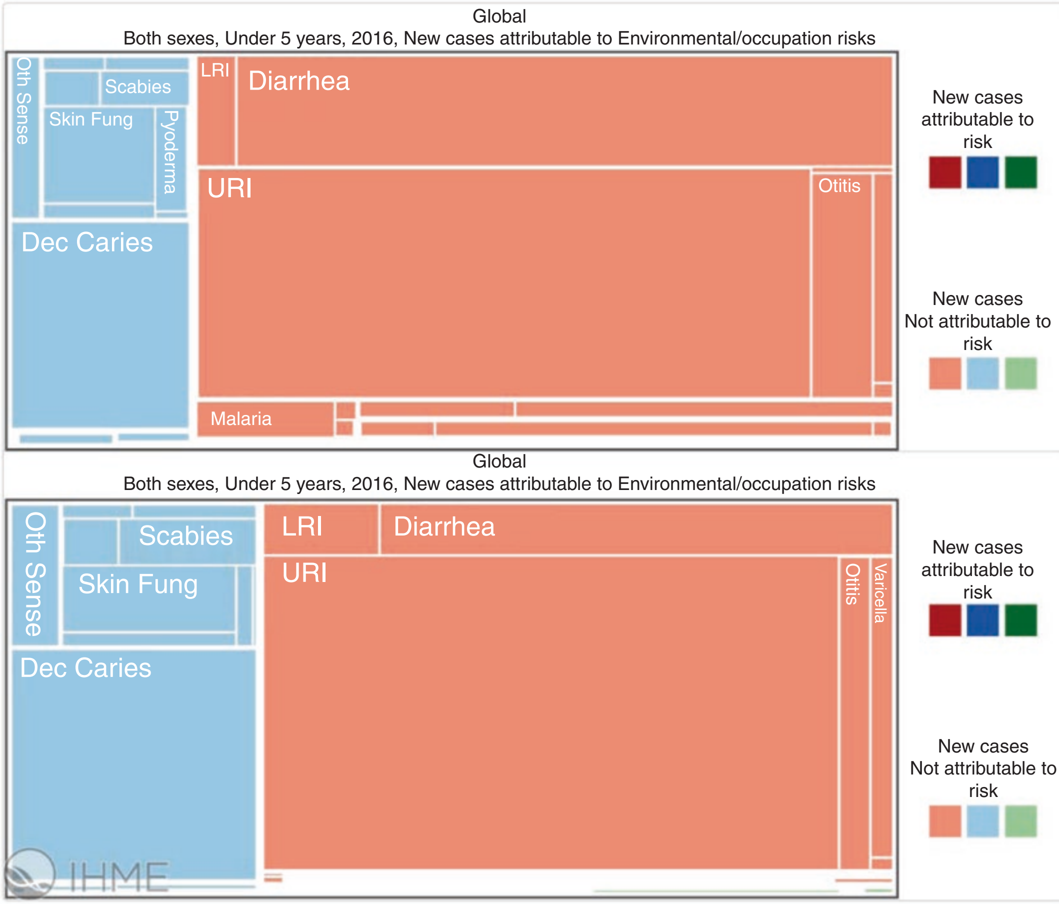


Fig. 6.5 Comparison between global and China on the incidences attributable to environmental risks among children under 5 years in 2016 (Source from IHME, website: https://healthdata.org)

6.3.1 Direct Effect on Early Childhood Health

6.3.1.1 Infectious Disease

Temperature change, especially diurnal temperature change, can be an inducement of children suffering from infectious diseases.

According to a study conducted in Changsha, China, temperature difference, which mainly affected by environment change, is an important risk factor of childhood pneumonia. From 2004 to 2005, the daily temperature difference is greater than from 2006 to 2008. In the meantime, between 2004 and 2005, incidence of childhood pneumonia is statistically significantly higher than 2006–2008 [21]. Last year, a study in Hefei, China, on childhood acute bronchitis suggested that the higher diurnal temperature difference, the greater the risk of acute bronchitis in children. The children aged 0–4 were the most sensitive group to diurnal temperature difference [22].

Hand, foot, and mouth disease is a common infectious disease caused by intestinal virus. It is often encountered in children under 5 [23]. In China, coxsackie virus C4 is the most common subtype of infection, in which C4a is mostly detected [6]. A study conducted in Guangzhou Province found that the incidence of hand, foot, and mouth disease was associated with climate change, especially the anomalous small peak during autumn and winter. When the temperature was above 10 °C, the incidence of hand, foot, and mouth disease increased dramatically as the temperature rises. However, when the temperature

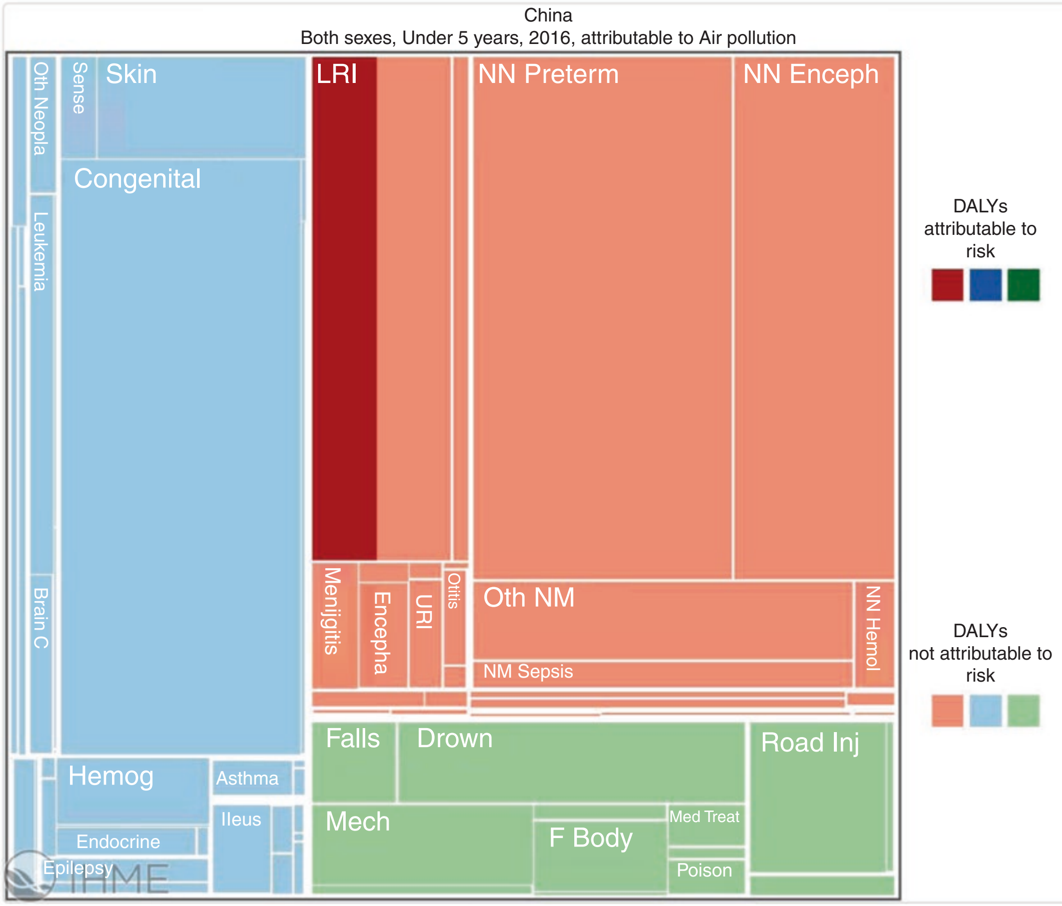


Fig. 6.6 DALYs attributable to air pollution among children less than 5 years in China in 2016. (Source from IHME, website: https://healthdata.org)

was greater than 25 °C, the risk no longer increases. Humidity had a similar effect on incidence of hand, foot, and mouth disease. When the humidity was higher than 70%, the incidence of hand, foot, and mouth disease was increasing significantly with rising humidity until the humidity was more than 90% [24]. In recent years of China, especially in Guangdong Province, hand, foot, and mouth disease was shown to have characteristics such as high incidence intensity, long duration, and widespread [23]. It is corresponding to the climate and temperature change over the last few years [25].

6.3.1.2 Other Disease

Temperature change not only has effects on children's infectious disease but also can influence individual genetic autoimmune. Yinling Chen et al. collected type I diabetes cases from 72 countries and conducted a study on the association between temperature and childhood type I diabetes [26].

6.3.2 Indirect Effect on Early Childhood Health

Infrared absorption gas such as atmospheric water vapor and carbon dioxide is important in maintaining a higher temperature on the earth's surface, which is vital for life on earth. Industrialization started from the 1950s has been bringing increasing emissions of greenhouse gases. To some extent it destroyed the natural balance and threatened human health [27] (Fig. 6.6).

6.3.2.1 Pollution and Childhood Asthma

J Gasana et al. conducted meta-analyses on environmental pollutants and childhood asthma. They concluded that nitrogen dioxide is a risk factor for childhood asthma [OR = 1.14 (1.06, 1.24)] and PM as a risk factor for pediatric breathing [OR = 1.05 (1.04, 1.07] [28]. Another study including 24 cities in China suggested that nitrogen dioxide, humidity, and air temperature were positively correlated with childhood asthma. PM10, sulfur dioxide, and sunshine duration were suggested as protective factors for asthma in children. However, when putting the PM10, sulfur dioxide, nitrogen dioxide, temperature, and humidity in the forecasting model together, air humidity and temperature contributed more to the risk of asthma development [29].

6.3.2.2 Pollution and Potential Malnutrition

Due to the lag of environment protection in China, according to the 2014 United Nations Environment Agency Report, China's environmental performance index ranked 118th in 178 countries. Environmental degradation was severe especially in China's major grain-producing area. Each year the cost of economic growth damage due to a double burden of air and water pollution was about 5.8% of the whole GDP. As the demand for food continues to grow globally, the difficulty of grain imports in China had been increasing [30]. So far, there is no report about child malnutrition caused by hunger.

References

1. The American College of Obstetricians and Gynecologists. Hypertension in pregnancy: executive summary. Obstet Gynecol. 2013;122(5):1122–31.
2. Tam WH, Sahota DS, Lau TK, Li CY, Fung TY. Seasonal variation in pre-eclamptic rate and its association with the ambient temperature and humidity in early pregnancy. Gynecol Obstet Invest. 2008;66(1):22–6.
3. Huang SH, Liu H, Dai LF, Zheng JS. Study on the correlation between seasonal climate change and occurrence regularity of hypertensive disorder complicating pregnancy in Nanchang area of Jiangxi province. Maternal Child Health Care China. 2014;29(9):1324–7.
4. Li X, Tan H, Huang X, Zhou S, Hu S, Wang X, Xu X, Liu Q, Wen SW. Similarities and differences between the risk factors for gestational hypertension and pre-eclampsia: a population based cohort study in South China. Preg Hypertens. 2016;6(1):66–71.
5. Lewington S, Li L, Sherliker P, Guo Y, Millwood I, Bian Z, Whitlock G, Yang L, Collins R, Chen J. Seasonal variation in blood pressure and its relationship with outdoor temperature in 10 diverse regions of China: the China Kadoorie Biobank. J Hypertens. 2012;30(7):1383.
6. Wang QM, Guo H, Tian Y. Exposure to cold and high blood pressure. Chin J Hypertens. 2013;(1):21–4.
7. Huang T, Wen YS, Liao DY. The risk factors of pregnancy-induced hypertension: a case-control study. Negative. 2006;27(16):1535–6.
8. Granger JP, Alexander BT, Bennett WA, Khalil RA. Pathophysiology of pregnancy-induced hypertension. Am J Hypertens. 2001;14(6 Pt 2):178S–85S.
9. Sun Z, Cade R, Morales C. Role of central angiotensin II receptors in cold-induced hypertension. Am J Hypertens. 2002;15(1):85–92.
10. Lin DB, Yin BM, Liang X, Zheng MK, Wang JH. A study on the incidence of eclampsia by seasonal climate according to solar terms. Ningxia Med J. 2007;29(5):451–2.
11. Zhao XJ. The risk factors of pregnancy-induced hypertension. Chin J Urban Rural Enterprise Hyg. 2001;(2):36–7.
12. Lai JY, Tan ZW, Wu SY. The serum biochemical indicators and coagulation indexes in patients with pregnancy-induced hypertension. Chin J Birth Health Heredity. 2008;(10):79–80.
13. He JR, Liu Y, Xia XY, Ma WJ, Lin HL, Kan HD, Lu JH, Feng Q, Mo WJ, Wang P, Xia HM, Qiu X, Muglia LJ. Ambient temperature and the risk of preterm birth in Guangzhou, China (2001-2011). Environ Health Perspect. 2016;124(7):1100–6.
14. Liang Z, Lin Y, Ma Y, Zhang L, Zhang X, Li L, Zhang S, Cheng Y, Zhou X, Lin H, Miao H, Zhao Q. The association between ambient temperature and preterm birth in Shenzhen, China: a distributed lag non-linear time series analysis. Environ Health. 2016;15(1):84.
15. Chen S, Yang Y, Qv Y, Zou Y, Zhu H, Gong F, Zou Y, Yang H, Wang L, Lian BQ, Liu C, Jiang Y, Yan C, Li J, Wang Q, Pan H. Paternal exposure to medical-related radiation associated with low birthweight infants: a large population-based, retrospective cohort study in rural China. Medicine (Baltimore). 2018;97(2):e9565.
16. Basu R, Malig B, Ostro B. High ambient temperature and the risk of preterm delivery. Am J Epidemiol. 2010;172(10):1108–17.
17. Stan CM, Boulvain M, Pfister R, Hirsbrunner-Almagbaly P. Hydration for treatment of preterm labour. Cochrane Database Syst Rev. 2013;(11):CD003096.
18. Yackerson N, Piura B, Sheiner E. The influence of meteorological factors on the emergence of preterm delivery and preterm premature rupture of membrane. J Perinatol. 2008;28(10):707–11.

19. Zhao J, Jin Y. Effects of climate change on environment and human health. J Environ Health. 2010;27(5):462–5.
20. Wu SH, Luo Y, Wang H, Gao JB, Li CZ. Climate change impacts and adaptation in China: current situation and future prospect. Chin Sci Bull. 2016;61(10):1042–54.
21. Zeng J, Lu C, Deng Q. Prenatal exposure to diurnal temperature variation and early childhood pneumonia. J Therm Biol. 2017;65:105–12.
22. Xie MY, Ni H, Zhao DS, Cheng J, Wen LY, Li KS, Yang HH, Wang SS, Zhang H, Wang X, Su H. Effect of diurnal temperature range on the outpatient visits for acute bronchitis in children: a time-series study in Hefei, China. Public Health. 2017;144:103–8.
23. Hu YH, Xiao GX, Guo Y, Yu SC, Ma JQ. The epidemic features of the hand, foot, and mouth disease during 2008–2011 in China. Chin J Dis Control Prev. 2014;18(8):693–7.
24. Zhang W, Du Z, Zhang D, Yu S, Hao Y. Boosted regression tree model-based assessment of the impacts of meteorological drivers of hand, foot and mouth disease in Guangdong, China. Sci Total Environ. 2016;553:366–71.
25. Huang ZZ, Zhang JH, Shi XJ, He J, Chen HH. Global warming and climate changes in the climatic zones of Guangdong Province. Trop Geogr. 2008;28(4):302–5.
26. Yinling C, Yongcheng H, Yongchao Q, Wei L, Yanhong P, Lijun G, Jianlong X, Xiaoxi Z, Hailu Z. Climates on incidence of childhood type 1 diabetes mellitus in 72 countries. Posting of the 12th Annual Meeting of Chinese Society for Immunology, Tianjin in China; 2017.
27. Wang M, Zhang R, Zheng X. Sources and sinks of green house gases. Clim Environ Res. 2000;5(1):75–9.
28. Gasana J, Dillikar D, Mendy A, Forno E, Ramos Vieira E. Motor vehicle air pollution and asthma in children: a meta-analysis. Environ Res. 2012;117:36–45.
29. Zhang J, Dai J, Yan L, Fu W, Yi J, Chen Y, Liu C, Xu D, Wang Q. Air pollutants, climate, and the prevalence of pediatric asthma in urban areas of China. Biomed Res Int. 2016;2016:2935163.
30. Chen X. Several major issues in the development of China's rural reform currently. Issues Agric Econ. 2013;34(01):4–6.

7 The Interaction of Ambient Temperature and Air Pollution in China

Yixuan Jiang, Renjie Chen, and Haidong Kan

Abstract

Numerous studies have revealed that both ambient temperature and air pollution are associated with human health. However, whether there are interactions between temperature and air pollution remains undefined, and the results are inconsistent. In this review, we searched related studies and summarized the conclusions to obtain an overview of this issue. We focused on two air pollutants, particulate matter (PM) and ozone. Most studies suggested that there were interactive effects between temperature and air pollution on human health, and the results varied among different geographic regions. Further studies conducted in larger populations and areas are needed to clarify the underlying mechanisms of the interactions. Furthermore, it is necessary for the government to strengthen targeted protection of susceptible populations during high-pollution and extreme-temperature days.

Keywords

Ambient temperature · Particulate matter · Ozone · Interaction

Y. Jiang · R. Chen · H. Kan (✉)
Department of Environmental Health, School of Public Health, Fudan University, Shanghai, China
e-mail: 18211020018@fudan.edu.cn; chenrenjie@fudan.edu.cn; kanh@fudan.edu.cn

7.1 An Overview of Air Pollution and Health in China

With rapid development of the society, China is suffering from severe air pollution, which has been a major hazard to public health. Numerous studies have suggested that both short- and long-term exposure to many kinds of air pollutants are linked to increased rates of adverse health outcomes [1–4]. Among all the air pollutants, the government mainly monitors particulate matter (PM), nitrogen dioxide (NO_2), ozone (O_3), and sulfur dioxide (SO_2) [5]. This section will briefly summarize the health effects of PM and ozone and the disease burden caused by air pollution in China.

Many epidemiological studies have indicated the adverse health effects of PM, such as increased blood pressure (BP), inflammatory levels, impaired lung function [2, 6, 7], and changes in heart rate variability [4, 8]. Both $PM_{2.5}$ and PM_{10} have been found to be positively associated with mortality and morbidity of all causes, especially cardiovascular and respiratory diseases. A systematic literature search conducted by Liu et al. found that for each 10 μg/m^3 increment of PM_{10}, the overall excess risk (ER) for all-cause mortality, the pooled ER for cardiovascular and respiratory mortality was 0.33% (95% CI: 0.26%, 0.40%), 0.38% (95% CI: 0.24%, 0.52%), and 0.48% (95% CI: 0.37%, 0.60%), respectively [5].

H. Lin et al. (eds.), *Ambient Temperature and Health in China*,
https://doi.org/10.1007/978-981-13-2583-0_7

As one of the main traffic-related and secondary pollutants in urban areas, ozone has also been reported to be associated with several adverse health effects in the cardiovascular system [9]. Many studies have indicated that dysfunction of the cardiac autonomic nervous system (ANS) and disturbed heart rate variability (HRV) may be the underlying mechanisms by which ozone increases cardiovascular risks [10]. A study conducted by Jia et al. among 20 healthy elderly subjects found that there was a decrement of 4.87% (95% CI: 0.97%, 8.62%) in HF with each 10 ppb increment of O_3 and suggested that LF and LFHFR were negatively and positively associated with increased O_3, respectively (*p* values of 0.092 and 0.069). In addition, both short- and long-term O_3 exposure may also bring adverse effects to lung function [11–13].

There is no doubt that rapid economic development has resulted in severe air pollution in China. Numerous studies that have reported the health hazards of air pollution should draw our attention to this serious problem.

7.2 The Interactions of Temperature and Particulate Matter on Human Health

According to the aforementioned studies, both short- and long-term exposure to PM have been linked to adverse health effects. Meanwhile, temperature has been considered as a potential risk factor that could lead to a series of adverse health outcomes [14–17]. Usually, there is a U-shaped relationship between temperature and mortality, with mortality being lowest at moderate temperatures and highest at extremely low and high temperatures [18]. In the previous studies, researchers often adjusted for temperature to efficiently analyze the associations between air pollution and health outcomes and similarly adjusted for air pollutants to study the health effects of temperature [19]. However, whether interactions between temperature and PM pollution affect human health remains undefined. The results of the present studies are also inconsistent. This section presents a review of original studies conducted in China and summarizes the conclusions for an overview of this issue.

7.2.1 High Temperature Enhances the Health Effects of Particulate Matter

According to the studies we searched, the interactive effects between PM and high temperatures were mainly on non-accidental, cardiovascular, respiratory, and cardiopulmonary mortality. A meta-analysis of 16 studies revealed that the impacts of PM_{10} on non-accidental, cardiovascular, and respiratory deaths were greatest at high temperatures [20]. In addition, in Wuhan, which is a highly polluted city and is called "oven city," Zhu et al. found that extremely high temperatures (daily mean temperature ≥33.4 °C) could enhance the associations between PM_{10} and mortality. At extremely high temperatures, each 10 μg/m^3 increment of PM_{10} was associated with a 2.95% (95% CI: 1.68%, 4.24%), 3.58% (95% CI: 1.72%, 5.49%), and 5.07% (95% CI: 2.03%, 9.51%) increase in non-accidental, cardiovascular, and respiratory mortality, respectively [21]. Qian et al. also observed consistently and significantly synergistic effects between PM_{10} and extremely high temperatures on daily mortality in Wuhan [22]. Li et al. conducted a study in Tianjin using time-series analysis and found that for each 10 μg/m^3 increment of PM_{10} concentration, cardiovascular, respiratory, and cardiopulmonary mortality increased by 0.92% (95% CI: 0.47%, 1.36%), 0.74% (95% CI: −0.33%, 1.82%), and 0.89% (95% CI: 0.47%, 1.32%), respectively, at high-temperature levels, and 0.25% (−0.01%, 0.50%), 0.46% (−0.12%, 1.04%), and 0.28% (0.04%, 0.52%), respectively, at low temperatures [19]. The results of a study by Tian et al. also showed that the adverse effects of PM_{10} on non-accidental, cardiovascular, and respiratory mortality were stronger at high-temperature levels than at low-temperature levels [23]. Furthermore, temperature might also interact with $PM_{2.5}$ on daily mortality. A study in Beijing revealed that for each 10 μg/m^3 increment of $PM_{2.5}$ concentration, there was a 1.70% (95% CI: 0.92%, 3.33%) increment in relative risk (RR) for respiratory mortality during the highest stratum (23.50–31.80 °C) [24].

Some studies have indicated a possibility of interactions between temperature and PM on lung function. A panel investigation conducted among 21 healthy young adults from the Healthy Volunteer Natural Relocation (HVNR) study by Wu et al. revealed that during high temperatures, the effects of $PM_{2.5}$ on both morning/evening FEV_1 and evening PEF were usually stronger than those during low temperatures, and the effects of temperature on both morning FEV_1 and morning/evening PEF were also usually stronger when the $PM_{2.5}$ concentrations were higher, suggesting that there may be synergistic interactions between ambient PM and temperature in leading to harmful respiratory health outcomes [25]. Interestingly, in another panel study which estimated the joint short-term effects of $PM_{2.5}$ and temperature on lung function among healthy young students in Wuhan, Zhang et al. found that the interactions between PM and temperature were slight but significantly antagonistic [7].

We also reviewed multicity studies. Meng et al. conducted a stratified time-series analysis in eight Chinese cities and reported significant interactions between PM_{10} and high temperature (>95th percentile) rather than extremely low temperature. They concluded that extremely high temperature could enhance the association between PM_{10} and daily mortality. Besides, they found that the health effects of PM_{10} were significantly modified by extremely high temperature in southern Chinese cities only, probably due to the higher 95th percentile of daily mean temperature in southern cities [26]. Li et al. also found that the interactive term coefficients for per interquartile range increase in PM_{10} concentrations and high-temperature levels were 1.95% (95% CI: 0.08%, 3.83%) in Brisbane on the current day and 0.25% (95% CI: 0.05%, 0.45%) in Beijing, China, 2 days before the current day, suggesting that the joint effects of mean temperature and PM_{10} were synergistic [27].

Some studies investigated the vulnerability to the interaction between high temperatures and PM. According to Qin et al., the effects of PM_{10} on non-accidental mortality were significantly stronger during high temperatures than during median. Furthermore, the interaction was stronger in females and the illiterate, indicating that they were more vulnerable to these interactions [28].

7.2.2 Low Temperature Enhances the Health Effects of Particulate Matter

Some other researches we searched focused on low temperature and PM. And most of them revealed that there were also interactions between the two.

Both cardiovascular and respiratory mortality were affected by the interactions between PM and low temperatures. In a study conducted in Beijing, Li et al. revealed that the health risks $PM_{2.5}$ posed to cardiovascular system could be significantly enhanced by low temperatures. For each 10 μg/m^3 increment of $PM_{2.5}$ concentrations during the lowest temperature range (−9.7–2.6 °C), there was a 1.27% (95% CI: 0.38%, 2.17%) increase in the RR for cardiovascular mortality, which was much higher when compared with the whole temperature range (0.59%, 95% CI: 0.22%, 1.16%) [29]. Dai et al. compared the effects of air pollution on out-of-hospital coronary deaths (OHCDs) at different temperatures in Shanghai and found that the highest risks arose when the temperature was low for all pollutants, including $PM_{2.5}$ and PM_{10}. For example, the daily OHCD mortality increased by 0.75% (95% CI: 0.18%, 1.32%), 0.36% (95% CI: −0.19%, 0.91%), and 0.52% (95% CI: 0.03%, 1.01%) with per 10 μg/m^3 increase in the same-day PM_{10} concentrations at low, moderate, and high temperatures, respectively [30]. In Hong Kong, Sun et al. reported that there was a stronger association between $PM_{2.5}$ and mortality when the temperature was low than high. The results also illustrated statistically significant interactions between $PM_{2.5}$ and temperature in low stratum for all non-accidental mortality, suggesting that in Hong Kong, the $PM_{2.5}$ effects on mortality could be modified by temperature [31]. In a community-based time-series analysis in Shanghai, Cheng et al. found significant interactions between PM_{10} and extremely low temperature for both all-cause and cause-specific mortality, but no significant interactions between air pollution and high temperatures. The increase in total, cardiovascular, and respiratory mortality with each 10 μg/m^3 increment of PM_{10} was 0.17% (95% CI: 0.03%, 0.32%), 0.23% (95% CI: 0.02%, 0.44%), and 0.26% (95% CI: −0.07%, 0.60%) during normal-temperature days, while the estimates changed to 0.40% (95% CI: 0.21%, 0.58%), 0.49% (95% CI: 0.13%, 0.86%), and 0.24% (95% CI: −0.33%, 0.82%) during low-temperature days, respectively [32].

Other studies focused on hospital admissions and emergency room visits. In Lanzhou, a city in western China, a study conducted by Wang et al. demonstrated that the effects of PM_{10} on hospital admissions for respiratory diseases were greatest on low-temperature days, smaller on normal-temperature days, and insignificant on high-temperature days, indicating the potential interactions between PM_{10} and extreme temperatures [33]. A study in Beijing also suggested significant interactive effects between PM and average apparent temperature (AT)-minimum AT in low-temperature levels on emergency room visits for respiratory diseases. With regard to AT, in low-, medium-, and high-temperature strata, the excess risks of PM were 5.90% (95% CI: 2.15%, 9.78%), 0.01% (95% CI: −0.65%, 0.63%), and −0.22% (95% CI: −0.63%, 0.17%), respectively [34].

7.2.3 Particulate Matter Modifies the Health Effects of Temperature

Only a few researches studied the modifications of air pollution on temperature-health relationships in China, and some found statistically significant results.

Most studies focused on different causes of mortality. For example, a study exploring whether PM_{10} could modify the effects of temperature on mortality demonstrated that the interactions between PM_{10} and mean temperature on all-cause ($F = 3.028$, $p = 0.006$) and non-accidental ($F = 3.177$, $p = 0.005$) were both statistically significant [35]. In another study conducted in three Chinese cities, Luo et al. found a significant effect modification of PM_{10} on temperature variability (TV)-cardiovascular mortality. For the entire population, higher PM_{10} exposure levels were associated with higher TV's effects estimates, while middle and lower levels were associated with milder effects [36].

Besides mortality, some studies used heart rate variability (HRV) or lung function as outcomes. A panel study conducted among healthy taxi drivers revealed that the effects of temperature on HRV could be modified by $PM_{2.5}$. The results showed that $PM_{2.5}$ and temperature interacted synergistically with each other on the standard deviations of normal to normal intervals in the whole range of temperature ($p < 0.05$ for the interaction terms) except for the "≤25 °C" stratum in the cold season ($p = 0.22$ for the interaction terms). Besides, researchers also found that temperature interacted with $PM_{2.5}$ most significantly in the warm season but not in the cold season ($p < 0.05$ for the interaction terms) on low-frequency power and high-frequency power [37]. Li et al. found that the impacts of low temperature on children's PEF were enhanced during those days with high $PM_{2.5}$ concentrations, meaning that $PM_{2.5}$ may have interactive effects with temperature [24].

7.2.4 Possible Explanations for the Interactions Between Temperature and Particulate Matter

Although the underlying mechanism remains unclear, researchers have proposed several explanations for the interactions between temperature and PM.

First, both extremely high and low temperatures could improve the workload of the cardiovascular system and lead to adverse cardiovascular events such as myocardial infarction [26, 38]. Arterial pressure, heart rate, and blood viscosity might also increase during exposure to heat and cold. From a panel study conducted among 39 healthy university students in Beijing, Wu et al. found stronger temperature effects on BP at higher pollutant concentrations as well as greater air pollution effects on BP at lower temperatures, suggesting significant synergistic interactive effects between temperature and traffic-related air pollutants including $PM_{2.5}$ on BP [39]. Furthermore, red cell counts, plasma cholesterol, and fibrinogen concentrations might increase during exposure to extreme temperatures. When blood pressure increases suddenly, there may be oxygen deficiency in the cardiac muscle, which could lead to myocardial ischemia or arrhythmia. Besides, increased blood pressure may also induce vascular spasms and ruptures of the atherosclerotic plaque that cause thrombus [29]. These marked changes play an important role in cardiovascular health and can cause physiological stress, making people more susceptible to the adverse health outcomes resulting from PM, leading to interactions on cardiovascular mortality between temperature and PM.

Second, regarding respiratory mortality, there are also plausible explanations for the modification of both high and low temperatures on PM effects. During hot days, the elderly, especially COPD patients, may have worse excess heat dissipation through circulatory regulation, and the accompanying heat stress can then improve the risk of developing pulmonary vascular resistance, which may lead to severe health outcomes among these people [29]. During cold days, the number of neutrophils and macrophages in the airways increases, which can increase inflammation levels, induce bronchospasm among asthma patients, and worsen airway obstruction among COPD patients. As a well-established biomarker of airway inflammation, fractional exhaled nitric oxide (FeNO) has been widely used in both clinical practice and epidemiological researches [40–42]. Li et al. revealed that both high and low temperatures, as well as exposure to fine and coarse PM, played important roles in increasing FeNO, which may be a useful result for understanding the underlying pathways that temperature and PM pollution act together to affect the respiratory health [43]. Furthermore, low temperatures can affect the scavenging rate of PM by reducing the beat frequencies in the nasal and trachea cilia, making people more susceptible to PM.

Third, the thermoregulation of the human body in the thermal environment depends on the activation of three key mechanisms, including the secretion of sweat glands, vasodilatation, and increased respiration. Activation of these systems can directly or indirectly affect toxic substances entering the body and increase the total intake of air pollutants [44]. As a result, exposure levels to air pollutants are much greater in high temperatures than in normal temperatures.

Fourth, the main sources and components of PM might vary by seasons, causing different toxicities. As a result, the mortality due to PM might also vary in different seasons [45]. For example, coal is one of the major energy sources in China, and the combustion of coal is common especially in the northern China for heating in winter and for cooling from coal-fired stations in summer, causing coal to be the major source of PM in these two seasons. Besides, in northwestern China, sandstorms which mainly come from the deserts and degraded grasslands are major sources of PM in the spring [46]. A study by Yuan et al. revealed that local and nonlocal pollutants contributed differently to impairing public health in the cold and hot seasons [47].

Fifth, the exposure patterns might change in different seasons. In warm periods, the exposure measurement error might be smaller because people would prefer to taking part in outdoor activities and inhale more PM [45, 48]. People open windows and doors more frequently to accelerate ventilation, which makes the monitoring data closer to individual exposure levels. However, Sun et al. found that in Hong Kong, a subtropical city, residents were more likely to go outdoors and open windows on cooler periods and remain at home with the air conditioners on during warmer periods, as a result of which, the mortality risks were higher in the cool seasons [31]. Despite the variations in different regions, the change of activity may help to explain the interactions between temperature and PM on public health.

Finally, meteorological variables such as temperature and relative humidity have an influence on the patterns of air quality through the emissions, transportation, dilution, chemical transformation, and the eventual deposition of air pollutants, which may also explain the interactive associations of temperature and PM [21].

7.2.5 Geographic Features of the Interactions Between Temperature and Particulate Matter

Overall, researchers found that both low and high temperatures had interactions with air pollution. However, the susceptibility of the human body to temperature varied by different geographic areas [29]. Most studies conducted in northern cities, such as Beijing and Tianjin, found interactions between high temperatures or warm seasons and PM, while studies conducted in southern cities, such as Hong Kong, Guangzhou, and Shanghai, found a stronger association between low temperatures or cool seasons and PM. This may result from the varied behavior patterns of people in different seasons. In the north where winters are always cold, people remain inside with windows closed and reduce natural ventilation, so they are exposed to less ambient air pollution than in warmer seasons. In the south where summers are always hot, however, people go outside and open windows in cooler seasons, so they are exposed to higher ambient air pollution in winter. As a result, in the northern cities, the interactive effects are stronger in the warmer seasons, whereas in the southern cities, the interactive effects are greater in the cooler seasons.

7.3 The Interactions of Temperature and Ozone on Human Health

The effects of ozone on health have been widely explored, but whether and how temperature have an influence on those associations remains to be discovered [49]. This section briefly summarizes studies exploring the interactions between temperature and ozone in China.

7.3.1 Temperature Modifies the Effect of Ozone

Most studies explored the interactions on daily and cause-specific mortality of low temperatures and ozone and were mainly conducted in subtropical cities such as Shanghai and Guangzhou. A study conducted in Shanghai by Cheng et al. revealed that there were statistically significant interactions between O_3 and extremely low temperature for both all-cause and cause-specific mortality, which remained robust after changing cut points for temperature strata [32]. Similarly, Dai et al. reported that there were no statistically significant associations between short-term O_3 exposure and OHCD mortality, but the greatest effects of O_3 appeared when the daily mean temperature was low, revealing possible interactions between O_3 and temperature [30]. In Guangzhou, Liu et al. found negative interactions between daily mean temperatures and ozone concentrations on non-accidental mortality in the cold seasons and when daily temperatures were in the 0–25th percentile [49]. In Suzhou, Chen et al. indicated that there were much stronger associations between ozone and daily mortality during the cool seasons and low temperatures than during the warm seasons and high temperatures, which suggested that low daily mean temperatures had significant effect modifications on the acute effects of ozone [50].

In addition to researches conducted in single cities, there were also multicity studies. In a meta-regression analysis of 272 Chinese cities, researchers found a much greater association between ozone and daily mortality with decrements in annual mean temperatures at the city level [51].

Only a few studies explored the interactions of high temperatures and ozone. Lin et al. examined the combined effects of temperature and air pollutants including ozone on daily mortality in Kaohsiung and found negative associations between the mortality rate and the ozone level on high-temperature days. There was also a significantly decreased RR of mortality with the increment of ozone levels observed at 27.6 °C among all ages [52]. Due to the lack of related studies in China, we compared the results to studies conducted in the USA and European countries. A study in the USA illustrated that temperature enhanced the health effects of ozone [53]. Another study conducted in eight European cities revealed that associations between temperature and mortality were generally greater when O_3 concentrations were high [54]. Lin et al. hypothesized that the inconsistent results of these studies may be due to the different levels of ozone and varying climates [52].

7.3.2 Seasons and the Health Effects of Ozone

The mean temperature varies in different seasons, which may influence the health effects of ozone. Some studies explored the possible effect modification of the seasons on the effects of ozone, but the findings are also inconsistent.

In a time-series study that investigated the relationship between ozone and daily mortality in Shanghai, Zhang et al. found significant associations between ozone and the all-cause and cardiovascular mortality in the cold seasons rather than in the warm seasons, which indicated that there may be interactions between ozone and seasons [55]. In a whole-year analysis, each increment of 10 μg/m^3 of 2-day average (lag01) O_3 was associated with a 0.45% (95% CI: 0.16%, 0.73%), 0.53% (95% CI: 0.10%, 0.96%), and 0.35% (95% CI: −0.40%, 1.09%) increase in all-cause, cardiovascular, and respiratory mortality, respectively. During cold seasons, the estimates changed to 1.38 (95% CI: 0.68%, 2.07%), 1.53% (95% CI: 0.54%, 2.52%), and 0.95% (95% CI: −0.71%, 2.60%), respectively. Another study conducted by Wong et al. in Hong Kong revealed that there were significant interactions between ozone and seasons for all causes of circulatory diseases, arrhythmias, and heart failure ($p < 0.05$), with the effects of ozone stronger in the cold seasons when personal ozone exposure is higher than in the hot seasons [56].

7.3.3 Possible Explanations for the Interactions of Temperature and Ozone

Although the underlying biological pathways are complicated and still to be discovered, the interactions between temperature and ozone on daily mortality are biologically plausible.

First, exposure to ozone may impair the airway directly through inhalation, causing injuries in the nasal cavity, trachea, bronchi, and alveoli, making people more susceptible to the health hazards from temperature [44, 57].

Second, marked changes in the ambient temperature can increase the body’s workload to maintain a normal body temperature. Both high and low temperatures may lead to increased blood pressure and heart rates and, as a result, make people, especially those susceptible, more vulnerable to air pollutants, including ozone [53].

Finally, some epidemiological studies have revealed that blood viscosity and levels of C-reactive protein (a biomarker reflecting inflammation levels) could increase with cumulative exposure to low temperatures, which may cause coronary thrombosis and increase daily cardiovascular mortality [58, 59]. As a result, the effects of ozone exposure can be enhanced during low-temperature days [50]. In addition, ozone may also impair fibrinolysis at elevated temperatures, causing a decrease in the efficiency of thrombus formation prevention and thrombolysis [60].

7.3.4 Geographic Features of the Interactions Between Temperature and Ozone

We found that the modification effect of temperature on ozone-mortality associations also varied among different geographic regions.

Some studies concluded that there were greater associations during warm seasons, which could be explained by the following reasons. First, generally speaking, ozone concentrations are higher during warm periods. Second, household heating is widespread in northern China during the cold seasons, and people take fewer outdoor activities and reduce natural ventilation, resulting in less outdoor ozone exposure [51]. Finally, there may be more secondary pollution in the summer due to the heat and stronger sunlight, causing greater effects [45].

Other studies, especially those conducted in southern China, concluded that the interactions were stronger during the cold seasons than during the hot seasons. Researchers assumed that exposure patterns contribute to these varied effects in different regions [32]. For example, Shanghai is a city with hot and rainy summers. A survey of 1106 families conducted there found that 32.7% never turned on an air conditioner during winters; this fell to only 3.7% during the summers [61]. With heavy rain outside and air conditioners on inside, people spend most of their time indoors, thus decreasing individual exposure to ozone in summer. In winter, however, the weather is relatively dry and warm; people go outdoors and open windows, increasing their exposure to ambient ozone. The conclusions are similar in other southern cities such as Hong Kong and Guangzhou. Conditions in the northern cities are opposite. As a result, the ozone exposure level was higher during low temperatures in the south, which resulted in stronger interactions during the cool seasons. In addition, higher humidity and more rainfall in summer in the southern regions may reduce the ozone concentration outside, which differs in the northern regions [53].

7.4 Studies Conducted in Other Countries

This review focused on studies conducted in China. However, we also compared them to researches conducted in other countries such as the USA, France, Germany, South Korea, and Japan. This section briefly introduces their similarities and differences.

Similarly, most studies in other countries were time-series or panel studies and used generalized additive models (GAM) to analyze the short-term interactive effects between extreme temperatures and air pollutant exposure on mortality. Generally speaking, most provided evidence of interactions between temperature and ambient air pollution, but there were some variations in specific results among studies in different regions.

Studies in Western countries usually reported significant interactions between high temperatures and ambient air pollution on daily mortality [62–69], which is consistent with studies in northern China while opposite to those in southern China. This difference may be explained by the varying latitudes and pollutant exposure patterns [50]. The studies we searched were mainly conducted in European countries and the USA, where the mean latitudes are similar to northern China but higher than southern China. We posit that the personal exposure patterns to ambient pollution and extreme temperatures in Western countries are similar to northern China, but different from southern China. That may be the source of the variations.

7.5 Summary

This section will summarize all the studies we searched, briefly introducing the limitations and implications for public health and policy-making.

7.5.1 Limitations

There are some common limitations in the studies we searched, so the interpretation of interactions between ambient temperature and air pollution requires caution.

First, most of the studies had ecologic designs that lacked individual exposure data, and exposure measurement errors were inevitable because the data were usually obtained from nearby fixed-site monitors. This method has several limitations: (a) pollutant concentrations usually vary among different monitoring locations, and (b) there are always differences between ambient concentrations and the real individual exposure levels [50]. This kind of measurement error can cause a bias toward zero and underestimate the effect of air pollution [70]. In the future, volunteers should wear portable devices in order to obtain personal exposure data.

Second, the present studies were conducted in limited cities with a lack of city-specific information, such as demography, chronic disease burdens, lifestyles, and other factors. Although there were some multicity studies [51], most were conducted in single cities; thus, the conclusions were less convincing. Furthermore, most were conducted in large cities with rapid economic development such as Shanghai, Beijing, Hong Kong, and Guangzhou, whereas few were administered in small and less-developed cities. More studies in a variety of cities are needed in the future.

Third, $PM_{2.5}$ and its chemical components may be the potential confounding factors when estimating the ozone-mortality associations [71]. However, in studies exploring the interactions between ozone and temperature, $PM_{2.5}$ data were usually not included in the analysis, partly because $PM_{2.5}$ was not officially monitored in China until 2012 [50].

Fourth, the sample size of some of the panel studies was small, which might decrease reliability. For example, there were only 14 volunteers in the panel study conducted by Wu et al. to explore the interactions between temperature and traffic-related air pollution on heart rate variability in Beijing [37]. Future studies should use larger sample sizes to generalize their conclusions.

Fifth, most of the studies included used mortality data. Further research is needed to reveal the modification effects of ambient temperature and air pollution on morbidity, clinical and subclinical biomarkers to better comprehend the temperature-pollution interactions [54].

Finally, although there are several explanations for the interactions between temperature and air pollution, the underlying mechanism remains unclear and should be assessed by future research. More epidemiological studies are needed to explore the molecular mechanisms behind the interactions. Future studies should also evaluate the health effects of other potential modifiers. And further researches should identify subgroups more susceptible to the interactive effects as defined by sex, age, occupation, social economic status, and many other factors [72].

7.5.2 Implications for Public Health and Policy-Making

The findings and conclusions have several important implications.

First, people should be cautious on days with extreme temperatures and high levels of air pollution [24]. There should be early warnings and appropriate and efficient measures to protect the public during extremely high-temperature or low-temperature days with heavy air pollution [72]. It is also necessary to control and reduce air pollution, particularly during extreme-temperature days [19].

Second, weather factors jointly modify the pollution effects and vice versa. It is important to consider weather factors when assessing the adverse health effects of air pollution and also to consider air pollutants when assessing the risks caused by extreme temperatures.

Third, some studies explored vulnerable subgroups. Their identification could help policymakers promote targeted early warning systems for extreme temperatures and air pollution.

Finally, these findings help reveal the health impacts attributed to air pollution and global climate change [26]. Researchers have noted that climate change will not only increase global average temperatures and improve the frequency of extreme-temperature days but may also improve air pollution levels in some areas [72].

Clarifying the interactive associations between temperature and air pollution assists in the management of the hazards caused by global warming.

These findings are meaningful for both policymakers to take efficient and adaptive measures to improve air quality and ordinary people to make contributions to reducing air pollutants in order to protect the public from adverse effects caused by air pollution and climate change.

References

1. Baccarelli A, Barretta F, Dou C, Zhang X, McCracken JP, Diaz A, Bertazzi PA, Schwartz J, Wang S, Hou L. Effects of particulate air pollution on blood pressure in a highly exposed population in Beijing, China: a repeated-measure study. Environ Health. 2011;10:108.
2. Baumgartner J, Zhang Y, Schauer JJ, Huang W, Wang Y, Ezzati M. Highway proximity and black carbon from cookstoves as a risk factor for higher blood pressure in rural China. Proc Natl Acad Sci. 2014;111(36):13229–34.
3. Dong GH, Qian ZM, Xaverius PK, Trevathan E, Maalouf S, Parker J, Yang L, Liu MM, Wang D, Ren WH, Ma W, Wang J, Zelicoff A, Fu Q, Simckes M. Association between long-term air pollution and increased blood pressure and hypertension in China. Hypertension. 2013;61(3):578–84.
4. Jia X, Song X, Shima M, Tamura K, Deng F, Guo X. Effects of fine particulate on heart rate variability in Beijing: a panel study of healthy elderly subjects. Int Arch Occup Environ Health. 2012;85(1):97–107.
5. Lin H, Wang X, Liu T, Li X, Xiao J, Zeng W, Ma W. Air pollution and mortality in China. Adv Exp Med Biol. 2017;1017:103.
6. Baccarelli AA, Zheng Y, Zhang X, Chang D, Liu L, Wolf K, Zhang Z, Mccracken JP, Díaz A, Bertazzi P. Air pollution exposure and lung function in highly exposed subjects in Beijing, China: a repeated-measure study. Part Fibre Toxicol. 2014;11(1):51.
7. Zhang Y, He M, Wu S, Zhu Y, Wang S, Shima M, Tamura K, Ma L. Short-term effects of fine particulate matter and temperature on lung function among healthy college students in Wuhan, China. Int J Environ Res Public Health. 2015;12(7):7777–93.
8. Wu SW, Deng FR, Niu J, Huang QS, Liu YC, Guo XB. Association of heart rate variability in taxi drivers with marked changes in particulate air pollution in Beijing in 2008. Environ Health Perspect. 2010;118(1):87.
9. Anderson HR, Leon APD, Bland JM, Bower JS, Strachan DP. Air pollution and daily mortality in London: 1987-92. BMJ. 1996;312(7032):665–9.
10. Kop WJ, Verdino RJ, Gottdiener JS, O'Leary ST, Bairey Merz CN, Krantz DS. Changes in heart rate and heart rate variability before ambulatory ischemic events (1). J Am Coll Cardiol. 2001;38(3):742–9.
11. Hwang BF, Chen YH, Lin YT, Wu XT, Leo Lee Y. Relationship between exposure to fine particulates and ozone and reduced lung function in children. Environ Res. 2015;137:382–90.
12. Li H, Wu S, Pan L, Xu J, Shan J, Yang X, Dong W, Deng F, Chen Y, Shima M, Guo X. Short-term effects of various ozone metrics on cardiopulmonary function in chronic obstructive pulmonary disease patients: results from a panel study in Beijing, China. Environ Pollut. 2018;232:358–66.
13. Yun Z, Liu Y, Song Y, Xie J, Cui X, Bing Z, Shi T, Jing Y, Chen W. Short-term effects of outdoor air pollution on lung function among female non-smokers in China. Sci Rep. 2016;6:34947.
14. Guo Y, Barnett AG, Pan X, Yu W, Tong S. The impact of temperature on mortality in Tianjin, China: a case-crossover design with a distributed lag nonlinear model. Environ Health Perspect. 2011;119(12):1719–25.
15. Huang J, Wang J, Yu W. The lag effects and vulnerabilities of temperature effects on cardiovascular disease mortality in a subtropical climate zone in China. Int J Environ Res Public Health. 2014;11(4):3982–94.
16. Yang J, Ou CQ, Guo Y, Li L, Guo C, Chen P-Y, Lin H-L, Liu Q-Y. The burden of ambient temperature on years of life lost in Guangzhou, China. Sci Rep. 2015;5(1):12250.
17. Zhou X, Zhao A, Meng X, Chen R, Kuang X, Duan X, Kan H. Acute effects of diurnal temperature range on mortality in 8 Chinese cities. Sci Total Environ. 2014;493:92–7.
18. Kan H, Jia J, Chen B. Temperature and daily mortality in Shanghai: a time-series study. Biomed Environ Sci. 2003;16(2):133–9.
19. Li G, Zhou M, Cai Y, Zhang Y, Pan X. Does temperature enhance acute mortality effects of ambient particle pollution in Tianjin City, China. Sci Total Environ. 2011;409(10):1811–7.
20. Chen F, Fan Z, Qiao Z, Cui Y, Zhang M, Zhao X, Li X. Does temperature modify the effect of PM10 on mortality? A systematic review and meta-analysis. Environ Pollut. 2017;224:326–35.
21. Zhu YH, Wu R, Zhong PR, Zhu CH, Ma L. Temperature modifies the acute effect of particulate air pollution on mortality in Jiang'an district of Wuhan. Zhonghua Yu Fang Yi Xue Za Zhi. 2016;50(6):519–24.
22. Qian Z, He Q, Lin HM, Kong L, Bentley CM, Liu W, Zhou D. High temperatures enhanced acute mortality effects of ambient particle pollution in the "oven" city of Wuhan, China. Environ Health Perspect. 2008;116(9):1172–8.
23. Tian L, Liang F, Guo Q, Chen S, Xiao S, Wu Z, Jin X, Pan X. The effects of interaction between particulate matter and temperature on mortality in Beijing, China. Environ Sci: Processes Impacts. 2018;20(2):395–405.

24. Li S, Guo Y, Williams G, Baker P, Ye X, Madaniyazi L, Kim DS, Pan X. The association between ambient temperature and children's lung function in Baotou, China. Int J Biometeorol. 2015;59(7):791–8.
25. Wu S, Deng F, Hao Y, Wang X, Zheng C, Lv H, Lu X, Wei H, Huang J, Qin Y, Shima M, Guo X. Fine particulate matter, temperature, and lung function in healthy adults: findings from the HVNR study. Chemosphere. 2014;108:168–74.
26. Meng X, Zhang Y, Zhao Z, Duan X, Xu X, Kan H. Temperature modifies the acute effect of particulate air pollution on mortality in eight Chinese cities. Sci Total Environ. 2012;435-436:215–21.
27. Li G, Sun J, Jayasinghe R, Pan X, Zhou M, Wang X, Cai Y, Sadler R, Shaw G. Temperature modifies the effects of particulate matter on non-accidental mortality: a comparative study of Beijing, China and Brisbane, Australia. Publ Health Res. 2012;2(2):21–7.
28. Qin RX, Xiao C, Zhu Y, Li J, Yang J, Gu S, Xia J, Su B, Liu Q, Woodward A. The interactive effects between high temperature and air pollution on mortality: a time-series analysis in Hefei, China. Sci Total Environ. 2017;575:1530–7.
29. Li Y, Ma Z, Zheng C, Shang Y. Ambient temperature enhanced acute cardiovascular-respiratory mortality effects of PM2.5 in Beijing, China. Int J Biometeorol. 2015;59(12):1761–70.
30. Dai J, Chen R, Meng X, Yang C, Zhao Z, Kan H. Ambient air pollution, temperature and out-of-hospital coronary deaths in Shanghai, China. Environ Pollut. 2015;203(4):116.
31. Sun S, Cao P, Chan KP, Tsang H, Wong CM, Thach TQ. Temperature as a modifier of the effects of fine particulate matter on acute mortality in Hong Kong. Environ Pollut. 2015;205:357–64.
32. Cheng Y, Kan H. Effect of the interaction between outdoor air pollution and extreme temperature on daily mortality in Shanghai, China. J Epidemiol. 2012;22(1):28–36.
33. Wang MZ, Zheng S, Wang SG, Tao Y, Shang KZ. The weather temperature and air pollution interaction and its effect on hospital admissions due to respiratory system diseases in western China. Biomed Environ Sci. 2013;26(5):403–7.
34. Li G, Hui T, Qun L. Interaction between inhalable particulate matter and apparent temperature on respiratory emergency room visits of a Hospital in Beijing. J Environ Health. 2012;29(6):483–6.
35. Li L, Yang J, Guo C, Chen PY, Ou CQ, Guo Y. Particulate matter modifies the magnitude and time course of the non-linear temperature-mortality association. Environ Pollut. 2015;196:423–30.
36. Luo K, Li R, Wang Z, Zhang R, Xu Q. Effect modification of the association between temperature variability and daily cardiovascular mortality by air pollutants in three Chinese cities. Environ Pollut. 2017;230:989–99.
37. Wu S, Deng F, Liu Y, Shima M, Niu J, Huang Q, Guo X. Temperature, traffic-related air pollution, and heart rate variability in a panel of healthy adults. Environ Res. 2013;120:82–9.
38. Qiu H, Yu IT, Wang X, Tian L, Tse LA, Wong TW. Cool and dry weather enhances the effects of air pollution on emergency IHD hospital admissions. Int J Cardiol. 2013;168(1):500–5.
39. Wu S, Deng F, Huang J, Wang X, Qin Y, Zheng C, Wei H, Shima M, Guo X. Does ambient temperature interact with air pollution to alter blood pressure? A repeated-measure study in healthy adults. J Hypertens. 2015;33(12):2414–21.
40. Dweik RA, Boggs PB, Erzurum SC, Irvin CG, Leigh MW, Lundberg JO, Olin AC, Plummer AL, Taylor DR. An official ATS clinical practice guideline: interpretation of exhaled nitric oxide levels (FENO) for clinical applications. Am J Respir Crit Care Med. 2011;184(5):602–15.
41. Sofia M, Maniscalco M, D'Onofrio G, Carratù P, Vatrella A, Vatrilla A. Exhaled nitric oxide as a marker of adverse respiratory health effect in environmental disease. Monaldi Arch Chest Dis. 2002;57(3–4):182.
42. van Amsterdam JG, Nierkens S, Vos SG, Opperhuizen A, Van LH, Steerenberg PA. Exhaled nitric oxide: a novel biomarker of adverse respiratory health effects in epidemiological studies. Arch Environ Health. 2000;55(6):418.
43. Li H, Bai H, Yang C, Chen R, Wang C, Zhao Z, Kan H. Acute effects of ambient temperature and particulate air pollution on fractional exhaled nitric oxide: a panel study among diabetic patients in Shanghai, China. J Epidemiol. 2017;27(12):584–9.
44. Gordon CJ. Role of environmental stress in the physiological response to chemical toxicants. Environ Res. 2003;92(1):1–7.
45. Chen R, Peng RD, Meng X, Zhou Z, Chen B, Kan H. Seasonal variation in the acute effect of particulate air pollution on mortality in the China air pollution and health effects study (CAPES). Sci Total Environ. 2013;450-451:259–65.
46. Wang XM, Dong ZB, Zhang JW, Liu LC. Modern dust storms in China: an overview. J Arid Environ. 2004;58(4):559–74.
47. Yuan Z, Yadav V, Turner JR, Louie PKK, Lau AKH. Long-term trends of ambient particulate matter emission source contributions and the accountability of control strategies in Hong Kong over 1998–2008. Atmos Environ. 2013;76(3):21–31.
48. Zhang Y, Ma L, Zhu Y, Long X, Li R, Wang S. Effect modification of season and temperature on the relationship between ambient particulate matter and mortality. Zhonghua yu fang yi xue za zhi [Chin J Prev Med]. 2015;49:97–100.
49. Liu T, Li TT, Zhang YH, Xu YJ, Lao XQ, Rutherford S, Chu C, Luo Y, Zhu Q, Xu XJ, Xie HY, Liu ZR, Ma WJ. The short-term effect of ambient ozone on mortality is modified by temperature in Guangzhou, China. Atmos Environ. 2013;76:59–67.
50. Chen K, Yang HB, Ma ZW, Bi J, Huang L. Influence of temperature to the short-term effects of various

ozone metrics on daily mortality in Suzhou, China. Atmos Environ. 2013;79:119–28.
51. Yin P, Chen R, Wang L, Meng X, Liu C, Niu Y, Lin Z, Liu Y, Liu J, Qi J, You J, Zhou M, Kan H. Ambient ozone pollution and daily mortality: a Nationwide study in 272 Chinese cities. Environ Health Perspect. 2017;125(11):117006.
52. Lin CM, Liao CM. Temperature-dependent association between mortality rate and carbon monoxide level in a subtropical city: Kaohsiung, Taiwan. Int J Environ Health Res. 2009;19(3):163–74.
53. Ren C, Williams GM, Mengersen K, Morawska L, Tong S. Temperature enhanced effects of ozone on cardiovascular mortality in 95 large US communities, 1987-2000: assessment using the NMMAPS data. Arch Environ Occup Health. 2009;64(3):177–84.
54. Chen K, Wolf K, Breitner S, Gasparrini A, Stafoggia M, Samoli E, Andersen ZJ, Bero-Bedada G, Bellander T, Hennig F, Jacquemin B, Pekkanen J, Hampel R, Cyrys J, Peters A, Schneider A. Two-way effect modifications of air pollution and air temperature on total natural and cardiovascular mortality in eight European urban areas. Environ Int. 2018;116:186–96.
55. Zhang Y, Huang W, London SJ, Song G, Chen G, Jiang L, Zhao N, Chen B, Kan H. Ozone and daily mortality in Shanghai, China. Environ Health Perspect. 2006;114(8):1227–32.
56. Wong CM, Ma S, Hedley AJ, Lam TH. Does ozone have any effect on daily hospital admissions for circulatory diseases? J Epidemiol Community Health. 1999;53(9):580–1.
57. Paige RC, Plopper CG. In: Holgate ST, Samet JM, Koren HS, Maynard RL, editors. 24—Acute and chronic effects of ozone in animal models. Air pollution and health. London: Academic Press; 1999. p. 531–57.
58. Halonen JI, Zanobetti A, Sparrow D, Vokonas PS, Schwartz J. Associations between outdoor temperature and markers of inflammation: a cohort study. Environ Health. 2010;9(1):1–9.
59. Keatinge WR. Winter mortality and its causes. Int J Circumpolar Health. 2012;61(4):292.
60. Kahle JJ, Neas LM, Devlin RB, Case MW, Schmitt MT, Madden MC, Diaz-Sanchez D. Interaction effects of temperature and ozone on lung function and markers of systemic inflammation, coagulation, and fibrinolysis: a crossover study of healthy young volunteers. Environ Health Perspect. 2015;123(4):310–6.
61. Long W, Zhong T, Zhang B. China: the issue of residential air conditioning. Tongji University; 2004.
62. Analitis A, Michelozzi P, D'Ippoliti D, De'Donato F, Menne B, Matthies F, Atkinson RW, Iniguez C, Basagana X, Schneider A, Lefranc A, Paldy A, Bisanti L, Katsouyanni K. Effects of heat waves on mortality: effect modification and confounding by air pollutants. Epidemiology. 2014;25(1):15–22.
63. Dear K, Ranmuthugala G, Kjellstrom T, Skinner C, Hanigan I. Effects of temperature and ozone on daily mortality during the August 2003 heat wave in France. Arch Environ Occup Health. 2005;60(4):205–12.
64. Jhun I, Fann N, Zanobetti A, Hubbell B. Effect modification of ozone-related mortality risks by temperature in 97 US cities. Environ Int. 2014;73:128–34.
65. Kim SE, Lim YH, Kim H. Temperature modifies the association between particulate air pollution and mortality: a multi-city study in South Korea. Sci Total Environ. 2015;524-525:376–83.
66. Pascal M, Wagner V, Chatignoux E, Falq G, Corso M, Blanchard M, Host S, Larrieu S, Pascal L, Declercq C. Ozone and short-term mortality in nine French cities: influence of temperature and season. Atmos Environ. 2012;62:566–72.
67. Ren C, Tong S. Temperature modifies the health effects of particulate matter in Brisbane, Australia. Int J Biometeorol. 2006;51(2):87–96.
68. Stafoggia M, Schwartz J, Forastiere F, Perucci CA, SISTI Group. Does temperature modify the association between air pollution and mortality? A multicity case-crossover analysis in Italy. Am J Epidemiol. 2008;167(12):1476–85.
69. Yi O, Hong YC, Kim H. Seasonal effect of PM(10) concentrations on mortality and morbidity in Seoul, Korea: a temperature-matched case-crossover analysis. Environ Res. 2010;110(1):89–95.
70. Zeger SL, Thomas D, Dominici F, Samet JM, Schwartz J, Dockery D, Cohen A. Exposure measurement error in time-series studies of air pollution: concepts and consequences. Environ Health Perspect. 2000;108(5):419–26.
71. Franklin M, Schwartz J. The impact of secondary particles on the association between ambient ozone and mortality. Environ Health Perspect. 2008;116(4):453–8.
72. Li J, Woodward A, Hou XY, Zhu T, Zhang J, Brown H, Yang J, Qin R, Gao J, Gu S, Li J, Xu L, Liu X, Liu Q. Modification of the effects of air pollutants on mortality by temperature: a systematic review and meta-analysis. Sci Total Environ. 2017;575:1556–70.

8 Future Temperature-Related Mortality Risk Under Climate Change Scenarios

Tiantian Li, Zhiying Sun, Yi Zhang, Chen Chen, and Jie Ban

Abstract

As the climate changes, global temperatures will increase in the future, and extreme weather will occur more frequently. Epidemiological studies have shown the significant relationship between the ambient temperature and an elevated risk of mortality. With temperature increases in the future, the population mortality risk may increase. Therefore, estimating the risk of future temperature-related mortality is significant for the protection of public health and the reduction of the burden of disease. Most studies assuming relationship between temperature and mortality remain constant; the projected future temperature and future population are substituted for future temperature-related mortality. This chapter will summarize the methods used to estimate the temperature-related mortality risk globally and the progress, results, and limitations of studies in China. By reviewing these studies, we provide a direction for future studies in China that project future temperature-related mortality risk.

Keywords

Mortality · Future temperature · Climate change · Projection

T. Li (✉) · Z. Sun · Y. Zhang · C. Chen · J. Ban
National Institute of Environmental Health, Chinese Center for Disease Control and Prevention, Beijing, China

8.1 Introduction

Climate change is one of the major issues of humanity. According to the fifth report of the Intergovernmental Panel on Climate Change (IPCC), the global temperature has risen 0.85 °C over the last 100 years. The report also assumed that the average global temperature would increase by 1.0 °C, 1.8 °C, 2.2 °C, and 3.7 °C in 2081–2100 under different scenarios. Many epidemiological studies have shown a significant relationship between the ambient temperature and an elevated risk of mortality and morbidity, and the effect is greater than previously documented in some sensitive populations, such as the population with cardiovascular disease and the elderly [1–5]. Furthermore, a meta-analysis showed that with a change in temperature condition, the risk of cardiovascular hospitalization would increase 2.8% (95% CI, 2.1–3.5%) for cold exposure, 2.2% (95% CI, 0.6–3.9%) for heat wave exposure, and 0.7% (95% CI, 0.2–1.2%) for an increase in diurnal temperature [6]. As the future temperature rises, the population health risk may increase. Therefore, the study of future projections is of great significance for the protection of public health and requires more attention.

Several studies from the 1990s have projected future temperature-related mortality risks, and the number of these studies increased obviously after 2007 for several possible reasons. One reason is that the data of both global and regional climate model simulations at the periods may be

H. Lin et al. (eds.), *Ambient Temperature and Health in China*,
https://doi.org/10.1007/978-981-13-2583-0_8

easier to obtain. Increased workstation computational power, improved epidemiological methods, and the convenience and increased speed of the Internet all might be other possible factors [7]. The majority of the locations in which studies were conducted were developed countries, including the USA, Canada, European countries, Australia, and South Korea. For example, Gasparrini et al. projected the temperature-related death risk in 451 locations of 23 countries across the world and found that the negative mortality risk of climate change under RCP 8.5 would disproportionately affect poorer and warmer regions, with the net change at the end of the century ranging from −1.2% (95% CI, −3.6–1.4%) in Australia to 12.7% (95% CI, −4.7–28.1%) in Southeast Asia and 1.5% (95% CI, −2.0–5.4%) in China [8]. These studies found that global warming is likely to cause increased heat-related, heat wave-related, and cold spell-related mortality and decreased cold-related mortality [9]. The current method of estimating future temperature-related mortality risk varies. Generally, there are three basic procedures. First, project the future daily temperature under the future scenario model proposed in the IPCC report; second, calculate the exposure-response relationship between temperature and health outcomes based on historical data; and third, combine the projected temperature and exposure-response relationship to obtain the future mortality risk under climate change.

In summary, the regions currently under study were not balanced, and the methods and results of each study were quite different. This chapter will introduce the methods of approach to the study of projecting future temperature-related mortality and will focus on the methods, results, and future research directions in China.

8.2 Method

Recent studies have been conducted to estimate future temperature-related mortality risks, including estimating the future risk of heat-related mortality cold-related mortality, heat wave-related mortality, and cold spell-related mortality [7, 10]. In this process, studies estimating future risk of temperature-related mortality are based primarily on historical data. Most studies assuming this relationship remain constant; the projected future temperature and future population are substituted for future temperature-related deaths. In the calculation of future temperature-related deaths, some studies consider future changes in the population and the population's adaptability to temperature, which would change the exposure-response relationship. The existing research methods will be summarized from five aspects: baseline exposure response, future regional temperature projection, future population changes, future population acclimatization, and uncertainties.

8.2.1 Baseline Temperature-Mortality Relationships

Thus far, many studies have explored and quantified the effect of temperature on mortality by time-series studies or case-crossover designs [11]. Studies have found that the adverse effect of temperature on mortality is a curve relationship, which significantly increases if the temperature exceeds or falls below the minimum mortality temperature (MMT). Therefore, the model of the exposure-response relationship between temperature and mortality is mainly the distributed lag nonlinear model (DLNM), which puts the lag and temperature into the generalized linear model (GLM) as a cross-basis and explores the effect of each lag day and each temperature on mortality [12, 13]. The general cold effect has a long lag time of up to 30 days, and the heat effect has a short lag time of approximately 0–7 days. In addition, the confounding factors of the exposure-response relationships include humidity, day of the week, holidays, or air pollution [14].

The relationship between temperature and mortality also largely concerned the baseline time periods and the measure of temperature. When summarizing the time span of the exposure-response relationship included in the relevant literature of this search, it was found that the time span of most of the studies is greater than 10 years to ensure that the exposure-response relationship at the baseline time period is stable enough and can be applied to the projection of future temperature-related death risk. The measure of temperature includes daily maximum temperature and daily average temperature. Most of the studies use daily average temperature, which represents the overall exposure level [15, 16]. However, it is more common to calculate the maximum temperature in the heat wave-related studies. For example, Heaviside et al. projected the future heat wave-related mortality risk in Cyprus in Europe, and the temperature index used in calculating the exposure-response relationship is the daily maximum temperature [17].

8.2.2 Future Temperature Projection

The projection of future temperature is mainly based on the use of different atmospheric cycle models under different climate change scenarios in the future and the use of downscaling to obtain the required regional future temperatures. The future climate change scenario caused by human activities has always been an important part of the work of the IPCC.

Before 2013, the world's most widely used scenario was a set of emission scenarios (SRES) announced by the IPCC in 2007, but the SRES did not consider the impact of climate change policies on future emissions. The IPCC published a set of representative concentration path (RCP) scenarios in 2013 (Table 8.1). The purpose of these scenarios is to provide possibilities for future scenarios depending on demographic, technological, political, social, and economic developments rather than assigned probabilities [18]. Half of the current studies that projected future temperature-related mortality risks used SRES emissions before 2013, which were generally combined with A1FI ("higher emissions"), A2 ("mid-high emissions"), and B1 ("lower emissions") [19]. Individual studies only used one of the high-emission models of A2, A1B, and A1F1 [20, 21]. A large number of studies used RCP scenarios after 2013, which were generally combined with medium- and high-emission scenario models, such as RCP 4.5 and RCP 8.5 [22]. Some studies used all four RCPs when projecting temperature, and an increasing number of studies used RCP 2.6 to explore the effect caused by policies [23, 24]. Individual studies only used RCP 8.5 when projecting temperature [16].

Table 8.1 The explanation of scenarios

Scenarios	Level	Explanation
SRES		
A1F1	High	Economic growth is very fast. The peak of the global population appears in the middle of this century. New and higher technologies are introduced and divided into three groups of scenarios: A1F1, A1F1, and A1B1
A1T	Medium-high	
A1B1	Medium-low	
A2	Medium-high	Unbalanced world, rapid population growth, slow economic development, slow technological progress
B2	Medium-low	The population and economic growth rates are in a middle-level world, emphasizing economically and socially sustainable development
B1	Low	The global population is the same as in the A1 scenario, but the economic structure is more rapidly adjusted toward the service and information economy
RCP		
RCP 8.5	High	In 2000–2100, the emission, concentration, and radiative forcing of the three major global greenhouse gases will increase with time. By 2100, the concentration of carbon dioxide in the air will be 3–4 times higher than the pre-industrial concentration
RCP 6.0	Medium-high	After 2080, human carbon emissions have decreased but still exceed the allowable value. After 2100, greenhouse gas radiative forcing is stable at 6 W/m^2
RCP 4.5	Medium-low	From 2000 to 2100, the world's three major greenhouse gas emissions peaked in 2040, and concentrations and radiative forcing tended to stabilize in 2070
RCP 2.6	Low	Assuming that humanity responds to climate change, adopt more active ways of promoting the cross-border peaks of the world's three major greenhouse gas emissions in 2010 and 2020 and of the concentration and radiative forcing in approximately 2040

The global climate model, also generally known as the general circulation model (GCM), is currently the main tool for temperature projection in climatic studies. The GCM can be traced back to the basic equations used by Smagorinsky in his study in 1963 to address atmospheric circulation. After more than 50 years of development, the GCM has not only been the first simple model of "atmospheric circulation" but has also joined the coupling modes of the Earth's hydrosphere, the cryosphere, the biosphere, and the human circle. By simulating the global and large-scale climate change process, the temperature data of the time series in the future time period are obtained. Future climate projections come from GCMs, which reflect the current understanding of the physical, dynamical, and chemical processes that control the climate system.

GCM is unique in that they contain different but reasonable methods of representing climate processes, numerical methods for solving equations, and representations of processes that occur on the spatial scale and cannot be resolved directly by climate models [25]. There is no standard for how to choose a GCM. In the current study on the projection of future temperature-related mortality risk, the number of GCMs used varies from 1 to 62. In recent years, most studies used ten or more GCMs to project future temperatures, and individual studies used only one GCM to simulate future temperatures [12, 26, 27]. Using more GCMs can reduce the uncertainty caused by the choice of GCM [7].

Due to the limitation of the calculation conditions, the resolution adopted by the GCM is generally low (currently between 125 and 400 km). If the climate change scenario is to be estimated at regional and local scales on a smaller scale, statistical or dynamic downscaling is required. The statistical downscaling method obtains downscaling results by establishing a link between large-scale model results and observational data, such as circulation and ground variables. Although the statistical downscaling method lacks the physical mechanism and is affected by the observational data of the training model, it is easy to calculate and can integrate multiple GCMs, and it has been used more in recent years [7]. Of the studies retrieved for this review that project future temperature-related mortality risks, many used statistical downscaling to obtain future temperatures in the study area [10]. Dynamic downscaling is simulated using global high-resolution climate models at global or regional scales. The dynamic downscaling method has the advantages of clear physical meaning, unaffected by observational data, and all points facing the coverage area. However, it has a large number of calculations, is inconvenient to simulate, and cannot integrate multiple GCMs. Few studies used dynamic downscaling methods to obtain future regional temperatures [28, 29].

8.2.3 Future Demographic Changes

Several studies have shown that the risk of temperature on people will be different in different age groups and older people are more susceptible to the effects of temperature [1, 5]. The world's population will increase to 5.5–14.0 billion by 2100, and the structure of the population in different age groups will also change [30, 31]. Changes in the composition of the future population will affect the projection of temperature-related death risks. In the event of future temperature-related mortality risks, if the aging of the population is not considered, the risk of future temperature-to-population deaths will be underestimated. For example, when Hajat et al. projected the future heat-related mortality risk in the UK, it was found that considering an aging population would increase the mortality risk by 206% [32].

Few of the previous studies projecting future temperature-related mortality risk have considered the impact of future demographic changes. The methods of studies obtaining future local population estimates varied. Many studies projected the risk of future temperature-related deaths using the local Bureau of Statistics projected population [17, 33]. Few studies projected the future temperature-related mortality risk utilizing the population projected by the United Nations for high, medium, and low fertility rates [34]. In addition, some studies projected the future temperature-related mortality risk and used the future population projected by the five population scenarios' shared socioeconomic pathways (SSPs) 1–5 provided by the IPCC5 [15]. Individual studies projected the future temperature-related mortality risk with future populations by a statistical model [29]. These methods of projecting future populations can be applied to the study of projecting temperature-related mortality risks, and the current study prefers to use the predicted population under the SSP scenario with the refinement of the IPCC report.

8.2.4 Future Population Acclimatization

The use of air conditioning in the future and the intervention of early warning systems will affect the population's adaptability to temperature, and different regions may differ in air-conditioning usage due to different socioeconomic conditions [35]. Whether or not the population's adaptability to temperature is taken into account in projecting the temperature-related mortality risk has an impact on the relationship between future temperature and mortality.

A small number of studies have considered the population's adaptability to temperature. The population will have increased adaptability to heat and heat waves due to physiological mechanisms. Jenkins et al. measured the risk of future heat-related deaths in London, UK, and found that considering the population's adaptability to heat, the risk of temperature-related mortality can be reduced by 69% [35].

Some studies hypothesized that the future relationship between heat and mortality will change as people's ability to adapt to temperature changes or that the MMT will change as people's ability to adapt to temperature changes [36, 37]. Some studies have assumed that the relationship between the future temperature and the mortality of the population of the study location was consistent with the exposure-response relationship at a previous stage in other similar cities [38]. Gosling et al. summarized six different adaptive model methods for estimating future heat-related death risk (absolute threshold temperature changes; relative threshold temperature changes; exposure-reaction relationship slope changes; absolute threshold temperature changes combined with changes in exposure-response relationships; and relative threshold temperature changes combined with changes in exposure-response relationships, using exposure-response relationships in similar cities) and found that different adaptive methods have a greater impact on projected results [26]. Gosling et al. suggested that we could combine the change of threshold temperature and the slope of the exposure response in the projection of future temperature-related mortality risk [26].

The adaptability to cold and cold waves was unclear [39]. A few studies assumed that climate change will reduce cold adaptation and that the cold-related mortality risk will increase with considerable acclimatization [40]. However, studies have shown that seasonality may affect the results of such adaptation [39].

8.2.5 Uncertainties

Uncertainty in estimating temperature-related mortality risk is mainly due to temperature projection (selection of GCM, selection of emission models), temperature-mortality relationship, changes in the number and composition of future populations, changes in adaption to heat and cold, socioeconomic changes in the future, and improvement of medical conditions [41]. Uncertainty in projecting temperature-related mortality risk is unavoidable, but researchers should minimize uncertainty and make projections more scientific. At present, the methods to reduce the uncertainty of the estimated temperature-related death risk mainly include selecting more GCMs and as many greenhouse gas scenarios as possible when projecting future temperature, choosing a better adaptive approach, and considering future demographic scenarios.

There have been studies that have begun to quantitatively estimate the uncertainty associated with temperature-related risks. Some studies estimated temperature-related mortality risk using ANOVA-type (Analysis of Variance) estimation of variance components to calculate uncertainty due to RCPs, GCM, and different demographic scenarios [34]. Individual methods used Monte Carlo simulations in the calculation of confidence intervals to represent the uncertainty by temperature-mortality relationship [8]. Gosling et al. quantified the uncertainties associated with six adaptive models, five GCMs, and two RCPs when estimating temperature-related mortality risk and found that the uncertainty caused by adaptability is greater than the uncertainty caused by GCM and RCP [26].

8.3 Review of Studies in China

Previous studies have shown that the risk of heat-related mortality increased with the future warming of the climate, and the results of developing countries were more pronounced. China recently conducted some studies to project the risk of temperature-related mortality (Table 8.2).

8.3.1 Research Progress

Of the studies in China, four project the future risk of heat-related mortality [15, 34, 37, 42]. The three studies simultaneously project the risk of future heat- and cold-related mortality [40, 43, 44]. There were seven single-center studies conducted in Beijing, Tianjin, and Jiangsu, four of which were conducted in Beijing. Only one relevant multicenter study was conducted in Beijing, Shanghai, and Guangzhou, to compare the results among different cities [44].

All studies project the future temperature-related mortality risk of different periods representing the short-term and long-term effects of climate change to allow for different strategies to be used in different periods. In the process of projecting future temperature, in addition to individual study-specified future temperatures, most of the research is based on different GCMs and different RCPs to obtain the future temperature.

Since the studies were all conducted after 2013, when the IPCC5 was published, they all used RCPs and mostly tend to use RCP 4.5 and RCP 8.5 for 2018. However, two studies also applied RCP 2.6, which assumed that emissions might be controlled by policies [40, 45]. By far, an increasing number of GCMs were used in the studies, which can reduce the uncertainty caused by GCM selection and make the projection results more scientific. Current studies used statistical downscaling methods to obtain the future temperatures of the region, which may be related to the greater number of GCMs and the fact that statistical downscaling is more convenient and feasible. In the calculation of the exposure-response relationship between temperature and mortality, the time span of most studies is very short (below 5 years), and individual studies range from 5 to 10 years. Most of the studies used DLNM, which is recognized worldwide; the daily average temperature is a more common temperature indicator. Finally, when projecting temperature-related mortality risk in the future, half of the studies projected the risk of future temperature-related deaths utilizing the population projected by the United Nations for high, medium, and low fertility rates and the future population projected by the five population scenarios' SSPs 1–5 provided by the IPCC5. Only two studies considered the population's adaptability to future temperatures, using methods that reduce the slope of exposure-response relationship and change the threshold temperature [34, 40]. In the process of projecting future temperature-related mortality, only two studies quantified the uncertainty and used the method of ANOVA-type estimation of variance components (VC) [34, 37].

8.3.2 Results

Although most of the studies were conducted in different cities, the results of China's studies showed a consistent direction. The studies projecting future heat-related mortality have all shown that it would increase and the risk of a longer projection period is greater [15, 34, 37, 40, 43, 44].

Table 8.2 Summary of the studies that included a quantitative estimate of future temperature-related mortality in China

References	Location	Periods[a]	Outcome	Temperature indicator	Model	Lag days	Number of GCMs	Scenarios	Downscaling method	Population change	Adaption method	Quantitative uncertainty
Zhang et al. [40]	Beijing	Future: 2050s, 2070s Base: 2007–2009 Obs: 2007–2009	Annual excess temperature-related cardiovascular deaths	Maximum temperature	DLNM	14	19	RCP 2.6, RCP 4.5, RCP 8.5	Statistics	Three SSPs	Change threshold temperature	None
Li et al. [45]	Tianjin	Future: 2050s, 2070s Baseline: 2006–2011 Obs: 2006–2011	Temperature-related years of life lost to stroke	Maximum temperature	DLNM	12	19	RCP 2.6, RCP 4.5, RCP 8.5	Statistics	None	None	None
Li et al. [37]	Beijing	Future: 2020s, 2050s, 2080s Baseline: 1970–1999 Obs: 2008–2013	Annual temperature-related mortality due to stroke deaths	Mean temperature	DLNM	14	31	RCP 4.5, RCP 8.5	Statistics	Four fertility rates by the UN	None	ANOVA-type estimation
Li et al. [43]	Tianjin	Future: 2050s, 2090s Baseline: 2006–2011 Obs: 2006–2011	Change in temperature-related years of life lost	Mean temperature	DLNM	15	None	None	None	None	None	None
Chen et al. [15]	Jiangsu	Future: 2016–2040, 2041–2065 Baseline: 1980–2005 Obs: 2009–2014	Annual excess heat-related deaths	Mean temperature	DLNM	Not applicable	21	RCP 4.5, RCP 8.5	Statistics	Five SSPs	None	None

(continued)

Table 8.2 (continued)

References	Location	Periods[a]	Outcome	Temperature indicator	Model	Lag days	Number of GCMs	Scenarios	Downscaling method	Population change	Adaption method	Quantitative uncertainty
Li et al. [34]	Beijing	Future: 2020s, 2050s, 2080s Baseline: 1970–1999 Obs: 2009–2011	Annual excess heat-related deaths in aging population	Mean temperature	DLNM	14	31	RCP 4.5, RCP 8.5	Statistics	Four fertility rates	Reduce slope	ANOVA-type estimation
Li et al. [42]	Beijing	Future: 2020s, 2050s, 2080s Baseline: 1971–2000 Obs: 2003–2005	Excess heat-related deaths of cardiovascular and respiratory diseases	Mean temperature	GAM	0–14	5	RCP 4.5, RCP 8.5	Statistics	None	None	None
Zhang et al. [44]	Beijing, Shanghai, Guangzhou	Future: 2080–2099 Baseline: 1980–1999 Obs: 2001–2008	Annual excess temperature-related mortality	Mean temperature	DLNM	30	None	None	None	None	None	None

[a]*Future* the projection period; *baseline* the baseline period; *Obs* the time span of the exposure-response relationship between temperature and mortality

Under the RCP 8.5 scenario, the number of heat-related deaths among aging individuals is projected to increase by a median of 39.1% (95% CI, 11.1–83.3%) in the 2020s and 264.9% (95% CI, 117.5–427.3%) in the 2080s, compared with the number of deaths in the 1980s in Beijing [34]. The studies simultaneously projecting future heat-related mortality and cold-related mortality have shown that the heat effects would increase and the cold effects would decrease. Zhang et al. indicated that with the temperature decreased 1 °C in the 2080–2099 period, Beijing, Shanghai, and Guangzhou would experience a decrease of 3.1, 2.2, and 4.8 deaths, respectively, per 100,000 people. In addition, the decreased cold-related mortality did not offset the effects of increased heat-related mortality [44]. The future temperature-related mortality risk will vary by different outcomes, populations, and adaptation abilities.

The projection of the causes of mortality is also an important issue under the changing climate. The current studies tended to project the future effects of temperature on cardiovascular disease [40, 42, 43]. The number of cold-related cardiovascular deaths of the 2070s would decrease by 694 under RCP 8.5 in Beijing, but it did not offset the increased heat-related cardiovascular mortality, which was 1013 deaths, under RCP 8.5 [40]. Compared to the corresponding risks of the baseline period, the future heat-related cardiovascular mortality risks in Beijing will increase by an average percentage of 18.4%, 47.8%, and 69.0% in the 2020s, 2050s, and 2080s, respectively, under RCP 4.5, and by 16.6%, 73.8%, and 134% in the 2020s, 2050s, and 2080s, respectively, under RCP 8.5 [42]. Recent studies have begun to project the future temperature effect of stroke and acute ischemic heart disease. Figure 8.1 showed that with the population held constant at the 2010 level, the annual number of net and heat-related acute deaths in Beijing from the 1980s to the 2080s under both RCP 4.5 and RCP 8.5 was highest for acute ischemic heart disease, followed by ischemic stroke and hemorrhagic stroke, and the annual number of cold-related acute deaths was highest for acute ischemic heart disease, followed by hemorrhagic stroke and ischemic stroke [37] (Fig. 8.1). In addition, this study also projected the percentage variation in the change of the monthly median number temperature-related deaths from the 1980s to the 2080s under RCP 4.5 and RCP 8.5. And this calculation showed that the percentage increases for the monthly death projections ischemic heart disease and stroke in the 2080s were greatest in the summer months, obviously occurring in August [37].

Understanding the future health risk of vulnerable populations under changing climates is crucial for policy making. So far, most studies only project the risk of future temperature-related deaths in the total population, and only one study regarded the elderly as a vulnerable population. Li et al. projected the heat-related mortality risk among the aging population in Beijing and found that under RCP 8.5 and a medium-sized scenario of population by the 2080s, the future number of deaths showed a 264.9% increase compared with the number of deaths in the 1980s [34] (Fig. 8.2). More research is needed to project the future temperature-related mortality risk of more vulnerable populations in China.

There are very few studies that consider adaptation when projecting the health risks under climate change. Only two studies considered the population's adaptability to future temperatures, using methods that reduce the slope of the exposure-response relationship and change the threshold temperature [34, 40]. Future heat-related mortality risk will decrease when this adaptation is considered. In the 2080s, with the adaptation rates assumed at 30 and 50% in Beijing, the increase in the number of heat-related deaths in the aging population is approximately 7.4 times and 1.3 times larger, respectively, than the corresponding number of deaths in the 1980s under a scenario of high-sized population and RCP 8.5 [34] (Fig. 8.3). The number of cold-related deaths may increase due to worse adaptation to colder temperatures. Zhang et al. indicated that under RCP 8.5, the number of cold-related deaths during the 2050s increased by 548 under 100% adaptation, compared with that under 0% adaptation [40].

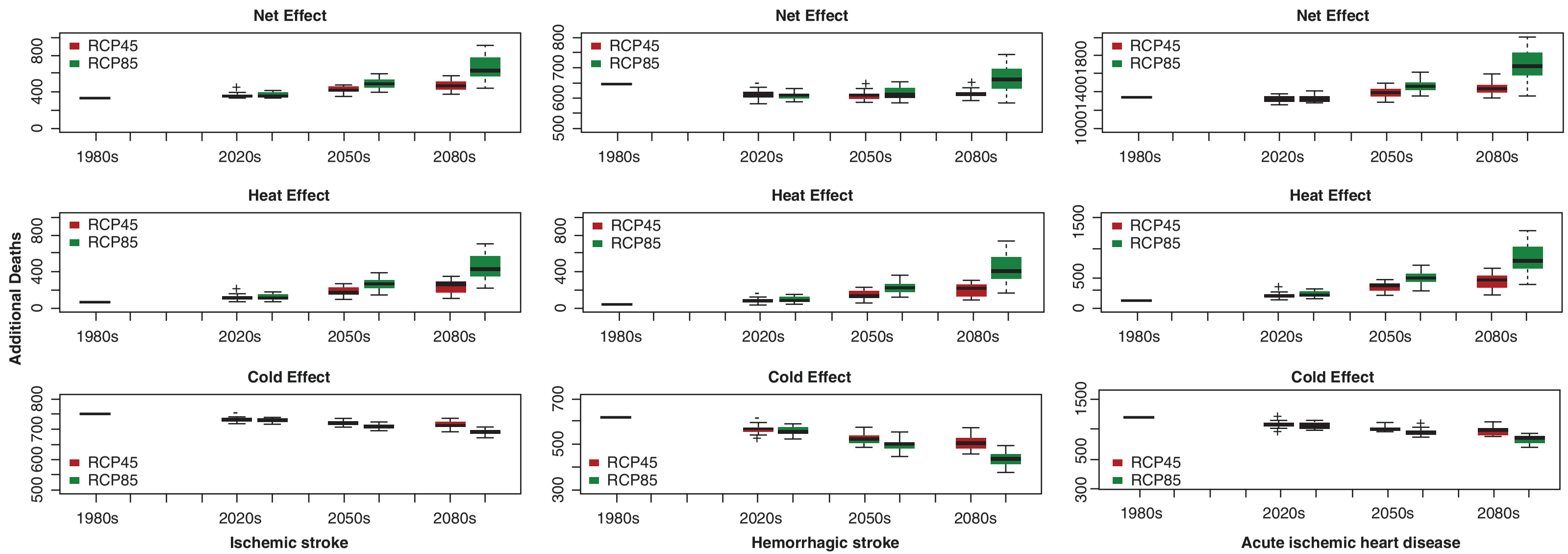


Fig. 8.1 Distribution of temperature-related annual acute deaths for ischemic stroke, hemorrhagic stroke, and acute ischemic hearth disease in the 1980s, 2020s, 2050s, and 2080s using 31 climate models and the RCP 4.5 and RCP 8.5 scenarios (Reproduced with permission from Li et al. [43])

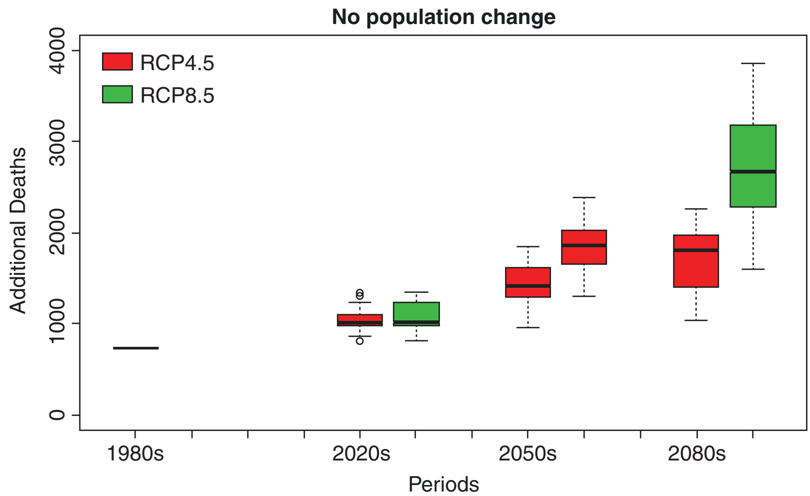


Fig. 8.2 Distribution of annual heat-related deaths for 31 GCMs and RCP 4.5 and RCP 8.5 scenarios in the 1980s, 2020s, 2050s, and 2080s, with constant population (Reproduced from Li et al. [34])

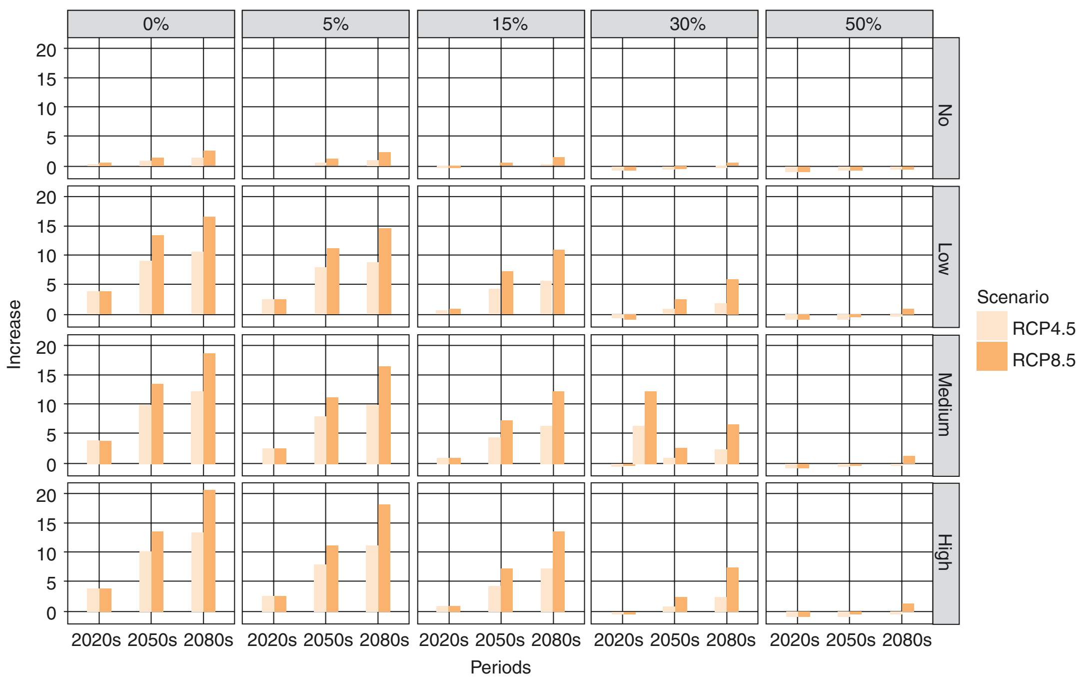


Fig. 8.3 Increases in the number of heat-related deaths from the 1980s (median of 31 models) in the 2020s, 2050s, and 2080s under RCP 4.5 and RCP 8.5 scenarios and different population-variant scenarios with different adaptation levels (Reproduced from Li et al. [34])

8.4 Limitations and Perspectives in China

In summary, the first study to project the temperature-related mortality risk in China was conducted in 2014, and there have been few studies in China until recently. Some limitations and perspectives are provided below.

First, current studies mostly concentrate on Chinese metropolitan areas (e.g., Beijing, Shanghai, Tianjin, Jiangsu, Guangzhou), ignoring the emerging health risk in other cities with higher future temperatures. Therefore, more multiple-city and multiple-county studies should be required to project the risk of future temperature-related mortality.

Second, future climate warming will not only increase the risk of heat-related mortality but also lead to a lower risk of cold-related mortality. Considering that current studies mostly focus on the risk of future heat-related mortality, more studies should also focus on the risk of future net temperature-related mortality.

Third, because the effect of temperature on different diseases is different, the outcome of future studies should focus not only on non-accidental mortality risk but should also continue to project the risk of mortality from sensitive diseases, such as myocardial infarction.

Fourth, the longer the historical data is, the more stable the exposure-relationship between the temperature and mortality. Now, in the calculation of the exposure-response relationship, the periods of historical data were too short (generally 3–5 years), and studies should extend the periods of historical data.

Fifth, it is best to obtain the time series of the daily values by multiple GCMs and multiple RCPs. When projecting future temperatures, some studies have specified the temperatures; because the specified temperature is published by the IPCC at the global level, it cannot accurately represent the temperature change in the study area, so this method cannot accurately project the time series of future daily deaths. In addition, some studies use fewer GCMs and RCPs, which would increase the uncertainty in projecting future temperatures.

Sixth, changes in the structure of the future population and adaptability to future temperatures will affect the projection of future temperature-related death risks; thus, demographic changes should be considered upon the assessment of future temperature-related mortality risk. In addition, future studies are required to address the changing acclimatization of the population to future temperatures.

References

1. Hopstock LA, Fors AS, Bønaa KH, et al. The effect of daily weather conditions on myocardial infarction incidence in a subarctic population: the Tromsø study 1974-2004. J Epidemiol Community Health. 2012;66:815–20.
2. Oudin Åström D, Schifano P, Asta F, et al. The effect of heat waves on mortality in susceptible groups: a cohort study of a Mediterranean and a northern European City. Environ Health. 2015;14:30.
3. Sen T, Astarcioglu MA, Asarcikli LD, et al. The effects of air pollution and weather conditions on the incidence of acute myocardial infarction. Am J Emerg Med. 2016;34:449–54.
4. Smith S, Elliot AJ, Hajat S, et al. The impact of heatwaves on community morbidity and healthcare usage: a retrospective observational study using real-time syndromic surveillance. Int J Environ Res Public Health. 2016;13(1):E132.
5. Wichmann J, Ketzel M, Ellermann T, Loft S. Apparent temperature and acute myocardial infarction hospital admissions in Copenhagen, Denmark: a case-crossover study. Environ Health. 2012;11:19.
6. Phung D, Thai PK, Guo Y, et al. Ambient temperature and risk of cardiovascular hospitalization: an updated systematic review and meta-analysis. Sci Total Environ. 2016;550:1084–102.
7. Sanderson M, Arbuthnott K, Kovats S, et al. The use of climate information to estimate future mortality from high ambient temperature: a systematic literature review. PLoS One. 2017;12:e0180369.
8. Gasparrini A, Guo Y, Sera F, et al. Projections of temperature-related excess mortality under climate change scenarios. Lancet Planet Health. 2017;1(9):e360–7.
9. Woodward A. Heat, cold and climate change. J Epidemiol Community Health. 2014;68(7):595–6.
10. Wang Y, Shi L, Zanobetti A, Schwartz JD. Estimating and projecting the effect of cold waves on mortality in 209 US cities. Environ Int. 2016;94:141–9.
11. Bhaskaran K, Gasparrini A, Hajat S, et al. Time series regression studies in environmental epidemiology. Int J Epidemiol. 2013;42:1187–95.
12. Lee JY, Lee SH, Hong S-C, Kim H. Projecting future summer mortality due to ambient ozone concentration and temperature changes. Atmos Environ. 2017;156:88–94.
13. Guo Y, Li S, Liu DL, et al. Projecting future temperature-related mortality in three largest Australian cities. Environ Pollut. 2016;208:66–73.
14. Bunker A, Wildenhain J, Vandenbergh A, et al. Effects of air temperature on climate-sensitive mortality and morbidity outcomes in the elderly; a systematic review and meta-analysis of epidemiological evidence. EBioMedicine. 2016;6:258–68.

15. Chen K, Horton RM, Bader DA, et al. Impact of climate change on heat-related mortality in Jiangsu Province, China. Environ Pollut. 2017;224:317–25.
16. Martinez GS, Baccini M, De Ridder K, et al. Projected heat-related mortality under climate change in the metropolitan area of Skopje. BMC Public Health. 2016;16:407.
17. Heaviside C, Tsangari H, Paschalidou A, et al. Heat-related mortality in Cyprus for current and future climate scenarios. Sci Total Environ. 2016;569–570:627–33.
18. Huang C, Barnett AG, Wang X, et al. Projecting future heat-related mortality under climate change scenarios: a systematic review. Environ Health Perspect. 2011;119:1681–90.
19. Sheridan SC, Allen MJ, Lee CC, Kalkstein LS. Future heat vulnerability in California, part II: projecting future heat-related mortality. Clim Change. 2012;115:311–26.
20. Barreca AI. Climate change, humidity, and mortality in the United States. J Environ Econ Manage. 2012;63(1):19–34.
21. Ostro B, Barrera-Gómez J, Ballester J, et al. The impact of future summer temperature on public health in Barcelona and Catalonia, Spain. Int J Biometeorol. 2012;56:1135–44.
22. Kingsley SL, Eliot MN, Gold J, et al. Current and projected heat-related morbidity and mortality in Rhode Island. Environ Health Perspect. 2016;124(4):460–7.
23. Lee JY, Kim H. Projection of future temperature-related mortality due to climate and demographic changes. Environ Int. 2016;94:489–94. https://doi.org/10.1016/j.envint.2016.06.007.
24. Wang Y, Nordio F, Nairn J, et al. Accounting for adaptation and intensity in projecting heat wave-related mortality. Environ Res. 2018;161:464–71.
25. Sexton DMH, Murphy JM, Collins M, et al. Multivariate probabilistic projections using imperfect climate models part I: outline of methodology. Climate Dynam. 2012;38(11–12):2513–42.
26. Gosling SN, Hondula DM, Bunker A, et al. Adaptation to climate change: a comparative analysis of modeling methods for heat-related mortality. Environ Health Perspect. 2017;125(8):087008.
27. Mills D, Schwartz J, Lee M, et al. Climate change impacts on extreme temperature mortality in select metropolitan areas in the United States. Clim Change. 2015;131:83–95.
28. Baaghideh N, Intergovernmental Panel on Climate Change, editors. Special report on emissions scenarios: a special report of Working Group III of the Intergovernmental Panel on Climate Change. Cambridge, New York: Cambridge University Press; 2000.
29. Petkova EP, Vink JK, Horton RM, et al. Towards more comprehensive projections of urban heat-related mortality: estimates for new York City under multiple population, adaptation, and climate scenarios. Environ Health Perspect. 2017;125(1):47–55.
30. Gerland P, et al. World population stabilization unlikely this century. Science. 2014;346:234–7.
31. Lutz W, Samir KC. Dimensions of global population projections: what do we know about future population trends and structures? Philos Trans R Soc Lond A. 2010;365(1554):2779–91.
32. Hajat S, Vardoulakis S, Heaviside C, Eggen B. Climate change effects on human health: projections of temperature-related mortality for the UK during the 2020s, 2050s and 2080s. J Epidemiol Community Health. 2014;68:641–8.
33. Kim D-W, Deo RC, Chung J-H, Lee J-S. Projection of heat wave mortality related to climate change in Korea. Nat Hazards. 2016;80(1):623–37.
34. Li T, Horton RM, Bader DA, et al. Aging will amplify the heat-related mortality risk under a changing climate: projection for the elderly in Beijing, China. Sci Rep. 2016;6:28161.
35. Jenkins K, Hall J, Glenis V, et al. Probabilistic spatial risk assessment of heat impacts and adaptations for London. Clim Change. 2014;124:105–17.
36. Ballester J, Robine J-M, Herrmann FR, Rodó X. Long-term projections and acclimatization scenarios of temperature-related mortality in Europe. Nat Commun. 2011;2:358.
37. Li T, Horton RM, Bader DA, et al. Long-term projections of temperature-related mortality risks for ischemic stroke, hemorrhagic stroke, and acute ischemic heart disease under changing climate in Beijing, China. Environ Int. 2018b;112:1–9.
38. Knowlton K, Lynn B, Goldberg RA, et al. Projecting heat-related mortality impacts under a changing climate in the new York City region. Am J Public Health. 2007;97:2028–34.
39. Kinney PL, Schwartz J, Pascal M, Petkova E, Tertre AL, Medina S, Vautard R. Winter season mortality: will climate warming bring benefits? Environ Res Lett. 2015;10(6):064016.
40. Zhang B, Li G, Ma Y, Pan X. Projection of temperature-related mortality due to cardiovascular disease in Beijing under different climate change, population, and adaptation scenarios. Environ Res. 2018;162:152–9.
41. Kinney PL, O'Neill MS, Bell ML, Schwartz J. Approaches for estimating effects of climate change on heat-related deaths: challenges and opportunities. Environ Sci Policy. 2008;11:87–96.
42. Li T, Ban J, Horton RM, et al. Heat-related mortality projections for cardiovascular and respiratory disease under the changing climate in Beijing, China. Sci Rep. 2015;5:11441. https://doi.org/10.1038/srep11441.
43. Li Y, Li G, Zeng Q, et al. Projecting temperature-related years of life lost under different climate

change scenarios in one temperate megacity, China. Environ Pollut. 2018;233:1068–75.

44. Zhang J, Li T, Tan JG, et al. Impact of temperature on mortality in three major Chinese cities. Biomed Environ Sci. 2014;27:485–94.
45. Li G, Guo Q, Liu Y, et al. Projected temperature-related years of life lost from stroke due to global warming in a temperate climate City, Asia: disease burden caused by future climate change. Stroke. 2018a;49:828–34.

9 Comparison of Health Impact of Ambient Temperature Between China and Other Countries

Qi Zhao, Kejia Hu, Shanshan Li, and Yuming Guo

Abstract

Global ambient temperature is increasing in the context of climate change, which causes a huge burden of mortality worldwide. Many epidemiological studies have been conducted to assess the health impacts of ambient temperature, consistently demonstrating significant health impacts of ambient temperature. Climate change problem in China is especially serious. It has become a big threat to the health of the Chinese people. In this review, we summarized existing literature, compared health impact of ambient temperature between China and other countries, and found both cold and hot temperatures increase the risk of mortality in different countries in different climatic zones. However, there is substantial heterogeneity in the risk estimates of ambient temperature. The effect heterogeneities may be due to the differences in the socioeconomic status, characteristics of populations (e.g., the proportion of the elder population and people with pre-existing diseases), human behavior, and adaptation to regional climate. This review highlights that public health strategies to alleviate the impact of ambient temperatures are important.

Keywords

Ambient temperature · Cold effect · Hot effect · Climate change · Effect heterogeneity

Qi Zhao and Kejia Hu contributed equally to this chapter

Q. Zhao · S. Li · Y. Guo (✉)
Department of Epidemiology and Preventive Medicine, School of Public Health and Preventive Medicine, Monash University, Melbourne, VIC, Australia
e-mail: Qi.Zhao@monash.edu; Shanshan.Li@monash.edu; yuming.guo@monash.edu

K. Hu
Department of Epidemiology and Preventive Medicine, School of Public Health and Preventive Medicine, Monash University, Melbourne, VIC, Australia

Institute of Island and Coastal Ecosystems, Ocean College, Zhejiang University, Zhoushan, China
e-mail: kejiahu@zju.edu.cn

9.1 Introduction

A large amount of epidemiological studies show evidence for the adverse health effects of ambient temperature on morbidity and mortality across the globe including China [1–3]. The estimated historical and future mortality burden attributed to ambient temperature vary by country, due to the spatial heterogeneity in temperature exposure, population, and population vulnerability (i.e., exposure-response relationships) [4, 5]. In addition, many studies have been conducted to examine the health impacts of heat waves and

H. Lin et al. (eds.), *Ambient Temperature and Health in China*,
https://doi.org/10.1007/978-981-13-2583-0_9

cold spells and found substantial heterogeneity in the risk estimates of those extreme temperature events [6–9]. Moreover, several individual characteristics (e.g., age, sex, and existing diseases) were identified to modify the temperature effects on health [10, 11].

Global warming resulting from rapid economic growth along with energy consumption has become a worldwide public health threat [12, 13]. China is one of the world's most rapidly growing economies, and it has experienced a rapid rise in energy consumption and carbon emissions in recent decades [14]. Unprecedented growth in anthropogenic greenhouse gas emissions (GHGs) has increased the intensity, frequency, duration, and spatial extent of extreme heat events in both China and the world, most notably in urban areas [15–17]. The response of climate change to human activities vary in regions, which may influence the between-country heterogeneity in the exposure to future extreme temperatures [18, 19]. Additionally, previous epidemiological studies on temperature-health impacts have been mainly conducted in developed countries [20, 21]; however, in recent years, literature in China has been increasingly produced [22–24]. As a developing country, China has a wide range of climatic conditions, as well as sociodemographic and cultural characteristics, which exhibit different patterns from the developed countries [25, 26]. Therefore, the health risk to ambient temperature and its determinants in China may differ from other countries. In this chapter, we make a comprehensive comparison of the health effects of ambient temperature in China and other countries, including the climatic characteristics, exposure-response functions, effect modifiers, and future health burden attributable to temperature.

Although numerous studies on health impacts of temperature have been conducted at the city, regional, and national level, these studies vary a lot with study design (e.g., descriptive, time-series, case-only, cohort, or case-crossover study) and health outcomes (e.g., mortality, or morbidity) [27–31]. Despite the temperature effects are fairly significant, types of study design may influence the effect estimates. For instance, case-crossover study cannot account for over-dispersion and may underestimate the variance of the effect estimates [32]. Typically, the most common statistical approach in this field is time-series analysis with Poisson regression. To date, most comparable studies, especially regional and national studies, focused on the health impact of ambient temperature on mortality [33–35]. Therefore, we restricted our comparative analysis of time-series studies to those estimates on mortality in order to reduce the complexities introduced by different health outcomes and analytic strategies.

9.2 Comparison of Climatic Characteristics Between China and Other Countries

9.2.1 Basic Climatic Characteristics

China is located in East Asia, between the Pacific Ocean and the Eurasian continent, and therefore also shows an east-to-west gradient from forests to steppe and desert. China is the third largest country across the globe, after Russia and Canada, and it covers a large land area of around 9.6 million km^2. The territory of China spans nearly 50 latitudes from north to south and over 60 latitudes from east to west. The topography of China is high in the west and low in the east and varies from the Qinghai-Tibet plateau (Mt. Everest or Chomolungma; 8850 m) to one of the lowest (Turpan Pendi; 154 m below sea level). The climate in China is governed by its geography and topography and most of its territory falling in the monsoon zone.

Given its vast territory, the climate in China is complicated. The climate and weather vary in different regions and change in different seasons. China's climate is mainly controlled by dry seasons in winter and wet monsoons in summer, which lead to pronounced temperature differences during the full year. In winter, northern winds from high-latitude areas are cold and dry; in summer, southern winds from coastal areas at lower latitudes are warm and moist. In terms of temperature, China can be divided from south to north into six zones: tropical, subtropical, warm-temperate, temperate, cold-temperate, and Qinghai-Tibet plateau temperate zone.

China is one of the countries with the most serious natural disasters, including heat waves and cold spells. There are strong regional variations in the characteristics of heat waves and cold spells globally [12]. The intensity, duration, and frequency of heat waves and cold spells in China also vary with cities and regions, due to the high heterogeneity in temperature across China [6, 36]. For instance, a global multicity study estimated annual heat wave days (daily mean temperature ≥ 95th percentile of temperature with duration ≥2 days) were 14 in Beijing, 16 in Shanghai, and 21 in Hong Kong [6].

9.2.2 Current and Future Climate Change

Global climate change is one of the key scientific and societal issues in the world. One of the major concerns with a potential change in climate is that a change in ambient temperature and extreme temperature events will occur [37–39]. There is general agreement that global air temperature has increased since the late nineteenth century and the decade of the 2000s has been the warmest [38, 40, 41]. The Intergovernmental Panel on Climate Change (IPCC) Fifth Assessment Report [42] estimated the globally averaged temperature has a warming of 0.85 [0.65–1.06] °C, over the period 1880–2012 (Fig. 9.1) [12]. The report stated that the warming in the early twentieth century was largely a northern hemisphere mid- to high-latitude phenomenon, but the more recent

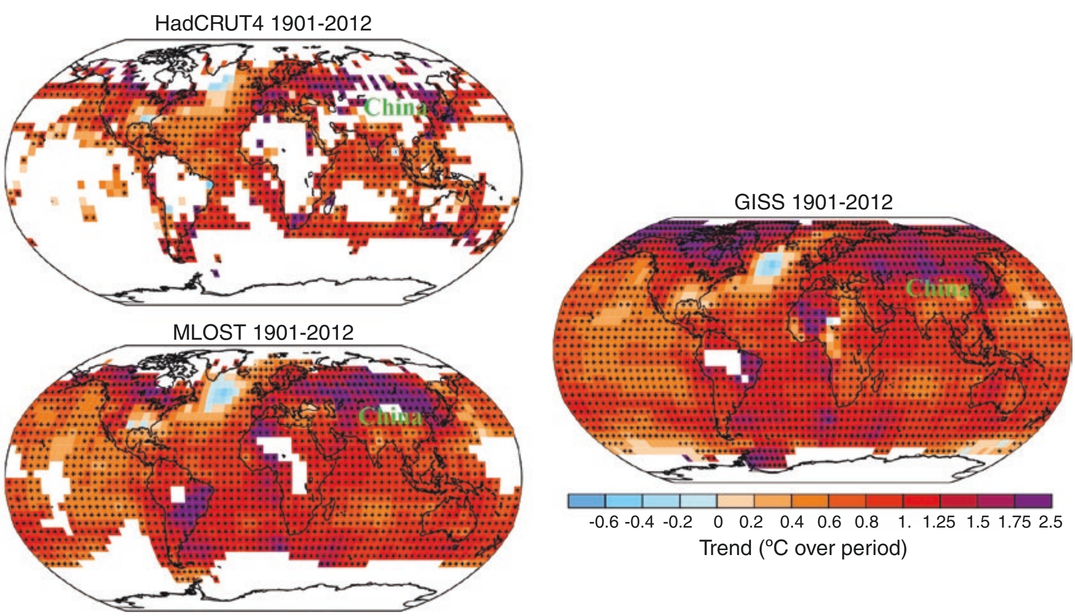


Fig. 9.1 Trends in surface temperature from the three data sets of HadCRUT4, MLOST, and GISS for 1901–2012. White areas indicate incomplete or missing data. Trends have been calculated only for those grid boxes with greater than 70% complete records and more than 20% data availability in first and last decile of the period. Black plus signs (+) indicate grid boxes where trends are significant (Reproduced with permission from IPCC report [12] (https://epic.awi.de/id/eprint/37530/))

warming is more likely to be a global issue in nature [12]. In addition to robust global warming, the cold spells were projected to significantly decrease in a future warmer climate, and it was considered very likely that heat waves would be more intense and more frequent and have longer durations toward the end of the twenty-first century [12, 43, 44]. Moreover, it's very certain that the number of warm days and nights increases and the number of cold days and nights decreases on the global scale [12].

IPCC also reported that mean annual temperature over most of the Asia region has very likely increased over the past century [12]. According to China's Third National Assessment Report on Climate Change in 2015, rise in China's annual average ambient temperature was estimated to be 0.9–1.5 °C during the past century since 1909, which was larger than the average global temperature increase [45]. The report also predicts that this increasing trend will further intensify in the future, and temperatures across most of China will rise another 1.3–5.0 °C by the end of this century, whereas the global average estimate is 1.0–3.7 °C [45].

Numerous studies observed the increasing trend of heat waves in China, particularly in urban areas, while the cold spells have a declining trend [46–48]. Under the RCP8.5 scenario, it is estimated that the indices of heat wave frequency, heat wave days, and longest heat wave duration in China would increase from about 1.0 times/year, 5.4 and 2.5 days/year to about 3.2 times/year, 32.0 and 14.0 days/year for 1.5 and 5.0 °C warming targets, respectively [49]. In addition, the decreasing trend of cold days and cold nights and the increasing trend of warm days and warm nights were also widely reported in China [50–52], consistent with those of many other countries in Asia [53], Europe [54], and Australia [55]. You et al. [56] estimated the mean trends for cold days and cold nights have decreased by 0.47 and 2.06 days per decade in China, respectively, and warm days and warm nights have increased by 0.62 and 1.75 days per decade in China, respectively.

9.3 Comparison of Exposure-Response Functions Between China and Other Countries

Numerous epidemiological studies have reported ambient temperature was associated with adverse health outcomes at a local, regional, and global level [2–4]). It has been widely reported of the significant impacts of cold and hot temperature on cause-specific mortality, such as cardiovascular and respiratory mortality [22, 57, 58]. However, existing studies often used inconsistent model specifications, including model choice (e.g., single lag model, moving average lag model, or distributed lag nonlinear model), and lag days and other parameters (e.g., degrees of freedom and spaced knots) for smoothing splines. Model specifications may influence the effect estimates and limit the ability to compare the results between studies. Additionally, various temperature thresholds in relative risk calculation (e.g., 99th vs. minimum mortality temperature percentile, 99th vs. 75th, or per 1° increase, etc.) in different studies make the city- or regional-level results difficult to be compared and synthesized. Therefore, our comparison of the exposure-response functions between China and other countries was mainly based on national- and global-level studies.

9.3.1 Exposure-Response Relationship

The shape of the relationship between temperature and mortality has been mainly described as a reversed J-, V-, W, or U-pattern, with a nonlinear increase in mortality around an optimal temperature point (i.e., minimum mortality temperature) [1, 59]. These shapes have been observed in different climate zones and populations, and the optimal temperature varies by population and climate [24, 60, 61]. In a multicountry study, both hot and cold temperatures that were observed significantly increase the mortality risks in China and other 11 countries/regions (Fig. 9.2) [1]. Generally, a U-shaped pooled temperature-mortality association was observed in China; however, the shape varies a lot among cities and regions [1, 25, 35].

The mortality risks associated with cold [first percentile vs. minimum mortality temperature percentile (MMP)] and hot (99th percentile vs. MMP) temperatures differed by community and country (Fig. 9.3). In summary, effect estimates for cold effects (first vs. MMP) were higher than hot effects (99th vs. MMP) in all the countries/regions [1, 4]. For example, in China, the pooled cold effects (first vs. MMP) is 1.22 (1.12–1.34), and the pooled hot effects (99th vs. MMP) is 1.10 (1.03–1.17). These estimates are comparable with the estimates in other countries. The cold effects (first vs. MMP)

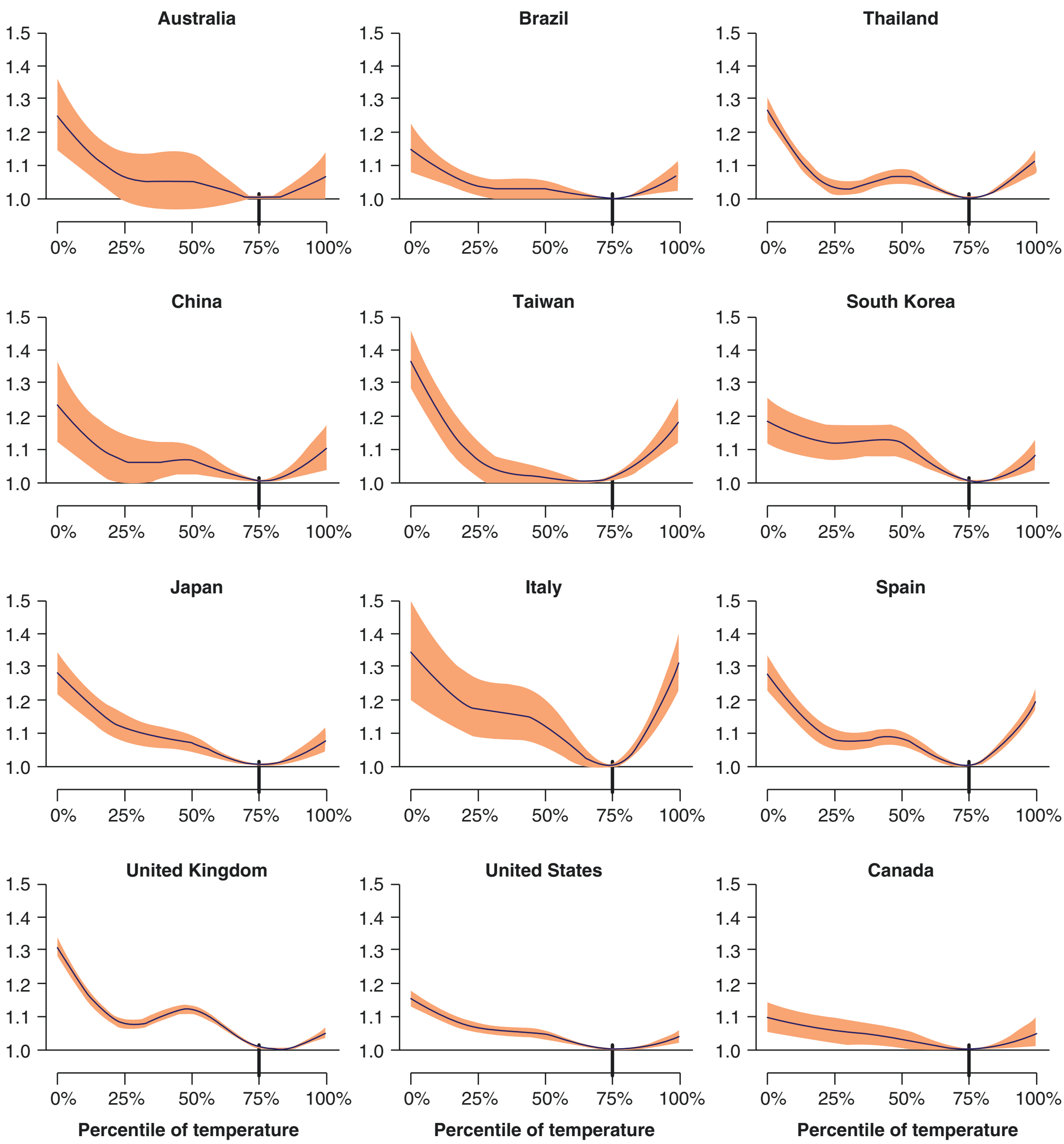


Fig. 9.2 The pooled overall cumulative relationship between temperature and mortality over lag 0–21 days in 12 countries/regions (Reproduced with permission from Guo et al. [1] (https://www.ncbi.nlm.nih.gov/pubmed/25166878))

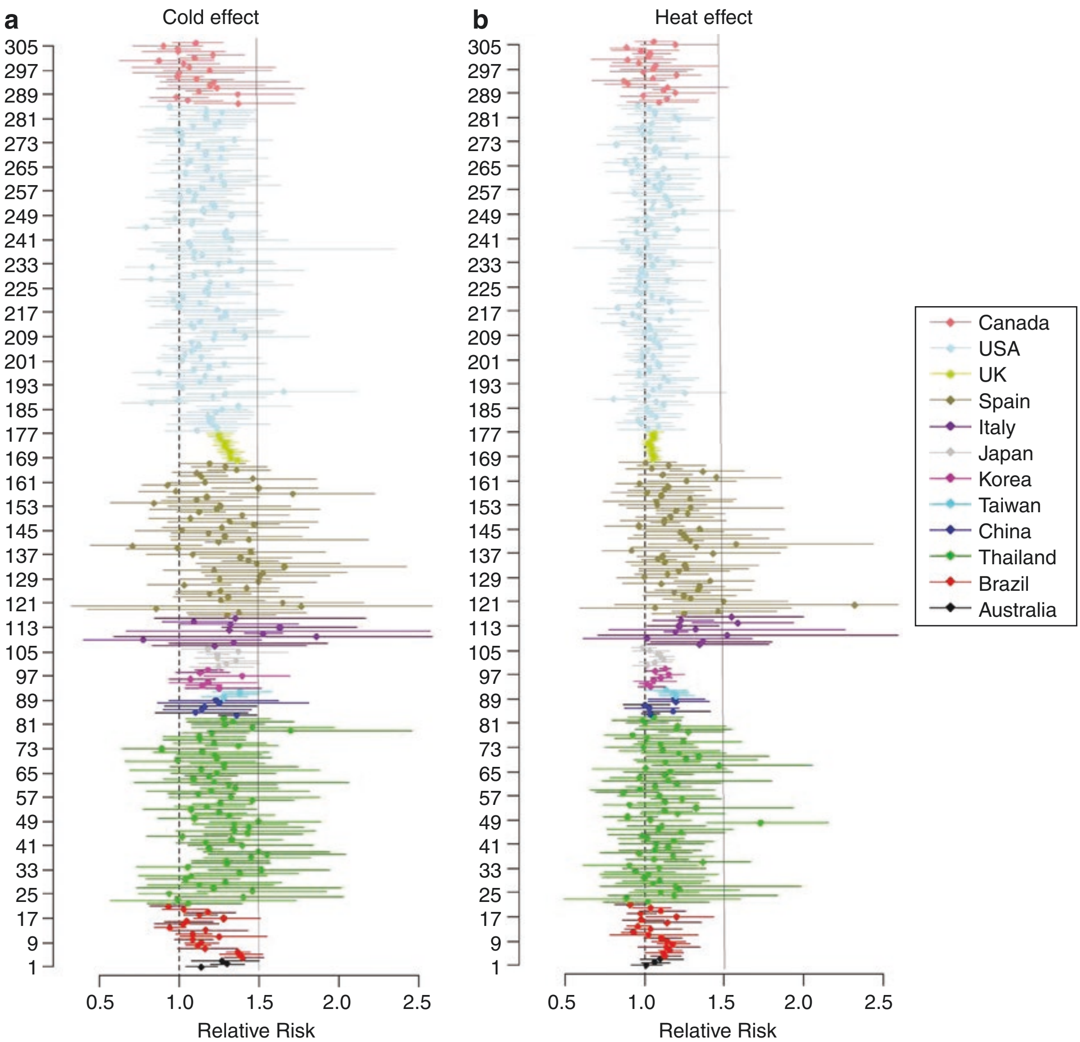


Fig. 9.3 The relative risks of (**a**) cold temperature (first percentile versus minimum mortality temperature) and (**b**) hot temperature (99th percentile versus minimum mortality temperature) on deaths cumulated over lags of 0–21 days in each community of the 12 countries/regions (Reproduced with permission from Guo et al. [1] (https://www.ncbi.nlm.nih.gov/pubmed/25166878))

in China is lower than those in Australia, Thailand, Taiwan, Japan, Italy, Spain, and the UK and higher than those in Brazil, South Korea, Canada, and the USA (Table 9.1). However, their differences are generally not statistically significant. Table 9.1 also shows that the estimate of hot effect (99th vs. MMP) in China is similar as those in other countries, which is slightly lower than the estimates in Thailand, Taiwan, Italy, and Spain but slightly higher than the estimates in Australia, Brazil, Japan, Canada, the UK, and the USA.

The minimum mortality temperatures (MMT) were higher in countries with high mean temperature or close to equator (Fig. 9.2). In China, a national-wide study also found lower MMTs in colder regions and higher MMTs in hotter regions [25]. But the MMTs distributed almost around the 75th percentile of temperature in all countries according to a global-wide study, ranging from the 66th percentile in Taiwan to the 80th percentile in the UK (Table 9.1). In China, the MMT in the pooled temperature-mortality association is around 76th. The consistency of the MMT around

Table 9.1 The pooled percentage increase of deaths associated with cold temperature (first percentile of temperature) and hot temperature (99th percentile of temperature) cumulated over lags of 0–21 days in the 12 countries/regions (Reproduced with permission from Guo et al. [1] (https://www.ncbi.nlm.nih.gov/pubmed/25166878))

Countries and regions	Percentage increase (and 95%CI)		
	Cold effects	Hot effects	
	1st vs. MMP	99th vs. MMP	MMP
Australia	24% (14–35%)	6% (0–13%)	76
Brazil	14% (8–21%)	7% (2–11%)	72
Thailand	25% (22–29%)	11% (8–14%)	76
China	22% (12–34%)	10% (3–17%)	76
Taiwan	35% (27–44%)	18% (12–25%)	66
South Korea	18% (11–25%)	8% (4–12%)	78
Japan	27% (21–33%)	7% (4–11%)	76
Italy	33% (20–48%)	30% (22–39%)	74
Spain	26% (22–32%)	19% (16–23%)	74
UK	30% (27–33%)	5% (4–6%)	80
USA	15% (13–18)	4% (2, 6%)	76
Canada	10% (5–14%)	5% (1, 9%)	74

the 75th percentile at a global scale suggests that, in the long term, people may have ability to adapt to local climate conditions by means of various physiological, behavioral, and technological adaptations [1, 25, 62].

9.3.2 Lag Effects of Hot and Cold Temperature

The distribute lag nonlinear model was widely used to model the exposure-lag-response relationships in epidemiological studies, particularly in time-series analysis of temperature-mortality associations [63, 64]. Based on DLNM, a large amount of studies reported the nonlinear delayed effects of the temperatures on mortality [1, 65, 66]. Generally, it was observed that the hot effects often appeared immediately and lasted generally less than 1 week, while the cold effects appeared after several days but lasted at least 10 days [1, 59, 67].

The effects of cold temperature (first vs. MMP) delayed for longer days in Taiwan, Italy, Spain, and the UK than in China (Fig. 9.4), which lasts for about 10 days, as observed in Japan, Canada, South Korea, Thailand, and the USA. The effects of hot temperature (99th vs. MMP) lasted only 3 or 4 days in China (Fig. 9.5), while longer-lasting days were found in Italy and Spain. There were several days when the relative risk was lower than 1.0 at longer lag days (i.e., mortality displacement) after exposure to hot temperatures in South Korea and the UK, and to a lesser extent in Japan and Canada, whereas it was not found in other countries including China [1]. The findings of lag effects suggest that timely preventive measures should be implemented to reduce the heat effects on mortality, while several days' protection is effective to reduce the cold effects on mortality both in China and other countries [1].

9.3.3 Mortality Burden Attributable to Temperature

Measures of the attributable burden to environmental health risk factors are helpful for the planning and evaluation of public health interventions. Attributable risk can be estimated based on the exposure-response functions and the environmental and health data [68]. To date, increasingly studies estimated the mortality burden, including the attributable mortality fractions and attributable death counts related to temperatures [4, 69].

A multicountry study [4] estimated that the total mortality fraction caused by both heat (temperature above MMT) and cold (temperature below MMT) was 7.71% [95% empirical CI (eCI) 7.43–7.91]. This fraction largely varied between countries, with the highest estimates of attributable risk in Italy, China, and Japan and the lowest estimates in Thailand, Brazil, and Sweden (Table 9.2). Cold was responsible for the vast majority of the burden (total estimate 7.29%, 95% eCI 7.02–7.49%), while the mortality fraction attributable to heat was small (0.42%, 95% eCI 0.39–0.44%). This difference was mainly due to the fact that the minimum mortality temperature percentile was often high; therefore, most of the mean daily temperatures was lower than the minimum mortality temperature. Attributable mortality fractions related to cold temperature were estimated to be the highest in

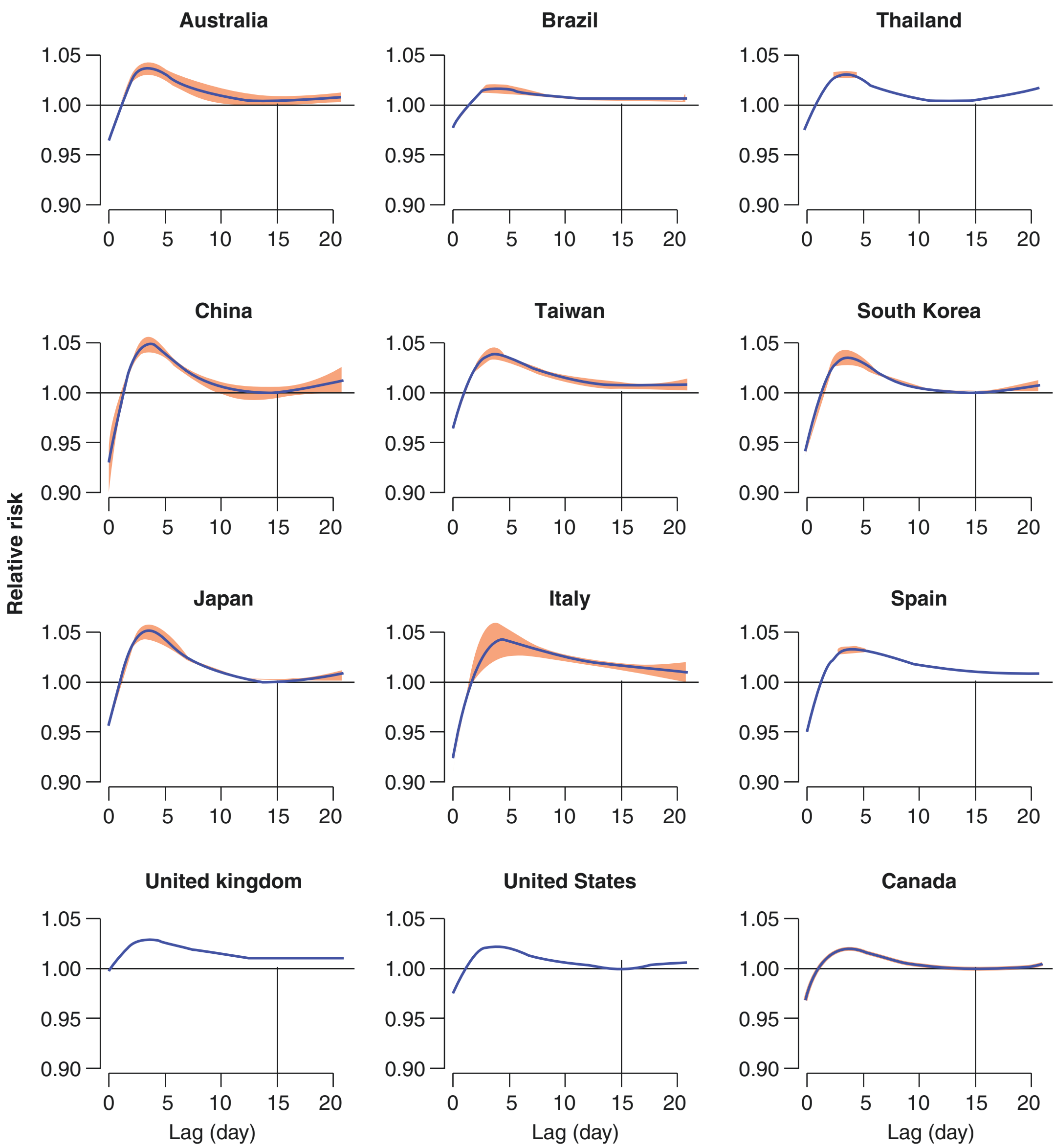


Fig. 9.4 The pooled lag-response relationship associated with cold temperature (first percentile versus minimum mortality temperature) on deaths along lags of 0–21 days in the 12 countries/regions (Reproduced with permission from Guo et al. [1] (https://www.ncbi.nlm.nih.gov/pubmed/25166878))

China than other countries (Table 9.2). The attributable mortality fraction related to hot temperature in China is lower than the estimates in Brazil, Italy, Spain, Taiwan, and Thailand but is higher than the estimates in other countries such as the USA, the UK, and Australia (Table 9.2).

The attributable mortality burden can be divided into two components related to moderate and extreme temperatures, respectively. It is reported that most of the mortality risk attributable to temperature was related to moderate cold (from 2.5th percentile of temperature to minimum mortality temperature), estimated to be 6.66% (95% eCI 6.41–6.86%) [4]. Extreme temperatures (extreme cold defined by temperature below 2.5th percentile and extreme heat

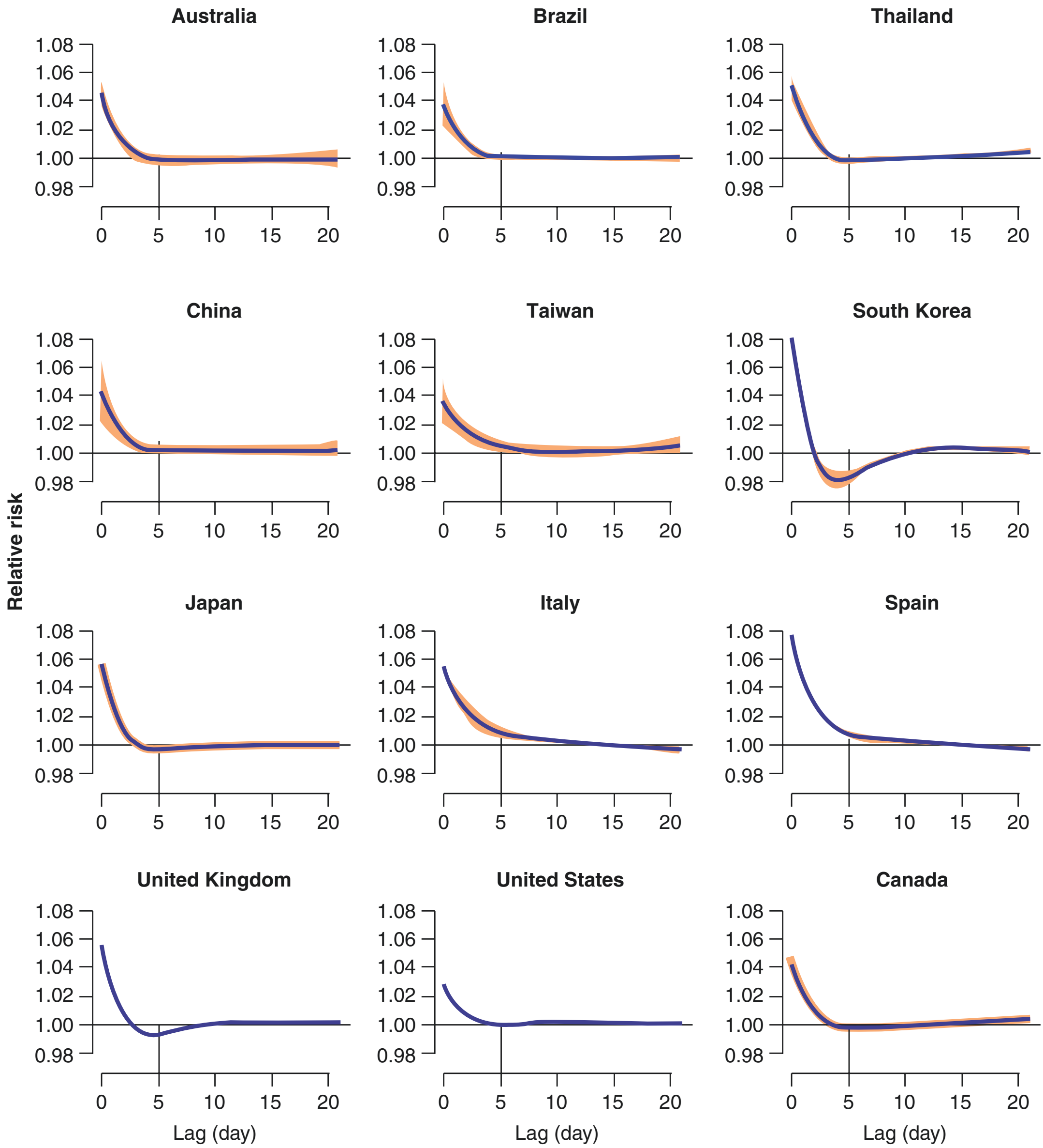


Fig. 9.5 The pooled lag-response relationship associated with hot temperature (99th percentile versus minimum mortality temperature) along lags of 0–21 days in the 12 countries/regions (Reproduced with permission from Guo et al. [1] (https://www.ncbi.nlm.nih.gov/pubmed/25166878))

defined by temperature above 97.5th percentile) were responsible for a small fraction, estimated to be 0.86% (95% eCI 0.84–0.87%), with a mortality fraction of 0.63% (95% eCI 0.61–0.64%) attributable to extreme cold and a mortality fraction of 0.23% (95% eCI 0.22–0.24%) attributable to extreme heat (Fig. 9.6). Attributable mortality fractions were estimated to be 1.06% (95% CI 0.96–1.15%) to extreme cold and 0.40% (95% eCI 0.32–0.47%) to extreme heat in China. It indicates population in China may be more affected by cold (either extreme or moderate) than population in other countries.

Table 9.2 Attributable fraction of mortality (and 95% empirical CI) due to non-optimum temperature, cold, and heat by country (Reproduced with permission from Gasparrini et al. [4] (https://www.sciencedirect.com/science/article/pii/S0140673614621140))

Country	Attributable fraction (%)		
	Total	Cold	Heat
Australia	6.96 (4.27–9.51)	6.50 (3.91–8.94)	0.45 (0.20–0.70)
Brazil	3.53 (3.00–4.01)	2.83 (2.34–3.30)	0.70 (0.45–0.93)
Canada	5.00 (3.83–6.07)	4.46 (3.39–5.48)	0.54 (0.39–0.66)
China	11.00 (9.29–12.47)	10.36 (8.72–11.77)	0.64 (0.47–0.79)
Italy	10.97 (8.03–13.43)	9.35 (6.59–11.72)	1.62 (1.24–1.98)
Japan	10.12 (9.61–10.56)	9.81 (9.32–10.22)	0.32 (0.27–0.36)
South Korea	7.24 (4.45–9.73)	6.93 (4.12–9.44)	0.31 (0.15–0.45)
Spain	6.52 (5.82–7.16)	5.46 (4.79–6.07)	1.06 (0.96–1.16)
Sweden	3.87 (−6.20 to 12.93)	3.69 (−6.31 to 12.61)	0.18 (−0.47 to 0.65)
Taiwan	4.75 (3.26–6.06)	3.89 (2.50–5.31)	0.86 (0.12–1.50)
Thailand	3.37 (3.06–3.63)	2.61 (2.31–2.88)	0.76 (0.65–0.86)
UK	8.78 (8.00–9.54)	8.48 (7.72–9.25)	0.30 (0.25–0.36)
USA	5.86 (5.50–6.17)	5.51 (5.17–5.82)	0.35 (0.30–0.39)
Total	7.71 (7.43–7.91)	7.29 (7.02–7.49)	0.42 (0.39–0.44)

9.4 Health Burden Associated with Heat Waves and Cold Spells

The health risk associated with heat waves as well as cold spells is well recorded [70]: between 1936 and 2017, heat waves and cold spells caused more than 160,000 and 17,000 direct deaths worldwide, respectively, with 91% and 63% of cases occurring after 2000.

9.4.1 Health Impact of Heat Waves

There is no standard criterion regarding the temperature threshold and duration of heat waves across the globe. For example, in Sweden a heat wave is considered as ≥5 consecutive days with the daily maximum temperatures >25 °C [71]; in Maine, US heat wave is reported if there are >2 consecutive days with daily temperatures > 95 °F (35 °C) [72]. Numerous studies have indicated that the effect of heat waves on mortality may vary across regions/countries as a result of local acclimation and other factors [73, 74]. However, it is a challenge to assess the geographical variation in the adverse effect of heat waves without a unified definition of heat waves. The use of different methodologies (e.g., time-series analysis, case-crossover design, and case-only approach)

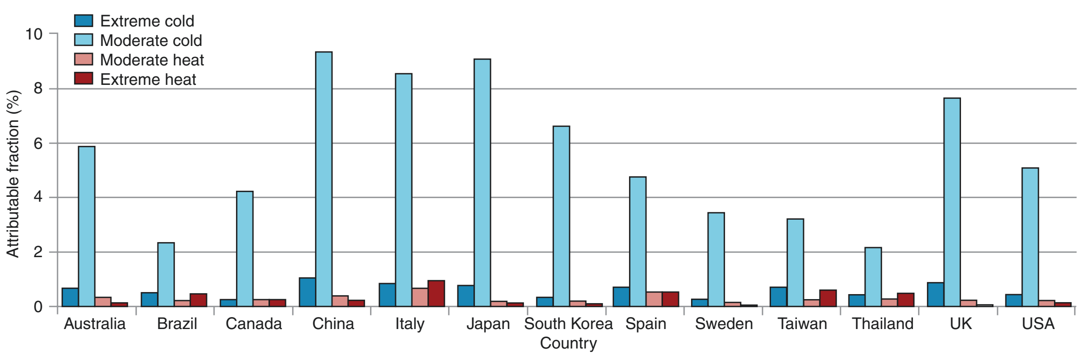


Fig. 9.6 Fraction of all-cause mortality attributable to moderate and extreme hot and cold temperature by country. Note: Extreme and moderate high and low temperatures were defined with the minimum mortality temperature and the 2.5th and 97.5th percentiles of temperature distribution as cutoffs (Reproduced with permission from Gasparrini et al. [4] (https://www.sciencedirect.com/science/article/pii/S0140673614621140))

and parameters (e.g., with or without considering lag effect) further exaggerates the difficulty of comparing previous findings. Multi-site studies can solve this problem by applying the same definitions of heat waves according to the local climatic characteristics with the same statistical design.

Guo et al. [6] assessed the mortality risk of 12 heat wave definitions (from moderate to severe) in 18 countries/regions (400 communities) over lag 0–10 days, by setting threshold at the community-specific daily mean temperature ≥ 90th, 92.5th, 95th, and 97.5th percentiles of year-round temperature with duration ≥2, 3, and 4 consecutive days, respectively. The results indicated that the risk of mortality was strongly associated with heat waves of all definitions in all countries/regions, with the effect estimates higher in Italy, Moldova, and Vietnam than other countries (Fig. 9.7).

Generally, heat waves with higher temperature threshold had higher effect (except for China), while there was minimal distinction between different durations. The adverse effect of heat waves was highest during the first day after exposure, and lasted for 3–4 days, after which mortality displacement (harvesting effect) appeared in the majority of countries. Findings from this study showed that heat waves defined using daily mean and maximum temperatures had similar performance in predicting the risk mortality, better than the daily minimum temperature.

Evidence about the heat wave-mortality association in China has been mainly from single-site population, with little information available across different regions. Ma et al. [75] explored this association in 66 Chinese communities (located in 28 provinces or municipalities) during lag 0–1 days. For each community, heat waves were defined as ≥2 adjacent days when daily mean temperatures were ≥95th percentile of year-round temperature distribution. Approximately 5% [95% confidence interval (CI): 2.9–7.2%] of deaths were linked to heat waves in China, with the attributable mortality burden greatest in the northern China [6.0% (95%CI: 1.0–11.3%)] and lowest in the south [4.5% (95%CI: 1.4–7.6%)].

Some investigations have indicated that the heat wave-mortality association varies by disease category, potentially depending on which physiological system of the body is primarily affected. For example, in the Chinese population, cardiovascular deaths were more associated with heat waves than respiratory deaths [75]. Another heat wave study provides more cause-specific details in the French population between 1971 and 2003 [76]. Of the 18 cause categories, the effect of heat waves was higher for mortality relevant to heat-related causes (e.g., hyperthermia), respiratory condition, nervous disorder, mental problem, communicable disease, and endocrine/nutritional disease.

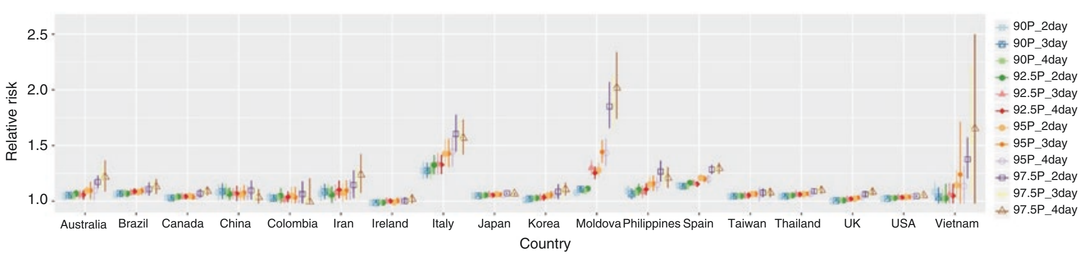


Fig. 9.7 Cumulative effects of heat waves on mortality over lag 0–10 days in 18 countries/regions for 12 types of heat waves (Reproduced with permission from Guo et al. [6] (https://ehp.niehs.nih.gov/doi/10.1289/EHP1026))

9.4.2 Health Impact of Cold Spells

Cold spells are extreme cold temperatures that last for a few continuum days, but there is no unified definition worldwide. While in Spain a cold spell is identified when the daily minimum temperature is under the fifth percentile of local temperature during winter [77], a previous study defined cold spells in the Czech Republic as ≥3 adjacent days with daily maximum temperatures below −3.5 °C [78]. Different from heat waves, few multi-site investigations focusing the health impact of cold spells are available, which limits the comparison of relevant health impact across countries or regions. This section thus only discusses the health impact of cold spells in China.

China has various climatic zones and geographic characteristics. Compared with population in other areas, those living in the subtropical south are more affected by cold spells due to the lack of acclimation and preparation (e.g., without heat supply). In the beginning of 2008, the majority of sites in China experienced preeminent cold temperatures that lasted for an extraordinary long duration. Zhou et al. [79] quantified the health impact associated with this unprecedented cold event on excess death in 15 provinces. For each community, cold spell was considered as ≥5 adjacent days with daily mean temperatures below the fifth percentile of temperature distribution from December to March during 2006–2010. They found that this cold spell was associated with 43.8% (95% CI: 34.8–53.4%) increase in the risk of mortality, with a higher susceptibility found in the South and central China than in the Southwest and East. Unlike heat waves, the effect of this cold spell lasted much longer, which peaked on the third day after exposure, declined in the next 4 days, and then leveled off. This study also found that the risk of mortality of this cold spell was mainly associated with cold temperature instead of the added effect of duration.

9.5 Modifiers for Exposure-Response Functions

There is a large amount of evidence indicating that the effect of suboptimal temperatures does not equally distribute across population but exhibits its spatial and demographic variations [4, 80–82]. In this section, we summarize several well-documented effect modifiers that may contribute to the various exposure-response functions.

9.5.1 Demographic Factors

Although the underpinning mechanisms of the association between suboptimal temperatures and mortality remain unknown, most studies tend to explain this as due to the insufficient response of the automatic thermoregulatory system of the body to thermal stress [83]. Considering the heterogeneous personal characteristics (e.g., age, sex, pre-existing diseases, and socioeconomic status), the within-population variation is expected.

9.5.1.1 Age

Age is an important modifier for the impact of suboptimal temperature events on a variety of health outcomes (e.g., cardiovascular and all-cause mortality), with the youth and the elderly more susceptible than adults. For example, the risk of mortality in the elderly ≥75 years old increased by 4.2% (95%CI: 1.3–7.2%) per 1 °C rise in maximum apparent temperature above city-specific thresholds in seven Mediterranean European cities (e.g., Athens, Rome, and Barcelona) during the 1990–2000 hot seasons [84]. By contrast, the effect of heat was 0.9% (95%CI: −1.29 to 3.1%) in the population aged 15–64 years. Some other studies with finer age groups found that children under 5 years of age, particular infants ≤1 year, might be more affected by heat exposure than the elderly [85]. Similar age pattern was also observed previously for the health impact of cold temperature [86, 87]. The enhanced vulnerability in these age groups is potentially because the immature or impaired physiological systems cannot respond adequately to suboptimal temperature events. The higher susceptibility in children is consistent with the fact that 90% of disease burden associated with climate change is in children <5 years [88, 89]. Reasonable explanation may be that children can absorb more thermal stress per unit of mass and have an immature adaption to suboptimal temperature [90, 91].

9.5.1.2 Gender

The modification effect of gender has also been investigated, and the findings are inconsistent. Some studies have reported that there is minimal sex difference in response to extreme cold or hot temperatures, particularly in some high-income countries/regions/cities [85, 92, 93]. However, some other research suggests that males or females may be more affected by exposure to suboptimal temperatures [94, 95]. The heterogeneous findings in different countries or regions regarding the modification effect of gender may be relevant to several factors:

1. Physiological difference in thermoregulation. Findings from several experimental studies indicate that there is no evident sex difference in the effectiveness of thermoregulation after controlling for physiological factors, e.g., muscle mass, age, body size, and aerobic capacity [96, 97]. However, in the general population (i.e., without considering those factors), dynamics of sweating in women are lower than in men, implying that women may be less efficient in response to heat load [98]. During cold exposure, women are probably also of disadvantage due to lower resting metabolic rate, higher thermal loss per unit of weight, and smaller body weight [99, 100]. However, the higher subcutaneous fat content may improve women's tolerance to heat loss.
2. In some less developed countries or regions, women may have lower socioeconomic status and are less likely access to healthcare resources.
3. The disease-specific burden, which has various temperature sensitivities, generally shows sex difference and differs across countries [101].
4. Previous studies did not consider the difference in age structure between men and women.

9.5.1.3 Socioeconomic Status and Other Factors

There is a large number of studies showing that the population with lower socioeconomic status, such as low income and educational attainment, is more associated with temperature-related health outcomes [102]. This may be due to the limited access to healthcare unitizations and lack of infrastructure improvements (e.g., air conditioning and building insulation), especially in some low- and middle-income countries. However, some other studies, particularly those derived from populations in high-income countries/regions, indicate that lower socioeconomic status is not a substantial effect modifier [92, 95].

In addition to these factors, some recent evidence implies that race or ethnic group may modify the temperature-health association, with Black racial group and other non-Whites more affected by suboptimal temperature in the USA [11, 103]. Although China is a multiracial country, little information is available regarding whether there is various thermal responses across different racial groups.

9.5.2 Latitude and Other City-Specific Factors

There is increasing evidence from multiple countries showing that residents in high latitude is more susceptible to heat exposure and those living in low latitude are more vulnerable to cold exposure [10, 11, 75]. For example, Ma et al. [25] found U- or J-shaped temperature-mortality associations in China, with the minimum mortality temperature increasing from 17.7 °C in the northeast to 27.4 °C in the south (Fig. 9.8). The reasonable explanation is that people are more easily to acclimate the local climate while less prepared for the uncommon extreme weather conditions.

Findings from some studies suggest that the effect of high temperature events (e.g., heat waves) are more pronounced for population in urban cities, largely attributable to the heat island effect [75]. However, limited knowledge is known whether the population in rural areas would be more susceptible to cold events.

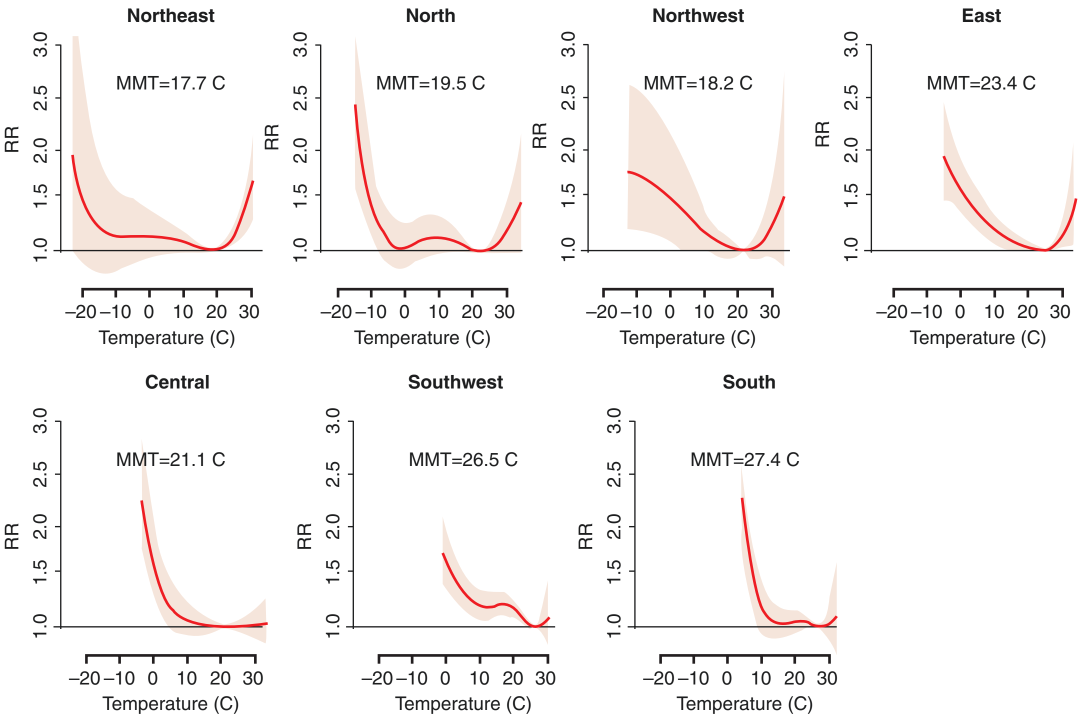


Fig. 9.8 Temperature-mortality relationship and minimum mortality temperature (MMT) by region for lag 0–21 days (Reproduced with permission from Ma et al. [25] (https://www.sciencedirect.com/science/article/pii/S0013935114004319))

9.6 Future Disease Burden Related to Temperature Change

Climate change is the world's single largest threat in the twenty-first century [104]. Under different scenarios of greenhouse gas emission and other socioeconomic assumptions, the world's average surface temperature is expected to increase by 0.3–4.8 °C during 2081–2100 relative to the 1986–2005 average [102]. As the result, there is increasing frequency/intensity and longer duration of temperature events globally, with some countries or regions more affected than others. Some studies have assessed the future temperature-related mortality burden. However, most previous investigations only focused on the change in heat-related mortality, with few studies assessing the net variation due to temperature change [105].

A previous study predicted the temperature-related deaths in the UK from the 2020s to 2080s, relative to the 2000s under the medium A1B emission scenario [106]. Assuming a stable population size, the nationwide deaths related to heat exposure are predicted to increase by 329%, while the cold-related deaths will decrease by 40% in the 2080s. However, the change in mortality in the 2080s due to change in high and low temperatures will be 535% and −12%, respectively, after adjusting for population factor. In seven Korean cities, the temperature-related mortality in the 2090s is projected to increase 4–6 times as high than in the 1992–2010 baseline under four representative concentration pathway (RCP) scenarios (i.e., RCP2.6, 4.5, 6.0, and 8.5) [107]. Studies conducted in other countries (e.g., the USA and Australia) have similar findings that the heat-related deaths will increase and cold-related deaths will decline in the next decades [80, 108]. However, the use of various statistical approaches, assumptions, baseline study periods, and climate change scenarios inhibits the assessment regarding which countries or regions may be more vulnerable due to global warming [106, 109].

Recently, Gasparrini et al. [5] provided a quantitative comparison of the future change in mortality attributable to suboptimal temperature (for both heat and cold) across 451 sites in 23 countries of the world by using a consistent analytical design (Fig. 9.9).

Under the RCP8.5 scenario, and assuming stable population and thermal adaptation, the change in temperature-related mortality exhibits spatial variation from the 1990s to the 2090s (Fig. 9.10). In northern Europe, Australia, and East Asia, the mortality attributable to cold tem-

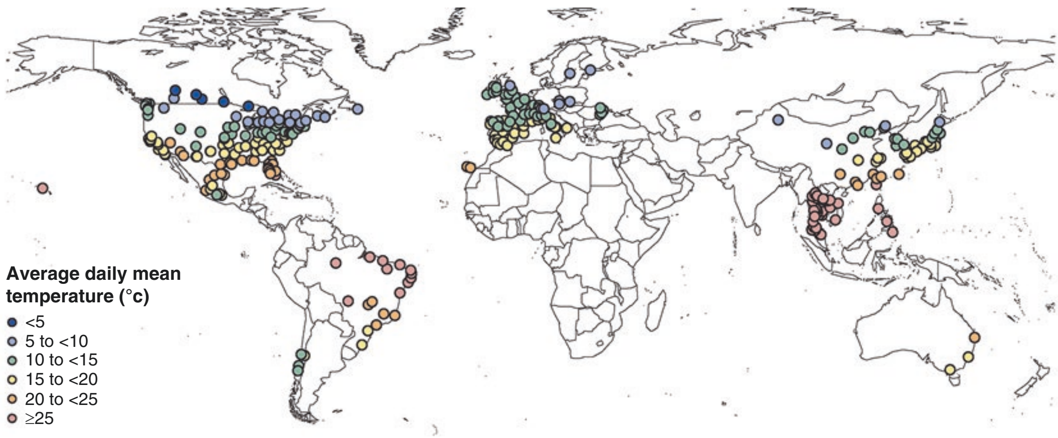


Fig. 9.9 Map of the 451 locations included in the analysis (Reproduced with permission from Gasparrini et al. [5] (https://www.sciencedirect.com/science/article/pii/S2542519617301560))

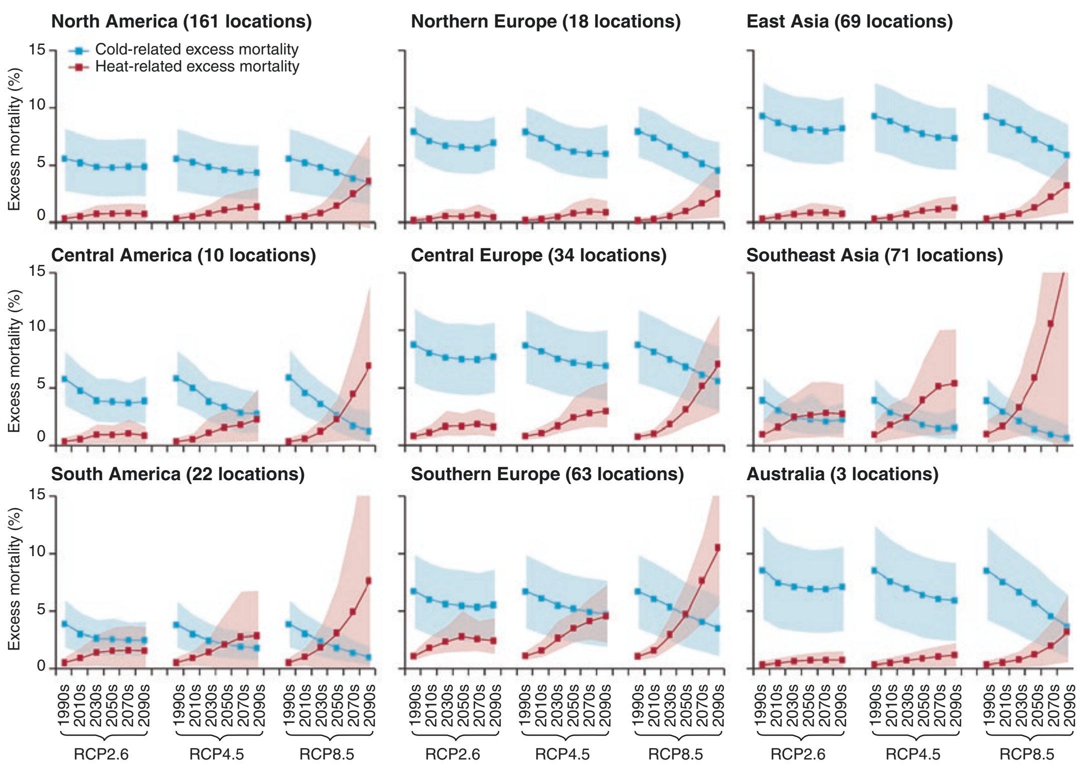


Fig. 9.10 Trends in heat-related and cold-related excess mortality by region (Reproduced with permission from Gasparrini et al. [5] (https://www.sciencedirect.com/science/article/pii/S2542519617301560))

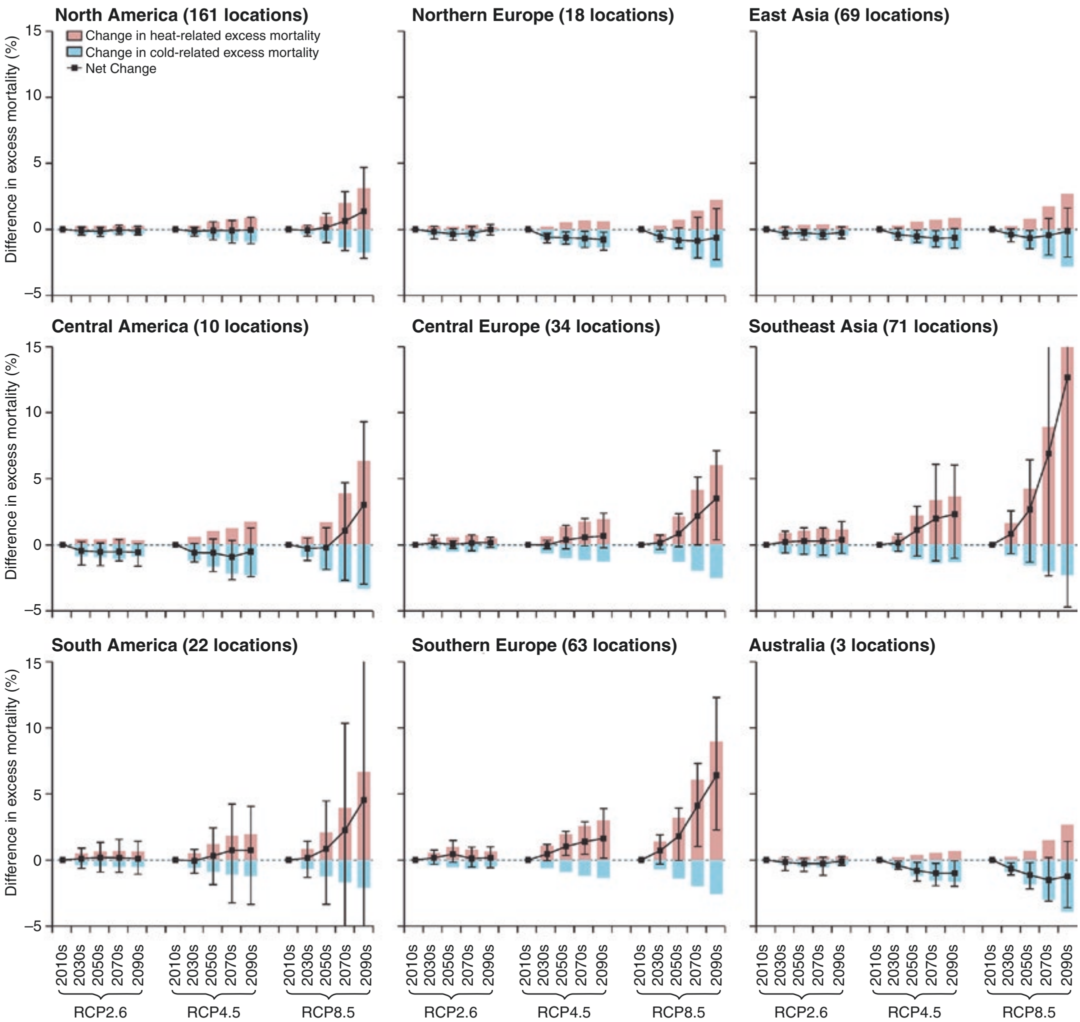


Fig. 9.11 Temporal change in excess mortality compared with 2010s by region (Reproduced with permission from Gasparrini et al. [5] (https://www.sciencedirect.com/science/article/pii/S2542519617301560))

perature is expected to decline from 7.4–8.7% in the 2010s to 3.7–5.9% in the 2090s, still higher than the change in heat-related excess death that would rise from 0.3–0.5% to 2.5–3.2% during the same study period. Conversely, heat-related excess mortality is projected to increase substantially in Central and South America, Central and southern Europe, and Southeast Asia, with cold impact becoming minimal in equatorial areas.

Globally, a net increase in excess death related to temperature change is expected in the 23 countries under the RCP8.5 scenario, with substantial geographic heterogeneity observed. The large decrease in cold effect and moderate increase in heat effect will cause net decline in temperature-related deaths in 2090s relative to 2010s in temperate regions including northern Europe (−0.6%), East Asia (−0.1%), and Australia (−1.2%) (Fig. 9.11). By contrast, the significant increase in heat effect is predicted to cause a large net increase in temperature-related mortality in the rest regions in 2090s compared with 2010s, increasing from 3.0% in Central America to 12.7% in Southeast Asia. However, the impact of global warming on mortality is expected to reduce significantly if efficient mitigation strategies would be involved (under the RCP2.6 scenario).

9.7 Summary

Both cold and hot temperatures (including cold spells and heat waves) are associated with risks of mortality across the globe. However, the mortality risk estimates of temperatures are heterogeneous across countries. The differences might be caused by different demographic characteristics, socioeconomic status, disease types, and local environmental types. Future climate will greatly increase the mortality burden attributable to hot temperatures but reduce the cold temperature-related mortality. There is sufficient evidence indicating that extreme temperatures have increased health risks to the Chinese population. Future studies are necessary to provide methods of adapting to extreme temperatures and evaluate the implementation of adaptation measures.

Acknowledgments Y. G. was supported by the Career Development Fellowship of Australian National Health and Medical Research Council (#APP1107107). S. L. was supported by the Early Career Fellowship of Australian National Health and Medical Research Council (#APP1109193). Q. Z. was supported by Monash University Scholarship. K. H. was supported by China Scholarship Council.

References

1. Guo Y, Gasparrini A, Armstrong B, Li S, Tawatsupa B, Tobias A, Lavigne E, Coelho MS, Leone M, Pan X. Global variation in the effects of ambient temperature on mortality: a systematic evaluation. Epidimiology. 2014;25(6):781.
2. Curriero FC, Heiner KS, Samet JM, Zeger SL, Strug L, Patz JA. Temperature and mortality in 11 cities of the eastern United States. Am J Epidemiol. 2002;155(1):80–7. https://doi.org/10.1093/aje/155.1.80.
3. Ma W, Chen R, Kan H. Temperature-related mortality in 17 large Chinese cities: how heat and cold affect mortality in China. Environ Res. 2014;134:127–33.
4. Gasparrini A, Guo Y, Hashizume M, Lavigne E, Zanobetti A, Schwartz J, Tobias A, Tong S, Rocklöv J, Forsberg B. Mortality risk attributable to high and low ambient temperature: a multicountry observational study. Lancet. 2015;386(9991):369–75.
5. Gasparrini A, Guo Y, Sera F, Vicedo-Cabrera AM, Huber V, Tong S, Coelho M d SZS, Saldiva PHN, Lavigne E, Correa PM. Projections of temperature-related excess mortality under climate change scenarios. Lancet Planet Health. 2017;1(9):e360–7.
6. Guo Y, Gasparrini A, Armstrong BG, Tawatsupa B, Tobias A, Lavigne E, Coelho MS, Pan X, Kim H, Hashizume M, Honda Y, Guo YL, Wu CF, Zanobetti A, Schwartz JD, Bell ML, Scortichini M, Michelozzi P, Punnasiri K, Li S, Tian L, Garcia SDO, Seposo X, Overcenco A, Zeka A, Goodman P, Dang TN, Dung DV, Mayvaneh F, Saldiva PHN, Williams G, Tong S. Heat wave and mortality: a multicountry, multicommunity study. Environ Health Perspect. 2017;125(8):087006.
7. Anderson BG, Bell ML. Weather-related mortality: how heat, cold, and heat waves affect mortality in the United States. Epidemiology. 2009;20(2):205.
8. Laaidi K, Zeghnoun A, Dousset B, Bretin P, Vandentorren S, Giraudet E, Beaudeau P. The Impact of Heat Islands on Mortality in Paris during the August 2003 Heat Wave. Environ Health Perspects. 2012;120(2):254–9. https://doi.org/10.1289/ehp.1103532.
9. Zeng W, Lao X, Rutherford S, Xu Y, Xu X, Lin H, et al. The effect of heat waves on mortality and effect modifiers in four communities of Guangdong Province, China. Sci Total Environ. 2014;482–483:214–21.
10. Anderson GB, Bell ML. Heat waves in the United States: mortality risk during heat waves and effect modification by heat wave characteristics in 43 US communities. Environ Health Perspect. 2011;119(2):210.
11. O'neill MS, Zanobetti A, Schwartz J. Modifiers of the temperature and mortality association in seven US cities. Am J Epidemiol. 2003;157(12):1074–82.
12. IPCC. Climate change 2014: synthesis report. Contribution of working groups I, II and III to the fifth assessment report of the intergovernmental panel on climate change; 2014.
13. Patz JA, Campbell-Lendrum D, Holloway T, Foley JA. Impact of regional climate change on human health. Nature. 2005;438(7066):310–7.
14. Zhang X-P, Cheng X-M. Energy consumption, carbon emissions, and economic growth in China. Ecol Econ. 2009;68(10):2706–12.
15. Meehl GA, Tebaldi C. More intense, more frequent, and longer lasting heat waves in the 21st century. Science. 2004;305(5686):994–7.
16. Mishra V, Ganguly AR, Nijssen B, Lettenmaier DP. Changes in observed climate extremes in global urban areas. Environ Res Lett. 2015;10(2):024005.
17. Yang X, Leung LR, Zhao N, Zhao C, Qian Y, Hu K, et al. Contribution of urbanization to the increase of extreme heat events in an urban agglomeration in east China: Geophys Res Lett; 2017. https://doi.org/10.1002/2017GL074084.

18. Fischer EM, Knutti R. Anthropogenic contribution to global occurrence of heavy-precipitation and high-temperature extremes. Nat Clim Change. 2015;5(6):560.
19. Horton RM, Mankin JS, Lesk C, Coffel E, Raymond C. A review of recent advances in research on extreme heat events. Curr Clim Change Rep. 2016;2(4):242–59. https://doi.org/10.1007/s40641-016-0042-x.
20. Basu R, Samet JM. Relation between elevated ambient temperature and mortality: a review of the epidemiologic evidence. Epidemiol Rev. 2002;24(2):190–202.
21. Basu R. High ambient temperature and mortality: a review of epidemiologic studies from 2001 to 2008. Environ Health. 2009;8(1):40.
22. Yang J, Yin P, Zhou M, Ou C-Q, Guo Y, Gasparrini A, et al. Cardiovascular mortality risk attributable to ambient temperature in China. Heart. 2015;101:1966–72.
23. Chen K, Zhou L, Chen X, Ma Z, Liu Y, Huang L, et al. Urbanization level and vulnerability to heat-related mortality in Jiangsu Province, China. Environ Health Perspect. 2016;124(12):1863–9. https://doi.org/10.1289/EHP204.
24. Zhang L, Zhang Z, Wang C, Zhou M, Yin P. Different mortality effects of extreme temperature stress in three large city clusters of northern and southern china. Int J Disaster Risk Sci. 2017;8(4):445–56. https://doi.org/10.1007/s13753-017-0149-2.
25. Ma W, Wang L, Lin H, Liu T, Zhang Y, Rutherford S, Luo Y, Zeng W, Zhang Y, Wang X. The temperature–mortality relationship in China: an analysis from 66 Chinese communities. Environ Res. 2015;137:72–7.
26. Qin D, Ding Y, Mu M. Climate and environmental change in China: 1951–2012. New York: Springer; 2015.
27. Whitman S, Good G, Donoghue ER, Benbow N, Shou W, Mou S. Mortality in Chicago attributed to the July 1995 heat wave. Am J Public Health. 1997;87(9):1515–8.
28. Halonen JI, Zanobetti A, Sparrow D, Vokonas PS, Schwartz J. Associations between outdoor temperature and markers of inflammation: a cohort study. Environ Health. 2010;9(1):42. https://doi.org/10.1186/1476-069x-9-42.
29. Guo Y, Barnett AG, Pan X, Yu W, Tong S. The impact of temperature on mortality in Tianjin, China: a case-crossover design with a distributed lag non-linear model. Environ Health Perspect. 2011;119:1719–25.
30. Glutting J-P. Excess heat-related mortality in micro-urban heat islands: a case-only study in Barcelona. Gi_Forum 2013: Creating the Gisociety; 2013. p. 137–146. https://doi.org/10.1553/giscience2013s137.
31. Peng Z, Wang Q, Kan H, Chen R, Wang W. Effects of ambient temperature on daily hospital admissions for mental disorders in Shanghai, China: a time-series analysis. Sci Total Environ. 2017;590–591:281–6. https://doi.org/10.1016/j.scitotenv.2017.02.237.
32. Dong G-H. Ambient air pollution and health impact in China, vol. 1017. Singapore: Springer; 2017.
33. Li TT, Gao YL, Wei ZH, Wang J, Guo YF, Liu F, et al. Assessing heat-related mortality risks in Beijing, China. Biomed Environ Sci. 2012;25(4):458–64.
34. Bai L, Cirendunzhu, Woodward A, Dawa X, Liu Q. Temperature and mortality on the roof of the world: a time-series analysis in three Tibetan counties, China. Sci Total Environ. 2014;485–486:41–8.
35. Ma W, Chen R, Kan H. Temperature-related mortality in 17 large Chinese cities: how heat and cold affect mortality in China. Environ Res. 2014;134:127–33.
36. Lu L, Wang Z, Shi P. Mapping cold wave risk of the World. In: World atlas of natural disaster risk. Berlin: Springer; 2015. p. 189–207.
37. Easterling DR, Evans J, Groisman PY, Karl TR, Kunkel KE, Ambenje P. Observed variability and trends in extreme climate events: a brief review. Bull Am Meteorol Soc. 2000;81(3):417–25.
38. Luber G, McGeehin M. Climate change and extreme heat events. Am J Prev Med. 2008;35(5):429–35.
39. Steinberg SL, Sprigg WA. Extreme weather, health, and communities. Switzerland: Springer; 2016.
40. Barata M, Ligeti E, De Simone G, Dickinson T, Jack D, Penney J, et al. Climate change and human health in cities. In: Climate change and cities: first assessment report of the urban climate change research network; 2011. p. 179–213.
41. Woodward A, Smith KR, Campbell-Lendrum D, Chadee DD, Honda Y, Liu Q, et al. Climate change and health: on the latest IPCC report. Lancet. 2014;383(9924):1185–9.
42. IPCC. Climate change 2014: synthesis report. Contribution of Working Groups I, II and III to the fifth assessment report of the Intergovernmental Panel on Climate Change; 2014.
43. Meehl GA, Tebaldi C. More intense, more frequent, and longer lasting heat waves in the 21st century. Science. 2004;305(5686):994–7.
44. Perkins S, Alexander L, Nairn J. Increasing frequency, intensity and duration of observed global heatwaves and warm spells. Geophys Res Lett. 2012;39(20):L20714.
45. Commitment for China's National Third Assessment Report on Climate Change. China's National third assessment report on climate change; 2015.
46. Ding T, Qian W, Yan Z. Changes in hot days and heat waves in China during 1961–2007. Int J Climatol. 2010;30(10):1452–62.
47. Zhou Y, Ren G. Change in extreme temperature event frequency over mainland China, 1961–2008. Clim Res. 2011;50(2–3):125–39.
48. Yang X, Leung LR, Zhao N, Zhao C, Qian Y, Hu K, et al. Contribution of urbanization to the increase of extreme heat events in an urban agglomeration in east China. Geophys Res Lett. 2017 https://doi.org/10.1002/2017GL074084.
49. Guo X, Huang J, Luo Y, Zhao Z, Xu Y. Projection of heat waves over China for eight different global

warming targets using 12 CMIP5 models. Theor Appl Climatol. 2017;128(3–4):507–22.
50. Zhai P, Pan X. Trends in temperature extremes during 1951–1999 in China. Geophys Res Lett. 2003;30(17) https://doi.org/10.1029/2003GL018004.
51. Qian W, Lin X. Regional trends in recent temperature indices in China. Clim Res. 2004;27(2): 119–34.
52. Griffiths G, Chambers L, Haylock M, Manton M, Nicholls N, Baek HJ, et al. Change in mean temperature as a predictor of extreme temperature change in the Asia–Pacific region. Int J Climatol. 2005;25(10):1301–30.
53. Manton M, Della-Marta P, Haylock MR, Hennessy K, Nicholls N, Chambers L, et al. Trends in extreme daily rainfall and temperature in Southeast Asia and the South Pacific: 1961–1998. Int J Climatol. 2001;21(3):269–84.
54. Bartholy J, Pongrácz R. Regional analysis of extreme temperature and precipitation indices for the Carpathian Basin from 1946 to 2001. Glob Planet Change. 2007;57(1):83–95. https://doi.org/10.1016/j.gloplacha.2006.11.002.
55. Collins D, Della-Marta P, Plummer N, Trewin B. Trends in annual frequencies of extreme temperature events in Australia. Aust Meteorol Mag. 2000;49(4):277–92.
56. You Q, Kang S, Aguilar E, Pepin N, Flügel W-A, Yan Y, et al. Changes in daily climate extremes in China and their connection to the large scale atmospheric circulation during 1961–2003. Clim Dyn. 2011;36(11–12):2399–417.
57. Lin S, Luo M, Walker RJ, Liu X, Hwang S-A, Chinery R. Extreme high temperatures and hospital admissions for respiratory and cardiovascular diseases. Epidemiology. 2009;20(5):738–46.
58. Liu L, Breitner S, Pan X, Franck U, Leitte AM, Wiedensohler A, et al. Associations between air temperature and cardio-respiratory mortality in the urban area of Beijing, China: a time-series analysis. Environ Health. 2011;10(1):51. https://doi.org/10.1186/1476-069x-10-51.
59. Lin Y-K, Ho T-J, Wang Y-C. Mortality risk associated with temperature and prolonged temperature extremes in elderly populations in Taiwan. Environ Res. 2011;111(8):1156–63.
60. Ma W, Chen R, Kan H. Temperature-related mortality in 17 large Chinese cities: how heat and cold affect mortality in China. Environ Res. 2014;134:127–33.
61. Song X, Wang S, Hu Y, Yue M, Zhang T, Liu Y, et al. Impact of ambient temperature on morbidity and mortality: an overview of reviews. Sci Total Environ. 2017;586:241–54. https://doi.org/10.1016/j.scitotenv.2017.01.212.
62. Barreca A, Clay K, Deschenes O, Greenstone M, Shapiro JS. Adapting to climate change: the remarkable decline in the US temperature-mortality relationship over the twentieth century. J Polit Econ. 2016;124(1):105–59.
63. Gasparrini A, Armstrong B, Kenward MG. Distributed lag non-linear models. Stat Med. 2010;29(21):2224–34.
64. Luan G, Yin P, Li T, Wang L, Zhou M. The years of life lost on cardiovascular disease attributable to ambient temperature in china. Sci Rep. 2017;7(1):13531.
65. Guo Y, Punnasiri K, Tong S. Effects of temperature on mortality in Chiang Mai city, Thailand: a time series study. Environ Health. 2012;11(1):36.
66. Zhang Y, Yu C, Bao J, Li X. Impact of temperature on mortality in Hubei, China: a multi-county time series analysis. Sci Rep. 2017;7:45093.
67. Yang J, Ou C-Q, Ding Y, Zhou Y-X, Chen P-Y. Daily temperature and mortality: a study of distributed lag non-linear effect and effect modification in Guangzhou. Environ Health. 2012;11(1):63. https://doi.org/10.1186/1476-069x-11-63.
68. Gasparrini A, Leone M. Attributable risk from distributed lag models. BMC Med Res Methodol. 2014;14(1):55.
69. Yang J, Yin P, Zhou M, Ou C-Q, Li M, Li J, et al. The burden of stroke mortality attributable to cold and hot ambient temperatures: epidemiological evidence from China. Environ Int. 2016;92:232–8.
70. Guha-Sapir D, Hoyois P, Below R. EM-DAT: the CRED/OFDA International Disaster Database. 2017. http://www.emdat.be. Accessed 5 Feb 2017.
71. Persson G, Wern L. Fact sheet No 49: heat waves in Sweden. SMHI; 2011. https://www.smhi.se/polopoly_fs/1.16889!/webbFaktablad_49.pdf. Accessed 20 Jun 2018.
72. National Oceanic and Atmospheric Administration. What is a heat wave? 2018. 2018.04.11. Accessed 13 Apr 2018.
73. Chien L-C, Guo Y, Zhang K. Spatiotemporal analysis of heat and heat wave effects on elderly mortality in Texas, 2006–2011. Sci Total Environ. 2016;562:845–51.
74. McGregor GR, Bessemoulin P, Ebi KL, Menne B. Heatwaves and health: guidance on warning-system development. Geneva: World Meteorological Organization; 2015.
75. Ma W, Zeng W, Zhou M, Wang L, Rutherford S, Lin H, Liu T, Zhang Y, Xiao J, Zhang Y. The short-term effect of heat waves on mortality and its modifiers in China: an analysis from 66 communities. Environ Int. 2015;75:103–9.
76. Rey G, Jougla E, Fouillet A, Pavillon G, Bessemoulin P, Frayssinet P, Clavel J, Hémon D. The impact of major heat waves on all-cause and cause-specific mortality in France from 1971 to 2003. Int Arch Occup Environ Health. 2007;80(7):615–26.
77. Montero J, Mirón I, Criado-Álvarez J, Linares C, Díaz J. Mortality from cold waves in Castile—La Mancha, Spain. Sci Total Environ. 2010;408(23):5768–74.
78. Kysely J, Pokorna L, Kyncl J, Kriz B. Excess cardiovascular mortality associated with cold spells in the Czech Republic. BMC Public Health. 2009;9(1):19.

79. Zhou MG, Wang LJ, Liu T, Zhang YH, Lin HL, Luo Y, Xiao JP, Zeng WL, Zhang YW, Wang XF. Health impact of the 2008 cold spell on mortality in subtropical China: the climate and health impact national assessment study (CHINAs). Environ Health. 2014;13(1):60.
80. Guo Y, Gasparrini A, Armstrong BG, Tawatsupa B, Tobias A, Lavigne E, Coelho M d SZS, Pan X, Kim H, Hashizume M. Temperature variability and mortality: a multi-country study. Environ Health Perspect. 2016;124(10):1554.
81. Guo Y, Li S, Liu DL, Chen D, Williams G, Tong S. Projecting future temperature-related mortality in three largest Australian cities. Environ Pollut. 2016;208:66–73.
82. Zhao Q, Zhang Y, Zhang W, Li S, Chen G, Wu Y, Qiu C, Ying K, Tang H, Huang J-A. Ambient temperature and emergency department visits: time-series analysis in 12 Chinese cities. Environ Pollut. 2017;224:310–6.
83. Phung D, Thai PK, Guo Y, Morawska L, Rutherford S, Chu C. Ambient temperature and risk of cardiovascular hospitalization: an updated systematic review and meta-analysis. Sci Total Environ. 2016;550:1084–102.
84. Baccini M, Biggeri A, Accetta G, Kosatsky T, Katsouyanni K, Analitis A, Anderson HR, Bisanti L, D'Ippoliti D, Danova J. Heat effects on mortality in 15 European cities. Epidemiology. 2008;19(5):711–9.
85. Basu R, Ostro BD. A multicounty analysis identifying the populations vulnerable to mortality associated with high ambient temperature in California. Am J Epidemiol. 2008;168(6):632–7.
86. Analitis A, Katsouyanni K, Biggeri A, Baccini M, Forsberg B, Bisanti L, Kirchmayer U, Ballester F, Cadum E, Goodman P. Effects of cold weather on mortality: results from 15 European cities within the PHEWE project. Am J Epidemiol. 2008;168(12):1397–408.
87. Ma W, Yang C, Chu C, Li T, Tan J, Kan H. The impact of the 2008 cold spell on mortality in Shanghai, China. Int J Biometeorol. 2013;57(1):179–84.
88. Haines A, Kovats RS, Campbell-Lendrum D, Corvalán C. Climate change and human health: impacts, vulnerability and public health. Public Health. 2006;120(7):585–96.
89. Ying Zhang M. Climate change and disability-adjusted life years. J Environ Health. 2007;70(3):32.
90. Committee on Sports Medicine Fitness. Climatic heat stress and the exercising child and adolescent. Pediatrics. 2000;106(1):158–9.
91. Landrigan P, Garg A. Children are not little adults. In: Pronczuk-Garbino J, editor. Children's health and the environment—a global perspective: a resource manual for the health sector. Geneva: World Health Organization; 2005. p. 3–16.
92. Ishigami A, Hajat S, Kovats RS, Bisanti L, Rognoni M, Russo A, Paldy A. An ecological time-series study of heat-related mortality in three European cities. Environ Health. 2008;7(1):5.
93. Ma W, Yang C, Tan J, Song W, Chen B, Kan H. Modifiers of the temperature–mortality association in Shanghai, China. Int J Biometeorol. 2012;56(1):205–7.
94. Díaz J, Linares C, Tobías A. Impact of extreme temperatures on daily mortality in Madrid (Spain) among the 45–64 age-group. Int J Biometeorol. 2006;50(6):342–8.
95. Yu W, Vaneckova P, Mengersen K, Pan X, Tong S. Is the association between temperature and mortality modified by age, gender and socio-economic status? Sci Total Environ. 2010;408(17):3513–8.
96. Andérson GS, Ward R, Mekjavić IB. Gender differences in physiological reactions to thermal stress. Eur J Appl Physiol Occup Physiol. 1995;71(2–3):95–101.
97. Kaciuba-Uscilko H, Grucza R. Gender differences in thermoregulation. Curr Opin Clin Nutr Metab Care. 2001;4(6):533–6.
98. Bar-Or O. Effects of age and gender on sweating pattern during exercise. Int J Sports Med. 1998;19(S2):S106–7.
99. Arciero PJ, Goran MI, Poehlman ET. Resting metabolic rate is lower in women than in men. J Appl Physiol. 1993;75(6):2514–20.
100. Cortright RN, Koves TR. Sex differences in substrate metabolism and energy homeostasis. Can J Appl Physiol. 2000;25(4):288–311.
101. Feigin V. Global, regional, and national life expectancy, all-cause mortality, and cause-specific mortality for 249 causes of death, 1980-2015: a systematic analysis for the Global Burden of Disease Study 2015. Lancet. 2016;388(10053):1459–544.
102. Pachauri RK, Allen MR, Barros VR, Broome J, Cramer W, Christ R, Church JA, Clarke L, Dahe Q, Dasgupta P. Climate change 2014: synthesis report. Contribution of working groups I, II and III to the fifth assessment report of the intergovernmental panel on climate change. Geneva: IPCC; 2014.
103. Schwartz J. Who is sensitive to extremes of temperature?: A case-only analysis. Epidemiology. 2005;16(1):67–72.
104. Watts N, Adger WN, Agnolucci P, Blackstock J, Byass P, Cai W, Chaytor S, Colbourn T, Collins M, Cooper A. Health and climate change: policy responses to protect public health. Lancet. 2015;386(10006):1861–914.
105. Huang C, Barnett AG, Wang X, Vaneckova P, FitzGerald G, Tong S. Projecting future heat-related mortality under climate change scenarios: a systematic review. Environ Health Perspect. 2011;119(12):1681.
106. Hajat S, Vardoulakis S, Heaviside C, Eggen B. Climate change effects on human health: projections of temperature-related mortality for the UK during the 2020s, 2050s and 2080s. J Epidemiol Community Health. 2014;68(7):641–8.

107. Lee JY, Kim H. Projection of future temperature-related mortality due to climate and demographic changes. Environ Int. 2016;94:489–94.
108. Schwartz JD, Lee M, Kinney PL, Yang S, Mills D, Sarofim MC, Jones R, Streeter R, Juliana AS, Peers J. Projections of temperature-attributable premature deaths in 209 US cities using a cluster-based Poisson approach. Environ Health. 2015;14(1):85.
109. Ballester J, Robine J-M, Herrmann FR, Rodó X. Long-term projections and acclimatization scenarios of temperature-related mortality in Europe. Nat Commun. 2011;2:358.

10 Health Vulnerability Assessment to Climate Change in China

Tao Liu, Xing Li, Jianpeng Xiao, Weilin Zeng, Xin Liu, Baixiang Feng, and Wenjun Ma

Abstract

Health vulnerability assessment is a crucial step in the roadmap of adapting to climate change. The results could help health departments to better understand who and where are more vulnerable to climate change and hence implement corresponding intervention actions to reduce the burden of public health impacts and even increase the equity of social and economic development. Considering the severe climate change process confronting China that has the largest population size and broad territory with contrasting climatic characteristics, understanding the spatiotemporal distributions of health vulnerability to climate change is profoundly significant for central and local governments. Therefore, in this chapter we aimed to systemically review all available evidence on the health vulnerability to temperature and extreme weather events in China. We believe that the findings could provide explicit information for the evidence-based policy-making and risk management on climate change.

Keywords

Climate change · Health vulnerability assessment · Exposure · Sensitivity · Adaptive capacity · Extreme weather events · Chinese

10.1 Introduction

The IPCC (Intergovernmental Panel on Climate Change) reports have argued that our planet is experiencing a rapid process of climate change, the global surface temperature is consecutively increasing, and the frequency and intensity of extreme weather events are also increasing. Furthermore, this climate change process is likely to continue in the next several decades [1–3]. It has been well demonstrated that variation of ambient temperature and extreme weather events can increase both mortality and morbidity risks for human health [4–10]. Besides these useful baseline information, more nuanced approaches and information are needed for the public health sectors to make specific policies and programs to response to the climate change. The health vulnerability of local populations and communities is a kind of such approach, which is defined as how much a system is susceptible to and unable to deal with the adverse impacts [2]. Vulnerability

T. Liu (✉) · W. Ma
Guangdong Provincial Institute of Public Health, Guangdong Provincial Center for Disease Control and Prevention, Guangzhou, China

General Practice Center, Nanhai Hospital, Southern Medical University, Foshan, Guangdong, China
e-mail: liut@gdiph.org.cn; mawj@gdiph.org.cn

X. Li · J. Xiao · W. Zeng · X. Liu · B. Feng
Guangdong Provincial Institute of Public Health, Guangdong Provincial Center for Disease Control and Prevention, Guangzhou, China
e-mail: lixing@gdiph.org.cn; xiaojp@gdiph.org.cn; zengwl@gdiph.org.cn; sonic@gdiph.org.cn

H. Lin et al. (eds.), *Ambient Temperature and Health in China*,
https://doi.org/10.1007/978-981-13-2583-0_10

is a collective function of exposure, adaptive capacity, and sensitivity [2]. Globally, the vulnerability to climate change has been widely studied in developed countries [11–14]. However, such studies are still inadequate for policy and adaptation strategy making in developing countries, particularly in China.

Under the background of global warming, China experienced more significant climate change in the past century. The increase rate of surface temperature between 1951 and 2017 was 0.24 °C per decade, which is higher than the global average level [15]. It has been projected that this warming process will continue in the near future [16, 17]. With the largest population size and third vastest territory in the world, China needs to identify the distribution of health vulnerability to climate change and further make specific adaptation measures in the future. Several studies have studied the spatial and temporal characteristics of health vulnerability to weather factors across China, such as high temperature, heat waves, floods, sea level rising, and drought [18–26]. However, no study has systematically reviewed these studies. Such information could provide explicit information for the policy-makers and stakeholders to take specific actions to protect the most vulnerable population in the future.

In this chapter, we systematically reviewed the available evidence on the health vulnerability to weather factors in China.

10.2 Literature Search, Selection, and Data Extraction

We have searched for all studies published before May 1, 2018, in Medline, PubMed, Web of Science, EMBASE, Chinese database of China Biological Medline, and Wanfang database. Only the original studies that met the following criteria were selected: (a) studies that investigated the health vulnerability to weather factors (temperature, heat waves, cold spells, floods, sea level rising, drought, and other extreme weather events); (b) studies that was conducted in China including Mainland China, Hong Kong, Taiwan, and Macao; (c) studies that have presented the detailed information of vulnerability framework, indicator selection, and data collection; and (d) if repeated studies for the same population were identified, only the study with the most recent information was included. Thirteen studies were selected, in which two were repeated studies. Finally, 11 studies were included in this review. Their studied locations were shown in Fig. 10.1. For each selected study, the following information was extracted: authors, study location, type of health vulnerability, vulnerability framework, main indicators, and main results. The detailed information of each included study can be seen in Table 10.1.

10.3 Health Vulnerability Assessment Frameworks

Most studies employed the framework provided by IPCC that defined the health vulnerability as “a collective function of the character, magnitude, and rate of climate variation to which a system if exposed, its sensitivity and its adaptive capacity” [18, 19, 22–26]. Exposure is defined as the nature and degree of a system exposed to significant climatic variations. Sensitivity is the degree of a system that is affected by climate-related *stimuli*. Adaptive capacity is the ability of a system to adjust to a climate event, moderate potential damages, take advantage of opportunities, or cope with the consequence. Exposure is related to climate, and sensitivity and adaptive capacity are associated with the socioeconomic characteristics. In this way, the combination of exposure and sensitivity can be defined as potential impact or total vulnerability, and the combination of sensitivity and adaptive capacity can also be defined as social vulnerability index (SVI) [1]. The vulnerability index (VI) can be modeled by the following equation [33]:

$$VI_j = EI_j{}^* \frac{\left(1 + SI_j + AI_j\right)}{n} \quad (10.1)$$

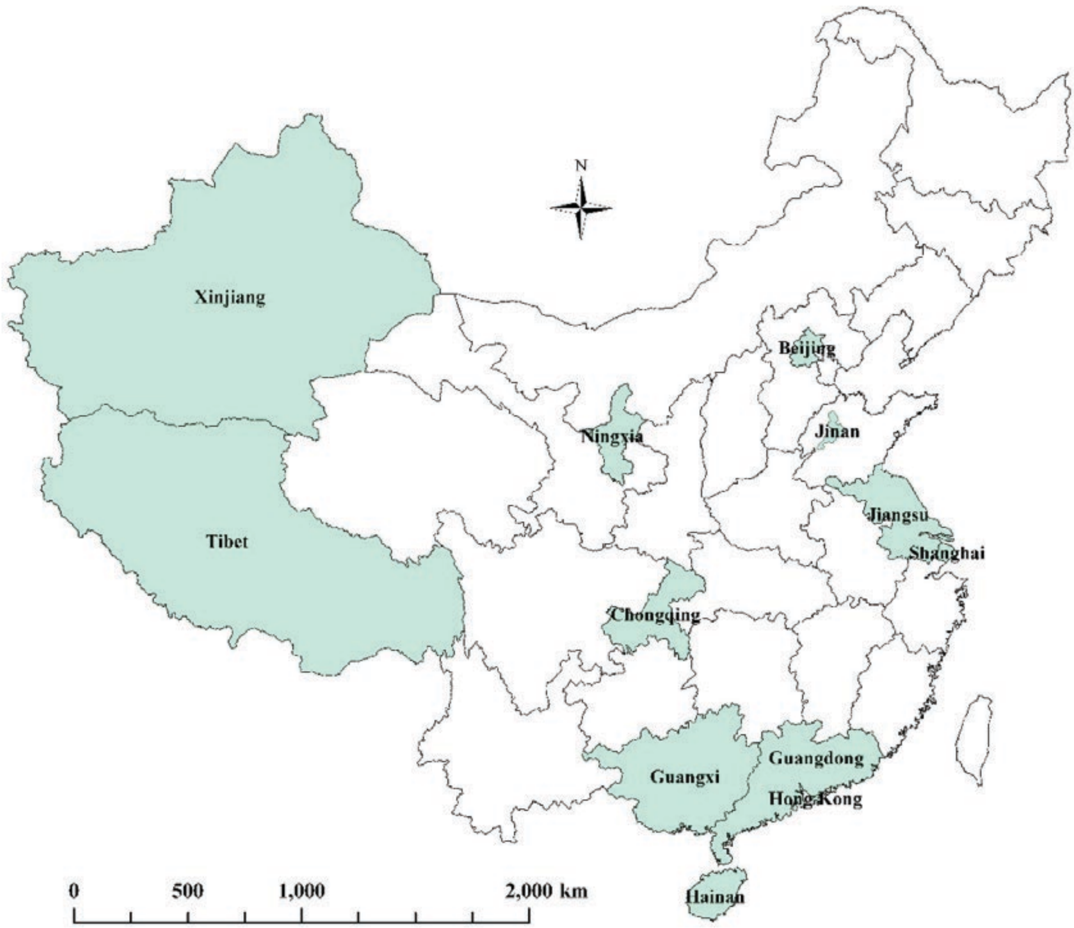


Fig. 10.1 The distribution of studied locations in the included studies in China (Publisher's note: Springer Nature remains neutral with regard to jurisdictional claims in published maps)

where VI_j denotes the overall vulnerability index. EI_j denotes the component measuring the level of exposure. SI_j denotes the sensitivity index, and AI_j denotes the adaptive capacity index. The framework is shown in Fig. 10.2.

In this framework, indicators are selected for the three dimensions using literature review and/or expert consultations. Then an analytic hierarchy process method or principle component analysis could be used to determine the weighting of each indicator based on the relative importance [21]. Briefly, an expert can judge the relative importance of all indicators subjectively. A judgment matrix could be established from each expert and was tested by a consistency test to examine the logical consistence of sorting results. Then the average weighting given by all experts was used as the final weighting of each indicator. The weighting matrix can also be determined by principal component analysis (PCA) [20]. The index for each dimension can be calculated using the following equations:

$$EI = w_{E_1} \cdot E_1 + w_{E_2} \cdot E_2 + \cdots + w_{E_n} \cdot E_n \quad (10.2)$$

$$SI = w_{S_1} \cdot S_1 + w_{S_2} \cdot S_2 + \cdots + w_{S_n} \cdot S_n \quad (10.3)$$

$$AI = w_{A_1} \cdot A_1 + w_{A_2} \cdot A_2 + \cdots + w_{A_n} \cdot A_n \quad (10.4)$$

where $E_1 - E_n$ represent exposure indicator $1 \sim n$, $S_1 - S_n$ represent sensitivity indicator $1 \sim n$, $A_1 - A_n$ represent adaptive capacity indicator

Table 10.1 General information of included studies

Author/year	Location	Type of vulnerability	Vulnerability framework	Indicators	Main findings
Zhu et al. (2012) [26]	Guangdong	Flood vulnerability	IPCC framework	Two indicators for exposure: maximum daily precipitation and historical frequency of floods Six indicators for sensitivity: percentage of people >65 years, percentage of people <5 years, percentage of immigrant population, unemployment rate, percentage of people engaged in agriculture, and infant mortality rate Five indicators for adaptive capacity: percentage of health professionals, GDP, percentage of people with per capital living space less than 8 m^2, percentage of harmless sanitary latrines, and percentage of illiterate in the people >15 years	The health vulnerability to flooding in Guangdong Province was higher in coastal areas, Beijiang River Delta, east areas of Dongjiang River Delta, and north areas of Pearl River Delta and was lower in several counties in Zhaoqing, Dongguan, Foshan, and Heyuan cities
Tan et al. (2013) [22]	Xinjiang and Ningxia	Natural disasters and climatic variation vulnerability	IPCC framework	Indicators for exposure: natural disaster- and climatic variation-related indicators such as number of natural disasters in the past 10 years Indicators for adaptive capacity: social demographical characteristics, family planning strategy, and social network-related indicators such as dependency ratio (ratio of population in and not in labor force) and percentage of illiterate Indicators for sensitivity: health-, food-, and water supply-related indicators such as prevalence of chronic diseases and percentage of family depending on crop planting	People in Xinjiang Province were more vulnerable to natural disasters and climatic variation vulnerability than people in Ningxia Province. The vulnerability in Xinjiang Province mainly came from demographic characteristics and social networks. By contrast, the vulnerability in Ningxia Province was mainly inducted by food and water supply

Table 10.1 (continued)

Author/year	Location	Type of vulnerability	Vulnerability framework	Indicators	Main findings
Zhu et al. (2014) [25]	Guangdong	Heat wave vulnerability	IPCC framework	Two indicators for exposure: temperature growth rate and number of days with maximum temperature over 35 °C Six indicators for sensitivity: percentage of people >65 years, percentage of people <5 years, percentage of immigrant population, unemployment rate, percentage of people engaged in agriculture, and infant mortality rate Five indicators for adaptive capacity: percentage of health professionals, GDP, percentage of people with per capital living space less than 8 m^2, percentage of harmless sanitary latrines, and percentage of illiterate in the people >15 years	The health vulnerability to heat waves in Guangdong Province was higher in northern inland regions than that in the southern coastal regions. The counties with the highest vulnerability were Lianzhou and Liannan of Qingyuan and the lowest in the Yantian District of Shenzhen
Wan (2014) [27]	Jinan, Shandong	Heat vulnerability	Four dimensions	Four indicators for health condition: prevalence of chronic diseases, prevalence of hospital visiting, change of health conditions, and prevalence of chronic disease during the heat days Three indicators for economic conditions: monthly family income, stability of income, and amount of saving money Four indicators for living resources: water, electric, early warning information of high temperature, and medical insurance Two indicators for living environments: per capital living space and ventilation condition of living house	In the center of urban area, health vulnerability induced by health condition, social connection, and living environment was relatively higher. In the suburb areas, health vulnerability was mainly caused by perception, adaptive behaviors, economic conditions, living resources, and working environments

(continued)

Table 10.1 (continued)

Author/year	Location	Type of vulnerability	Vulnerability framework	Indicators	Main findings
Christenson et al. (2014) [28]	Hong Kong and Macao	Cyclone, drought, and flood	Exposure in the IPCC framework	Indicators for exposure: frequency cyclone, drought, and flood	Hong Kong and Macao were listed in the first and third place in the multi-hazard exposure rank all over the world
Wang (2015) [23, 24]	Beijing, Shanghai, and Chongqing	Heat wave vulnerability	IPCC framework	Indicators for exposure: days of high temperature, urban population density, and areas of built-up district Indicators for adaptive capacity: treatment ability of healthcare system, coverage of green space, GDP, and comprehensive management ability of local governments Indicators for sensitivity: percentage of people >65 years, percentage of immigrant population, and percentage of low-income population	From 2004 to 2013, the heat wave vulnerability of Beijing shows a decreasing trend and that in Shanghai and Chongqing shows an increasing trend. The heat wave vulnerability in Shanghai is the highest and then followed by Chongqing and Beijing, respectively
Hou (2015) [19]	Guangxi	Flood vulnerability	IPCC framework	Three indicators for exposure: number of floods, annual number of heavy rain days, and average monthly precipitation Three indicators for sensitivity: population density, gender, and age Nine indicators for adaptive capacity: percentage of ethnic minority people, percentage of illiteracy, number of medical institutes per 1000 people, number of doctors per 1000 people, number of nurses per 1000 people, number of hospitals beds per 1000 people, percentage of population having basic medical insurance, yearly household income, and GDP	The most vulnerable prefectures located in north part of Guangxi Province, and it has a trend of vulnerability decreasing from northwest to southwest

Table 10.1 (continued)

Author/year	Location	Type of vulnerability	Vulnerability framework	Indicators	Main findings
Bai et al. (2016) [29, 30]	Tibet	Heat vulnerability	Four dimensions confirmed by principal component analysis (PCA)	Ten indicators: age ≥ 60, labor ability, illiterate, living alone, living alone with 60 years old or over, low income, low-income households, low income among seniors, households with only one room, and households ≤8 m^2 living spaces	The average levels of heat vulnerability were similar between the rural and urban population in Tibet area, but the patterns varied strongly from one county to another. The heat vulnerability was higher in counties with high altitude
Chen et al. (2016) [31]	Jiangsu	Heat vulnerability	Four indicators	Mean education level, percent of people with 65 years or over, and number of beds in health institutions per 1000 people, average air-conditioning units per household	The heat vulnerability was higher in the central counties than counties in other areas. Vulnerability was negatively associated with urbanicity indicator
Feng (2016) [18]	Hainan	Heat vulnerability	IPCC framework	Three indicators for exposure: number of days with maximum temperature over 35 °C, number of days with minimum temperature below 28 °C, and daily precipitation Six indicators for sensitivity: GDP, population density, percentage of people >65 years, percentage of minority people, percentage of people with minimum standard of living, and percentage of people engaged in agriculture, forestry, husbandry, and fishery industry Eleven indicators for adaptive capacity: coverage rate of green space, annual amount of garbage disposed, number of hospital beds per 10,000 people, number of health professionals per 10,000 people, percentage of primary and middle school students, ability of tap water supplying, etc.	Most regions were high and mid-high vulnerability areas. The exposure to high temperature/heat waves is high in the north and northwest region, medium in the central region, and low in south region. The sensitivity is high in central region and low in the south region. The distribution of adaptive capacity did not vary significantly across Hainan Province. In summary, the health vulnerability to high temperature/heat waves was relatively higher in the north and central regions in Hainan Province

(continued)

Table 10.1 (continued)

Author/year	Location	Type of vulnerability	Vulnerability framework	Indicators	Main findings
Luo et al. (2016) [32]	Guangdong	Heat wave vulnerability	Two dimensions	Six indicators for sensitivity: percentage of people >65 years, infant mortality, percentage of people <4 years, percentage of agriculture population, percentage of immigrant population, and unemployment rate Five indicators for adaptive capacity: GDP, percentage of people with per capital living space less than 8 m^2, percentage of illiterate in the people >15 years, number of health professionals per 10,000 people, and percentage of harmless sanitary latrines	Regions with higher sensitivity to heat waves were located in the west and north areas of Guangdong Province. The east area and Pearl River Delta has lower sensitivity The Pearl River Delta had the highest adaptive capacity for heat waves. East and southwest areas had the lowest adaptive capacity to heat waves

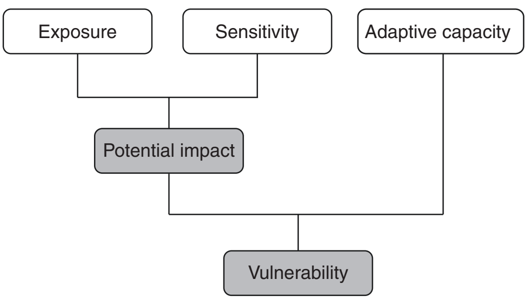


Fig. 10.2 The framework of vulnerability defined by IPCC

1~n, and *w* represents the weighting of each indicator. Finally, the vulnerability index can be calculated using Eq. (10.1).

The above framework is not the only one. In several studies, other frameworks were employed to assess the health vulnerability [23, 30–32, 34]. For example, Bai et al. collected ten variables to assess the county-level heat vulnerability of urban and rural residents at county level in Tibet, China. They employed a PCA to identify four principal factors (poverty, social isolation, small dwelling, and elderly/fragile health/illiterate). Then the heat vulnerability index of each county was estimated by summing the integer scores for four factors [29, 30]. Chen et al. computed a heat vulnerability index at county level based on four characteristics including education level, percent of elderly people ≥65 years, air-conditioning usage, and number of beds (/1000 people) in health institutions [31]. Wan et al. employed 13 indicators which were divided into four dimensions (health status, economic conditions, living resources, and living environment) to compose the vulnerability index in Jinan City, Shandong Province [34]. Similarly, Wang et al. applied a framework including ten indicators to evaluate the vulnerability to heat waves in Beijing, Shanghai, and Chongqing [23].

10.4 Indicator Selection for Health Vulnerability

The indicator selection is another key step of health vulnerability assessment. Several principles were proposed in previous studies [23, 25]. The first one is scientificalness which indicated that all indicators' selection was based on scientific evidence. For instance, the indicators should not only include the characteristics of nature environment and social economic development in a city or region but also reflect the intensity of external climatic factors and the pressure to the city. The second principle is systematicness. It was debated that the health vulnerability to climate change can be impacted by various factors including economic development, society, and nature environments. Therefore, the indicators should be selected based on a systematical view and include the above factors. Feasibility is the third principle. All indicators must be clearly defined and be available. Otherwise, they are not useful if the data is not available. The last principle is universality which indicates that the indicator system can be extrapolated to other regions or environments. In most studies, they first selected the indicators as many as possible by literature review and expert consultation. Then, the indicators were carefully screened based on the above four principles. Finally, the indicator system was decided and began to collect the data.

10.5 Health Vulnerability to Ambient Temperature and Extreme Events

10.5.1 High Temperature and Heat Waves

High temperature and heat waves were the most common weather factors assessed for the health vulnerability in China. Seven of the 11 studies assessed the high temperature and/or heat waves health vulnerability. In the light of the significant spatiotemporal distribution patterns of health vulnerability in different locations in China, here we qualitatively reviewed the main findings in studies conducted in different regions.

Hainan is the most south province in China. It is also the only province totally covered by tropical climate in China. In the past two decades, the increase rate of high temperature days ($T_{\mathrm{Max}} \geq 35$ °C) was 1.91 days/year, which is significantly higher than that in the 1930s (0.54 day/year). Feng used the IPCC framework to evaluate the health vulnerability to high temperature and heat waves at county level. They selected 20 indicators (3 exposure indicators, 6 sensitivity indicators, and 11 adaptive capacity indicators) into the IPCC framework. The weight of each indicator was quantified by primary component analysis. The results showed that most regions in Hainan Province were high and mid-high vulnerability areas. The exposure to high temperature/heat waves is high in the north and northwest region, medium in the central region, and low in south region. The sensitivity is high in central region and low in the south region. The distribution of adaptive capacity did not vary significantly across Hainan Province. In summary, the health vulnerability to high temperature and heat waves was relatively higher in the north and central regions in Hainan Province. These results could provide detailed information for the policy-making departments to make specific adaptation measures to reduce the heat vulnerability to the most vulnerable people [18].

Guangdong Province is located in South China covered by subtropical climate. High temperature and heat waves were the major meteorological threats to public health in Guangdong Province [35]. Zhu et al. have assessed the county-/district-level health vulnerability to heat waves and observed that the health vulnerability was higher in northern regions and lower in southern coastal regions. The vulnerability was gradiently decreased from northern to southern regions (Fig. 10.3). The counties that ranked the highest vulnerability were Lianzhou and Liannan located in Qingyuan City, and the county that ranked the lowest was Yantian District located in Shenzhen City. In the Lianzhou and Liannan counties, people had lower adaptive capacity to heat waves due to the lower economic development [25]. In another study conducted in 2016, Luo et al. have also assessed the health vulnerability to heat waves in Guangdong using a two-dimensional framework (sensitivity and adaptive capacity). They observed similar results with Zhu et al.'s study that the regions with higher sensitivity to heat waves were located in the west and north areas of Guangdong Province and that the east area and Pearl River Delta had lower sensitivity. The Pearl River Delta had the highest

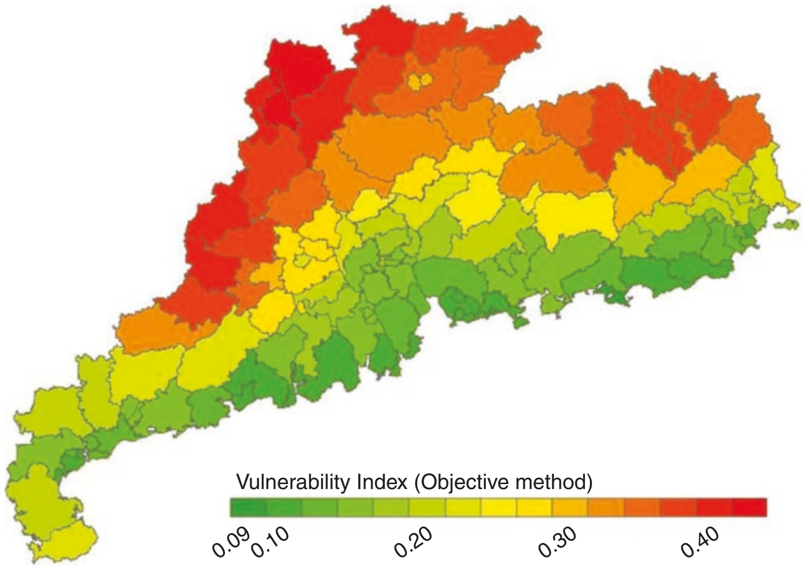


Fig. 10.3 Distribution of health vulnerability to heat waves in Guangdong Province (Reproduced with permission from Zhu et al. [25] (http://dx.doi.org/10.3402/gha.v7.25051))

adaptive capacity for heat waves, meanwhile the east and southwest areas had the lowest adaptive capacity to heat waves [32]. With the increasing trend of heat waves globally, they suggested that more resources should be allocated to the regions with higher vulnerability.

Tibet is a province located in Tibetan Plateau, Southwest China. It has been identified that Tibet is one of the regions most vulnerable to climate variability and change in the world [36]. Temperature in that region has been increased by 0.50 °C/decade during the past 30 years, which is much faster than that observed in China or Asia [37]. Bai et al. assessed the spatial distribution of heat vulnerability in Tibet area. They observed similar distribution of cumulative heat vulnerability between the urban and rural areas. However, in some areas such as Ngari, the heat vulnerability was lower in rural residents than in urban residents. In contrast, the heat vulnerability was higher in urban residents then in the rural residents, such as in Lhasa area. In the entire urban areas, they found higher vulnerability in the middle, northwest, and east areas of Tibet. In rural areas, they found high vulnerability clustered in western, central, and southeastern areas of Tibet. In addition, they found a lustering of lower vulnerability in Nyingchi area in southeastern Tibet. Generally, the heat vulnerability was higher in high-altitude counties because the people in these areas were more sensitive and had low adaptive capacity to high temperature (Fig. 10.4). They suggested that more targeted adaptation strategies are particularly needed for the residents in these areas [29, 30].

Chen et al. investigated the distribution of heat vulnerability at county level in Jiangsu Province located in East China. Their results revealed that the vulnerability was higher in central areas, but the heat exposures in southern areas were higher than counties in other areas (Fig. 10.5). In addition, the vulnerability level was negatively associated with the urbanicity level (Fig. 10.6). Their results indicate that the heat exposure level does not equate to vulnerability level, since the heat impacts were also determined by non-climate factors. The urban areas had lower vulnerability because the proportions of vulnerable populations were lower. They suggested that more enhanced adaptation plans are needed in the non-urban areas in China that is confronting serious climate change [31].

Wan assessed the heat vulnerability in the urban and suburb areas in Jinan, the capital city of Shandong Province by dividing 13 indicators into 4 dimensions. The weight of each indicator was estimated by a logistic regression model. They observed that the sources of health

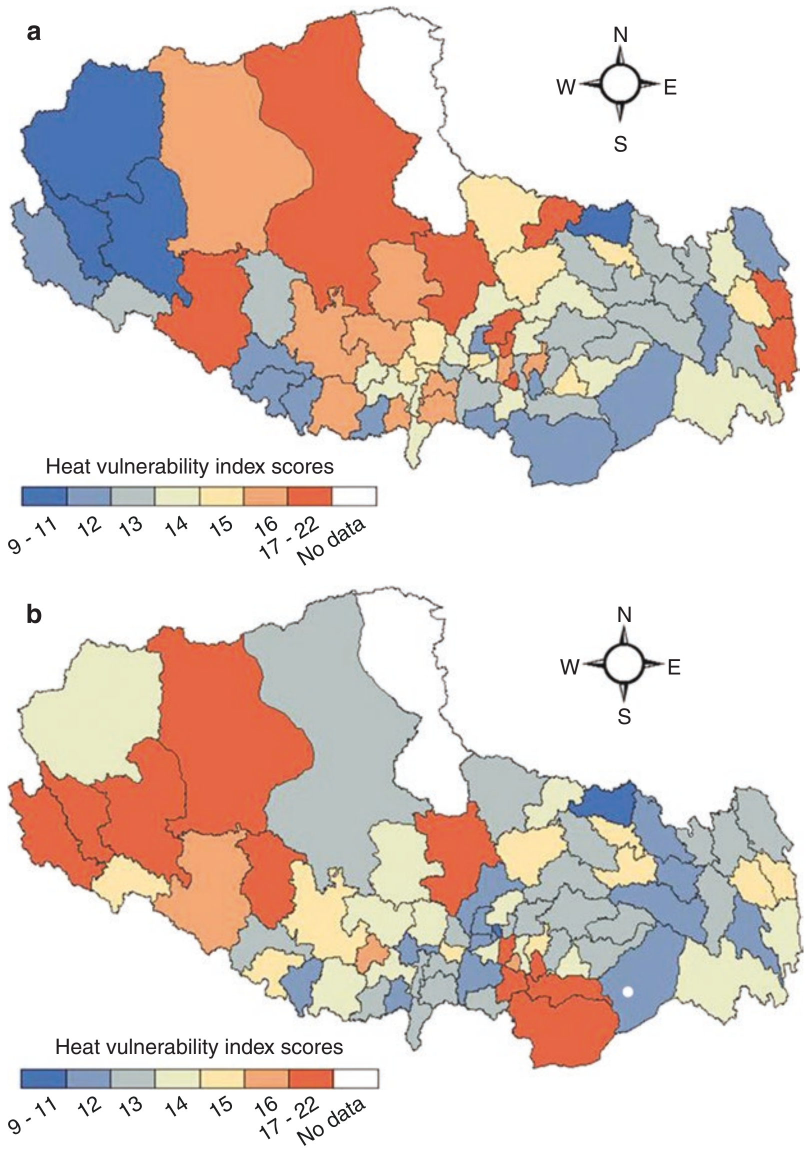


Fig. 10.4 Distribution of cumulative heat vulnerability in Tibet (Reproduced with permission from Bai et al. [30] (https://doi.org/10.1186/s12940-015-0081-0)). (**a**) For urban residents; (**b**) for rural residents

vulnerability to high temperature were different between the urban and suburb areas in Jinan City. In the center of urban area, health vulnerability induced by health condition, social connection, and living environment was relatively higher. In the suburb areas, health vulnerability was mainly caused by perception, adaptive behaviors, economic conditions, living resources, and working environments. Therefore, they suggested that specific adaptive measures are needed in the urban and suburb areas. For example, the heat island in the urban areas could be attenuated by good city planning. However, in the suburb areas, infrastructure projects are urgently needed, such as cooling center, tap water and electric power supply, and communication facilities [27].

Wang evaluated the spatial and temporal distribution of heat wave vulnerability in Beijing, Shanghai, and Chongqing, three metropolises in China, employing the IPCC vulnerability assessment framework [23, 24]. Both analytic hierarchy process (AHP) and entropy weight methods were employed to quantify the weight of each indicator. He found that whether the

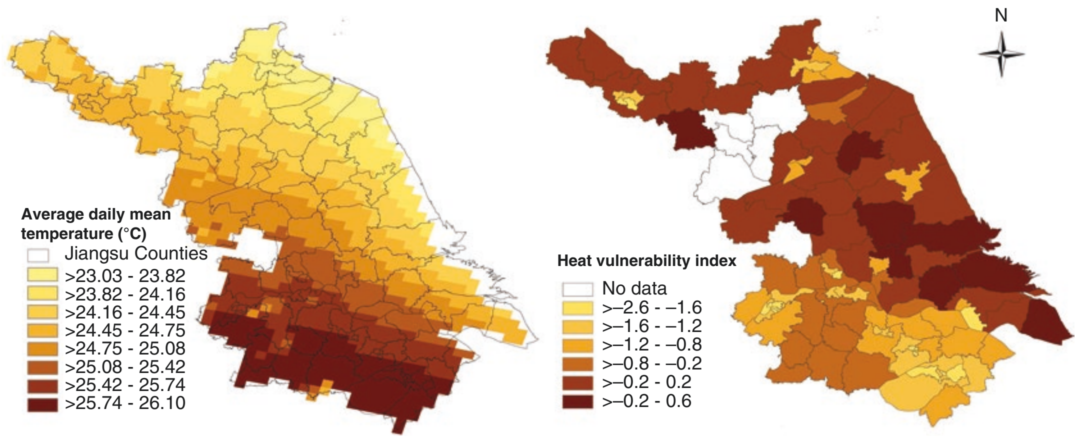


Fig. 10.5 Distribution of heat exposure and health vulnerability in Jiangsu Province (Reproduced with permission from Chen et al. [31] (http://dx.doi.org/10.1289/EHP204))

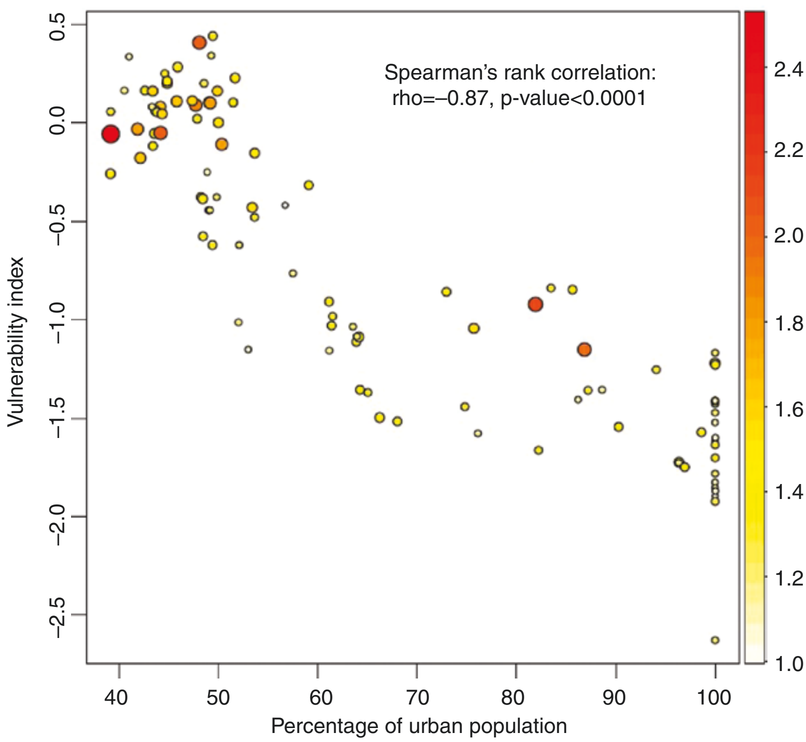


Fig. 10.6 The association of heat vulnerability index with the percentage of urban population at county level in Jiangsu Province (Reproduced with permission from Chen et al. [31] (http://dx.doi.org/10.1289/EHP204))

urban area under the influence of heat wave is the most significant factor in urban heat wave vulnerability. Comparing the vulnerability among the three cities, the heat wave vulnerability in Shanghai is the highest and then followed by Chongqing and Beijing, respectively. Temporally, the heat wave vulnerability of Beijing shows a decreasing trend and that in Shanghai and Chongqing shows an increasing trend from 2004 to 2013. It was debated that their locations and climatic types were the major reasons of this spatial variation. Beijing is located in relatively higher-latitude regions, while the other two cities are located in relatively lower-latitude regions. Beijing had less frequency of heat wave events than Shanghai and Chongqing. In addition, the adaptive capacity in Beijing increased significantly during 2004–2013. However, the increasing of adaption capacity in Shanghai and Chongqing is largely surpassed by the increasing of exposure.

10.5.2 Floods

Two studies were found to assess the flood vulnerability in Guangdong and Guangxi provinces, both of which were located in South China. Hou employed the IPCC vulnerability framework to assess the health vulnerability to floods in Guangxi Province. They observed higher vulnerability in north area than in south area of Guangxi Province. Baise, Hechi, and Guilin prefectures are the most vulnerable areas to flooding, which is a different view from conventional one. In the past 60 years, Guilin and Baise prefectures have experienced the most floods in Guangxi Province. Baise and Hechi had the lowest adaptive capacity to flooding (Fig. 10.7). He suggested that the local decision-makers need to consider reallocating resources, providing more policies and founding support to these areas, especially for Baise and Hechi prefectures, to help local communities increase their adaptive capacities [19].

In the second study, Zhu et al. assessed the spatial distribution of health vulnerability to floods using IPCC vulnerability framework in Guangdong Province. The results showed that the areas with higher health vulnerability were mainly distributed in the coastal areas, Beijiang River Delta, east areas of Dongjiang River Delta, and north areas of Pearl River Delta. The areas with relatively lower vulnerability levels were located in several counties in Zhaoqing, Dongguan, Foshan, and Heyuan cities. In addition, the results using different weighting methods (analytic hierarchy process vs. principal component analysis) were consistent [26] (Fig. 10.8).

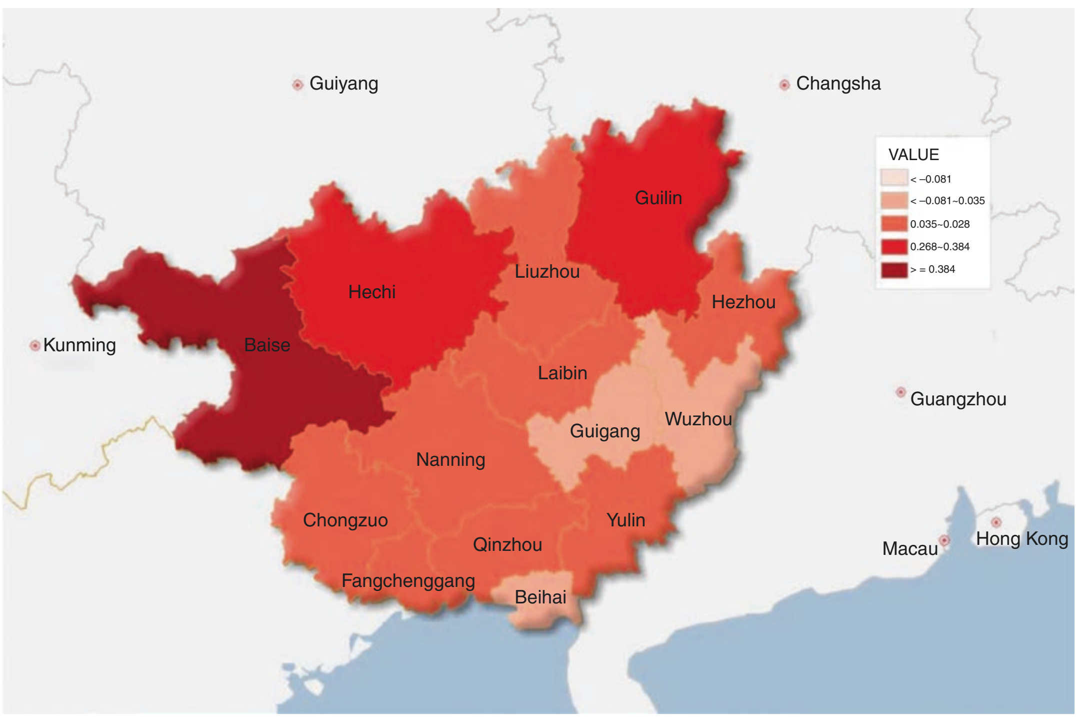


Fig. 10.7 The distribution of vulnerability to flood in Guangxi Province (Reproduced with permission from Hou [19] (https://experts.griffith.edu.au/publication/na869bfcedd3a43f46b95e99c7017cae1))

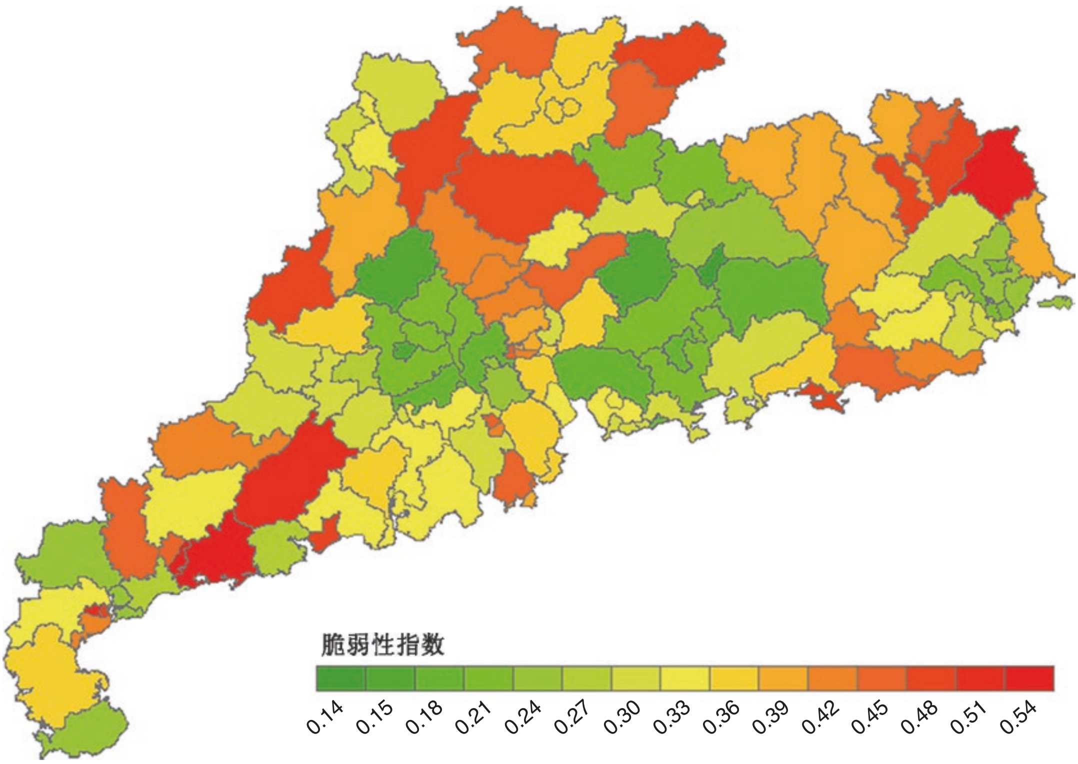


Fig. 10.8 The distribution of vulnerability to flood among 124 counties/districts in Guangdong Province (Reproduced with permission from Zhu et al. [26] (http://med.wanfangdata.com.cn/Paper/Detail/PeriodicalPaper_zhyfyx201211013))

10.5.3 Other Weather Factors

Fewer studies were conducted in China to evaluate the health vulnerability to other weather factors. Up to date, we have retrieved two studies that have assessed the vulnerability to natural disasters such as cyclones and droughts. Tan et al. assessed the general health vulnerability to climate change in Xinjiang and Ningxia provinces using the IPCC framework. Natural disasters and climatic variation were included in the assessment framework which contained 31 indicators. They observed that people in Xinjiang Province were more vulnerable to natural disasters and climatic variation vulnerability than people in Ningxia Province. The vulnerability in Xinjiang Province mainly came from demographic characteristics and social networks. By contrast, the vulnerability in Ningxia Province was mainly inducted by food and water supply [22]. In the second study, Christenson et al. assessed the global distribution of population exposure to cyclones, droughts, and floods and observed that Hong Kong and Macao were listed in the first and third place in the multi-hazard exposure rank. However, they did not assess the total health vulnerability to those weather events [28].

10.6 Summary

Climate change is the biggest global health threat of the twenty-first century [38]. Health vulnerability assessment can help stakeholders and health departments better understand the subgroup of population and areas that are more susceptible to the health impacts of climate change, implement targeted actions to reduce these health impacts, and even increase the equity of social and economic development. In this chapter, we symmetrically reviewed the studies on health vulnerability to climate change in China. We are glad to see that the health vulnerability assessment tool has been gradually employed to help policy-makers and stakeholders in China to comprehend the health impacts and vulnerability distribution of climate change. We believe these scientific results could help Chinese government to better adapt to the climate change. Meanwhile, several points need to be concerned:

(a) The number of studies is still inadequate, and the assessments were conducted in only several provinces. In addition, the health vulnerability metrics varied in different studies, which has led to the incomparability between studies. As a result, it is difficult to integrate these results at the national level. There is still exited unbalanced social and economic development in current China. The distribution of health vulnerability may largely differ between regions. Therefore, nationwide health vulnerability studies are wanted.
(b) Most studies assessed on heat vulnerability. Other weather factors and extreme events such as low temperature, cold spell, drought, and cyclones were seldomly assessed. It has been demonstrated that these extreme events in particular cold spells may lead to more health impacts than heat waves in warmer regions [10]. In addition, China is a vast geographical territory with contrasting climatic characteristics. The major weather factors impacting human health may largely differ. Hence, local specific studies are also needed to identify the major types of weather factors and the distribution of health vulnerability, which could provide the explicit information the local policy-makers and stakeholders to make corresponding adaptation measures to deal with the potential climate change.
(c) Few studies were conducted to assess the health vulnerability to climate change in population with different characteristics. Such studies could provide more corresponding information to take actions to protect the most vulnerable groups of people.
(d) In the process of health vulnerability assessments, the selection of indicators and their weightings was the critical step. In most previous studies, the unavailability of data is an important restriction on the indicator selection, which has led to some important indicators excluded, such as prevalence of air-conditioning usage, cooling fan usage, occupational exposures, and local building environments. Moreover, inclusion of different indicators may have led to different assessment outcomes. The ongoing information construction across China integrating different departments may partially overcome these restrictions in the future.

Acknowledgment This study was supported by the National Key Research and Development Program (2018YFA0606202), Guangdong Province Special Fund for Low-carbon Development (201616), Guangdong Province Public Health Innovation Platform Construction Program, and Guangzhou Science and Technology Program (201704020194).

References

1. McCarthy JJ, Canziani OF, Leary NA, Dokken DJ, White KS. Climate change 2001: impacts, adaptation, and vulnerability: contribution of working group II to the third assessment report of the intergovernmental panel on climate change. Cambridge: Cambridge University Press; 2001.
2. Pachauri RK, Reisinger A. Climate change 2007: synthesis report. Contribution of working groups I, II and III to the fourth assessment report of the intergovernmental panel on climate change. Geneva: Intergovernmental Panel on Climate Change; 2007.
3. Stocker TF, Qin D, Plattner G-K, Tignor M, Allen SK, Boschung J, Nauels A, Xia Y, Bex V, Midgley PM. IPCC, 2013: climate change 2013: the physical science basis. Contribution of working group I to the fifth assessment report of the intergovernmental panel on climate change. Cambridge: Cambridge University Press; 2013.
4. Gasparrini A, Guo Y, Hashizume M, Lavigne E, Zanobetti A, Schwartz J, Tobias A, Tong S, Rocklov J, Forsberg B, Leone M, De Sario M, Bell ML, Guo YL, Wu CF, Kan H, Yi SM, de Sousa Zanotti Stagliorio Coelho M, Saldiva PH, Honda Y, Kim H, Armstrong B. Mortality risk attributable to high and low ambient temperature: a multicountry observational study. Lancet. 2015;386(9991):369–75.
5. Guo Y, Gasparrini A, Armstrong B, Li S, Tawatsupa B, Tobias A, Lavigne E, de Sousa Zanotti Stagliorio Coelho M, Leone M, Pan X, Tong S, Tian L, Kim H, Hashizume M, Honda Y, Guo YL, Wu CF, Punnasiri K, Yi SM, Michelozzi P, Saldiva PH, Williams G. Global variation in the effects of ambient temperature on mortality: a systematic evaluation. Epidemiology. 2014;25(6):781–9.

6. Ma W, Wang L, Lin H, Liu T, Zhang Y, Rutherford S, Luo Y, Zeng W, Zhang Y, Wang X. The temperature–mortality relationship in China: an analysis from 66 Chinese communities. Environ Res. 2015a;137:72–7.
7. Ma W, Zeng W, Zhou M, Wang L, Rutherford S, Lin H, Liu T, Zhang Y, Xiao J, Zhang Y. The short-term effect of heat waves on mortality and its modifiers in China: an analysis from 66 communities. Environ Int. 2015b;75:103–9.
8. Phung D, Thai PK, Guo Y, Morawska L, Rutherford S, Chu C. Ambient temperature and risk of cardiovascular hospitalization: an updated systematic review and meta-analysis. Sci Total Environ. 2016;550:1084–102.
9. Turner LR, Barnett AG, Connell D, Tong S. Ambient temperature and cardiorespiratory morbidity: a systematic review and meta-analysis. Epidemiology. 2012;23(4):594–606.
10. Xie H, Yao Z, Zhang Y, Xu Y, Xu X, Liu T, Lin H, Lao X, Rutherford S, Chu C, Huang C, Baum S, Ma W. Short-term effects of the 2008 cold spell on mortality in three subtropical cities in Guangdong province, China. Environ Health Perspect. 2013;121(2):210–6.
11. Reid CE, O'Neill MS, Gronlund CJ, Brines SJ, Brown DG, Diez-Roux AV, Schwartz J. Mapping community determinants of heat vulnerability. Environ Health Perspect. 2009;117(11):1730–6.
12. Sheridan SC, Dolney TJ. Heat, mortality, and level of urbanization: measuring vulnerability across Ohio, USA. Clim Res. 2003;24(3):255–65.
13. Vescovi L, Rebetez M, Rong F. Assessing public health risk due to extremely high temperature events: climate and social parameters. Clim Res. 2005;30(1):71–8.
14. White-Newsome JL, Sánchez BN, Jolliet O, Zhang Z, Parker EA, Timothy Dvonch J, O'Neill MS. Climate change and health: indoor heat exposure in vulnerable populations. Environ Res. 2012;112:20–7.
15. Administration CM. China climate change blue book. 2018. http://www.cma.gov.cn/2011xwzx/2011xqxxw/2011xqxyw/201804/t20180404_465788.html.
16. Hodges M, Belle JH, Carlton EJ, Liang S, Li H, Luo W, Freeman MC, Liu Y, Gao Y, Hess JJ. Delays in reducing waterborne and water-related infectious diseases in China under climate change. Nat Clim Chang. 2014;4(12):1109–15.
17. Wang L, Chen W. A CMIP5 multimodel projection of future temperature, precipitation, and climatological drought in China. Int J Climatol. 2014;34(6):2059–78.
18. Feng L. Assessment of health vulnerability of heat waves in Hainan province. Beijing: Chinese Center for Disease Control and Prevention; 2016.
19. Hou X. Risk communication in vulnerability assessment towards development of climate change adaptation strategy for health in Guangxi, China. Brisbane: Griffith University; 2015.
20. Nelson R, Kokic P, Crimp S, Martin P, Meinke H, Howden S. The vulnerability of Australian rural communities to climate variability and change: part II—integrating impacts with adaptive capacity. Environ Sci Pol. 2010;13(1):8–17.
21. Saaty RW. The analytic hierarchy process—what it is and how it is used. Math Model. 1987;9(3):161–76.
22. Tan L, Wang G, Ma C. Effective livelihood adaptation to climate change disturbance-based on Xinjiang and Ningxia' social survey. Econ Manag. 2013;(3):10–6.
23. Wang YC. Study on the evaluation of urban high-temperature heat wave vulnerability from the perspective of climate change. Beijing: Beijing University of Architecture; 2015.
24. Zhang M, Wang Y. Research on evaluation system of heat wave vulnerability in Beijing city. Urban Environ Stud. 2015;(1):16–33.
25. Zhu Q, Liu T, Lin H, Xiao J, Luo Y, Zeng W, Zeng S, Wei Y, Chu C, Baum S. The spatial distribution of health vulnerability to heat waves in Guangdong Province, China. Glob Health Action. 2014;7:25051.
26. Zhu Q, Liu T, Zhang YH, Luo Y, Wei Y, Xiao JP, Zeng SQ, Ma WJ. The assessment of vulnerability to floods in Guangdong province at district level. Chin J Prev Med. 2012;46(11):1020–4.
27. Wan FJ. Evaluation of high-temperature vulnerability of residents in Jinan city center and marginal zone. Beijing: Chinese Center for Disease Control and Prevention; 2014.
28. Christenson E, Elliott M, Banerjee O, Hamrick L, Bartram J. Climate-related hazards: a method for global assessment of urban and rural population exposure to cyclones, droughts, and floods. Int J Environ Res Public Health. 2014;11(2):2169–92.
29. Bai L. Study on the influence of temperature on the health of the Tibetan autonomous region and its vulnerability assessment. Beijing: Chinese Center for Disease Control and Prevention; 2014.
30. Bai L, Woodward A, Liu Q. County-level heat vulnerability of urban and rural residents in Tibet, China. Environ Health. 2016;15(1):1–10.
31. Chen K, Zhou L, Chen X, Ma Z, Liu Y, Huang L, Bi J, Kinney PL. Urbanization level and vulnerability to heat-related mortality in Jiangsu Province, China. Environ Health Perspect. 2016;124(12):1863–9.
32. Luo XL, Du YD, Zheng J. Determining risk zones for human health during heatwaves in Guangdong. Clim Change Res. 2016;12(2):139–46.
33. Sano M, Baum S, Crick F, Choy D, Serrao-Neumann S, Tomlinson R. An assessment of coastal vulnerability to climate change in south East Queensland, Australia. Presented at the Littoral 2010. Adapting to global change at the coast: leadership, Innovation, and Investment. London. 2010. p. 09–23.
34. Wan F, Xin Z, Zhou L, Bai L, Wang Y, Gu S, Liu S, Li M, Sang S, Zhang J. Heat vulnerability assessment in Jinan city: a comparison between residents living in urban centers and urban-fringe areas. Chin J Epidemiol. 2014;35(6):669.
35. Composing Team for Assessment Report on Climate Change of Guangdong. Assessment report on climate

change of Guangdong (selection). Guangdong Meterology. 2007;29(3):1–14.
36. Yu C, Zhang Y, Claus H, Zeng R, Zhang X, Wang J. Ecological and environmental issues faced by a developing Tibet. Environ Sci Technol. 2012;46(4):1979–80.
37. Ding Y, Ren G, Shi G, Gong P, Zheng X, Zhai P, Zhang D, Zhao Z, Wang S, Wang H. National climate change assessment report (I): history and future trends of climate change in China. Adv Clim Chang Res. 2006;3(12):1–5.
38. Costello A, Abbas M, Allen A, Ball S, Bell S, Bellamy R, Friel S, Groce N, Johnson A, Kett M. Managing the health effects of climate change: Lancet and University College London Institute for Global Health Commission. Lancet. 2009;373(9676):1693–733.

11 Public Health Adaptation to Heat Waves in Response to Climate Change in China

Yiling He, Rui Ma, Meng Ren, Wenmin Liao, Na Zhang, Yanan Su, Cho Kwong Charlie Lam, Suhan Wang, and Cunrui Huang

Abstract

This chapter examines heat-related health effects and suggests public health adaptation strategies to heat waves in China. Due to climate change and urban heat island effects, a future increase in extreme heat events could lead to excess heat-related mortality and morbidity in urban populations. However, the risk of heat exposure is not evenly distributed. Some demographic groups are more prone to heat-related illnesses, such as outdoor workers, children, the elderly, and people with preexisting health conditions. Furthermore, population aging and acclimatization limits both present challenges for adapting to a warmer climate in China. Considering these challenges, this chapter identifies several adaptation strategies to address the health impacts of heat waves and discusses the issues of implementing these policies and measures. For example, heat-health action plans require the government to coordinate with supporting agencies for deciding the timing of activation and deactivation. Heat-health warning systems can also be developed based on temperature threshold, but this threshold varies in different cities. During heat waves, real-time surveillance data can provide early detection of heat-related health threats. In addition, the government can use heat vulnerability mapping to identify populations susceptible to heat waves and provide adequate healthcare and social services for these vulnerable groups. Identifying vulnerable populations alone is insufficient, as effective risk communication is also required for behavior change, including personal heat exposure reduction strategies. Finally, climate-sensitive urban planning such as optimizing building design and urban greening would alleviate the adverse health impacts of heat waves in China.

Keywords

Heat wave · Climate change · Health impact · Vulnerability · Adaptation strategy · China

Y. He · R. Ma · M. Ren · W. Liao · N. Zhang · Y. Su · S. Wang · C. Huang (✉)
School of Public Health, Sun Yat-sen University, Guangzhou, Guangdong, China
e-mail: heyling@mail2.sysu.edu.cn; marui6@mail2.sysu.edu.cn; renm23@mail2.sysu.edu.cn; liaowm3@mail2.sysu.edu.cn; zhangn23@mail2.sysu.edu.cn; suyn6@mail2.sysu.edu.cn; wangsuh@mail.sysu.edu.cn; huangcr@mail.sysu.edu.cn

C. K. C. Lam
School of Atmospheric Sciences, Sun Yat-sen University, Guangzhou, Guangdong, China
e-mail: linzug@mail.sysu.edu.cn

H. Lin et al. (eds.), *Ambient Temperature and Health in China*,
https://doi.org/10.1007/978-981-13-2583-0_11

11.1 Introduction

Countries worldwide have experienced numerous extreme heat events in the early twenty-first century, such as Europe in 2003, Russia in 2010, and Southeast Asia in 2016 [1]. These events were associated with increased rates of mortality and morbidity, with higher risks among vulnerable groups including outdoor labors, children, the elderly, and people with preexisting chronic diseases.

Most of the adverse health effects of hot weather are preventable, which can be achieved by appropriate and effective public health response, including strategies for short-term measures, medium-term preparedness, and long-term plans. In this chapter, we aim to reflect the work on epidemiological evidence about heat-related health effects, drawing attention to population susceptibility to heat, as well as the development of public health adaptation strategies to cope with problems associated with current and future heat waves in China.

11.2 Defining the Problem

Heat wave commonly refers to an extended period of unusually hot weather, but it seems that there is no simple definition. In general, magnitude, duration, and frequency are essential to constitute a heat wave, but the definition varies depending on the meteorological variables or health outcomes of interest. One debatable issue exists concerning definitions based on absolute temperatures versus percentiles. Absolute temperatures are important for human biophysical heat tolerances, but percentiles may be comparable across different areas and time scales given differences in acclimatization and preparedness [1]. Another issue arises because of the strong association between humidity and thermal stress in humans. Thus, "apparent temperature" or "humidex" [2], which combines temperature and humidity, is also a choice to define heat waves.

The trend of more heat events with increasing global temperature is ubiquitous. The Intergovernmental Panel on Climate Change (IPCC) concluded a 0.85 °C temperature rise has been detected from 1880 [3]. Fischer and Knutti [4] claimed that temperature rise by 0.85 °C is high enough to cause roughly 75% of moderate heat extremes globally. In an analysis from 217 urban areas around the world, Vimal et al. [5] found more than 50% of cities experienced a significant increase in extreme heat events. The same trend has been reported in China as well. Since the end of the twentieth century, annual mean surface temperature has risen by 0.5–0.8 °C, the frequency of extreme hot days ($T_{max} > 35$ °C) has increased at a rate of 0.12 days per decade, and annual averaged minimum temperature has increased at a rate of 0.3 °C per decade (Fig. 11.1) [6].

Heat waves can cause a wide range of health problems (Fig. 11.2). A rise of 1 °C above the local unusually hot threshold may account for 1–3% increase in all-cause mortality [8–10]. The increased mortality is mainly attributed to cardio-cerebrovascular system, central nervous system, and respiratory system, which are highly sensitive to heat [11, 12]. Compared with mortality, heat-related morbidity is less well studied for that death data are easier to access around the world [13]. Research so far has also shown inconsistent findings on morbidity. For example, during heat waves, increases in ischemic heart disease and stroke were found in California [14], while the rising number of respiratory and renal diseases was illustrated in London [15]. In general, the rising number of emergency hospitalization is mostly attributed to heat-related illnesses, such as heat stroke, dehydration, and electrolyte disturbances, as well as preexisting diseases with other International Classification of Diseases (ICD) chapters but actually related with heat, such as cardio-cerebrovascular diseases, respiratory illness, chronic renal diseases, reduced function of central nervous, and mental disorders [12].

The exposure-response relationship between temperature and mortality or morbidity is usually found to be U-, V-, or J-shaped, with increasing risk at upper end of the temperature scale [16]. However, the impacts of heat waves may be not restricted to the time period in which the event occurs which shows a lag effect ranging from the

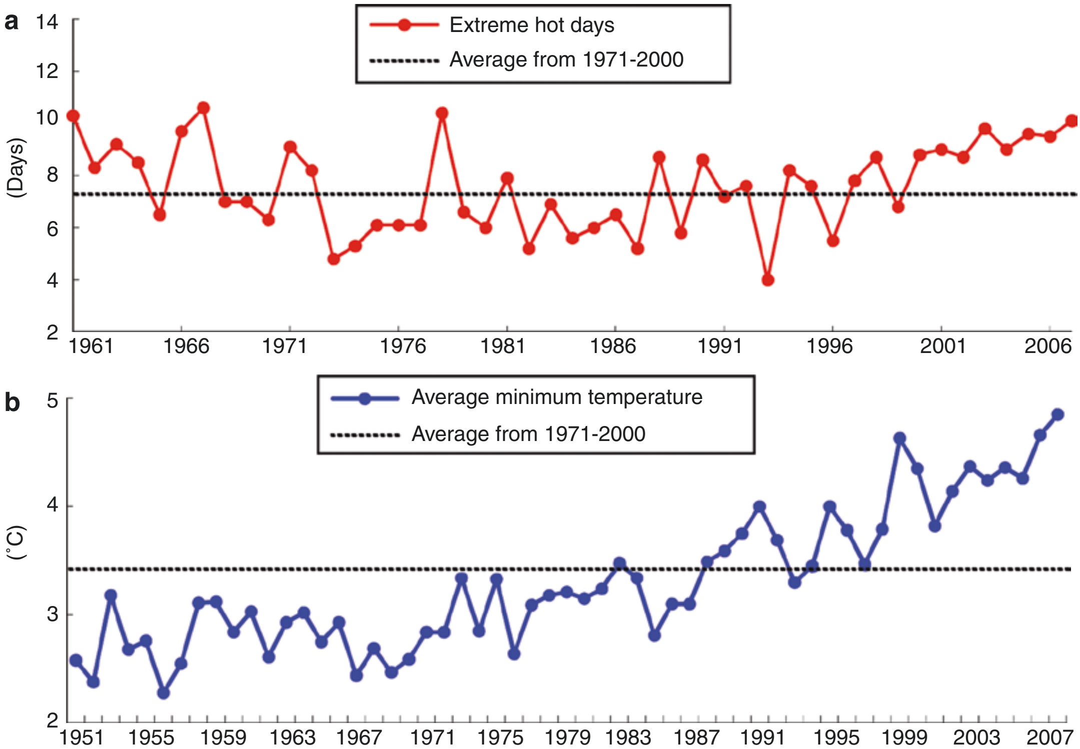


Fig. 11.1 (**a**) Variation of the annual averaged extreme hot days (daily $T_{max} > 35$ °C) during 1951–2007 and (**b**) average annual minimum daily temperature during 1961–2007 in China. Adapted from Luo et al. [6]

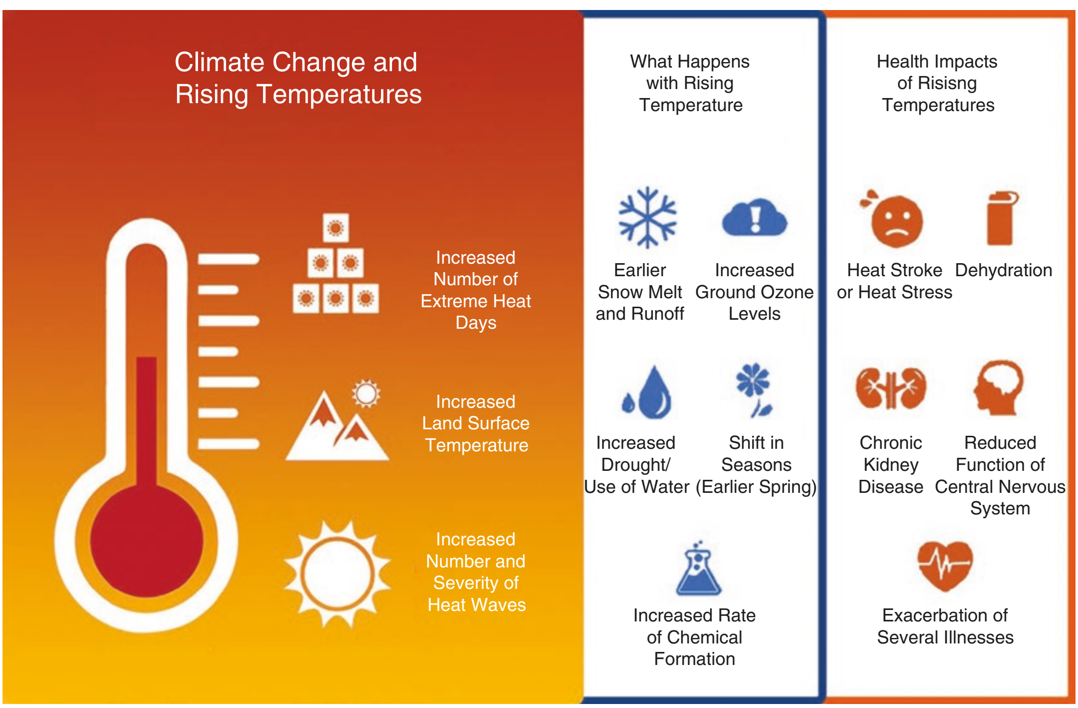


Fig. 11.2 Rising temperature and its health impacts. Adapted from Maggie Bailey et al. [7]

same day to 3 days [16, 17]. Moreover, the interactions between air pollution and high temperatures on health should not be ignored in many cases. Air pollutants such as particulate matters, ozone, and carbon monoxide are often associated with increased mortality at high temperatures, usually causing cardiovascular and cardiopulmonary diseases, and also the impact varies across regions [18]. In general, the adverse health effects are location-specific and seem to change over time as well [19]. Therefore, systematic collection and tracking of health outcomes are important for both assessing heat-related health effects among vulnerable groups and monitoring heat adaptation over time.

11.3 Understanding Susceptibility

As heat exposure is normally perceptible, it is relatively easy for exposed individuals to escape from thermal environments. However, individual behavior or ability in coping with heat events is often influenced by socioeconomic, behavioral, cultural, and other factors. Recent studies have identified multiple vulnerable subgroups, including outdoor workers, children, the elderly, people with preexisting diseases, urban residents, and those with low socioeconomic status [20].

11.3.1 Outdoor Workers

Outdoor workers are especially vulnerable because they are easy to accumulate excessive heat in the body during daytime extremes. Heat accumulation mainly roots in external heat exposure (high air temperature and solar radiation) and internal metabolic heat production due to heavy physical labors [21]. Required personal protective equipment may also increase workers' thermal storage. Furthermore, outdoor workers may be exposed to extra occupational hazards (like exhaust fumes, hot asphalt, and pesticides) [22]. Agriculture and construction are the most severely influenced outdoor sectors, but groundskeepers, transportation, and mining workers are also reported at the high risk of occupational heat-related health effects [23, 24].

11.3.2 Children and the Elderly

Children are sensitive to heat because of their developing organs and nervous systems, immature cognition, rapid metabolisms, limited experience, and behavioral characteristics [25]. Studies have found that children aged under 5 were at a significantly higher risk for heat stroke when playing outdoors because they are usually less equipped on many fronts to deal with heat stress and may lack appreciation about heat-related illnesses [26]. The vulnerability of older people is mainly due to the degeneration of thermoregulatory system, the increase of comorbidities, as well as medication use [27]. During the 2003 heat waves in Paris, the elderly over 75 accounted for >80% of the total excessive death [28]. However, many senior people were less tend to take protective measures during heat waves because of the under-appreciation of their vulnerability [29].

11.3.3 Preexisting Diseases

Cooling is usually achieved physiologically by increasing skin blood flow and sweating. The condition of the cardiovascular system as well as the endocrine, urinary, and integumentary systems will influence the heat dissipation progress [30]. Therefore, people with specific diseases which compromise the cooling mechanisms may be more susceptible to heat (e.g., cardiovascular and cerebrovascular diseases, renal diseases, respiratory diseases, diabetes, and mental disorders) [31–33]. Some medications used to treat physical and mental illnesses, such as prescribed antipsychotics, antidepressants, and antihypertensive drugs, may reduce the sensory perception of surrounding heat or inhibit thermoregulation. For example, thirsting and sweating progresses can be compromised [34, 35]. Thus patients taking these medications are at a higher risk during heat waves [36].

11.3.4 Urban Residents

Urban residents now comprise over half of the world's population. The temperature difference between urban regions and the surrounding rural areas ranged from 1 to 6 °C [37]. The reliable explanations on "urban heat island effects" include high thermal absorption in daytime and heat emission at night by pavements and buildings, lack of green space, and reduced airflow around high crowded buildings [31, 38–40]. With the rapid urbanization and population migration in China, more people are swarming into big coastal and southern cities. People used to live in cooler northern China may not adapt to the hot and wet climates in Southern China [41]. Moreover, people from cooler regions are usually not well acclimated and less likely to use air-conditioner, which could contribute to greater heat-related mortality and morbidity [12]. Research has also shown that the minimum temperatures for fatal heat-related illnesses decrease with increasing latitudes [42]. The differences between physiologic and technologic adaptations adopted by local residents could result in various health event thresholds [12].

11.3.5 Socioeconomic Factors

Income was associated with heat-related mortality at the neighborhood level in Hong Kong, China [43]. Plausible underlying explanation may include the following: (a) low-income individuals are less willing to respond to heat warnings or pay for transportation to cooler locations [44]; (b) low prevalence of air-conditioning, lack of medical care, and health insurance shortage [31, 44]; and (c) housing characteristics. Well-insulated homes were reported to have a protective effect against heat-related mortality, whereas individuals in older buildings with poor thermal insulation function were at a higher risk [45].

During the 2003 heat wave in Europe, higher education was reported as a protective factor of heat-related illnesses [46]. The composition of neighborhood education was related to the heat-associated mortality, whereas the results were mixed when considering education effects at the community level [47]. Other factors which are related with educational level, such as income inequality, distinction of occupations, or perception of heat events, may also affect the risk of heat-related illnesses.

Social isolation is usually reported as a risk factor of heat-related illnesses. People at higher risk typically have limited association with their relatives, neighbors, or social services (like unmarried or widowed, living alone, the elderly, the poor and homeless, and physically disabled) [48]. Social isolation may be a consequence of a physical, mental, or cognitive damage according to existing studies [39].

Summary indicators of socioeconomic status have also been applied to explore the vulnerable populations in heat waves. Summary indicators may have advantages in modeling the latent class represented by the combination of individual factors, and it is statistically advantageous when the components are strongly associated. However, the summary measure does not provide information concerning the individual effects of income or education on the vulnerability [43].

11.4 Future Drivers

11.4.1 Climate Change

Base on the observations worldwide, the IPCC has concluded that climate change has happened on a global scale. Though the Paris Agreement has set goals of limiting the warming within 2 °C and called on efforts on limiting temperature rise within 1.5 °C above pre-industrial levels, we will still facing deteriorated heat wave exposure with increasing intensity and frequency. According to Dosio et al. [49], in a 1.5 °C warming world, most regions at low latitudes will be affected by severe heat events, but the frequency of these events will even double with a 2 °C warming compared with 1.5 °C warming (Fig. 11.3). As for the affected people, 13.8% of world's population will be frequently exposed to severe heat events at a 1.5 °C warming, while the number will triple with a 2 °C

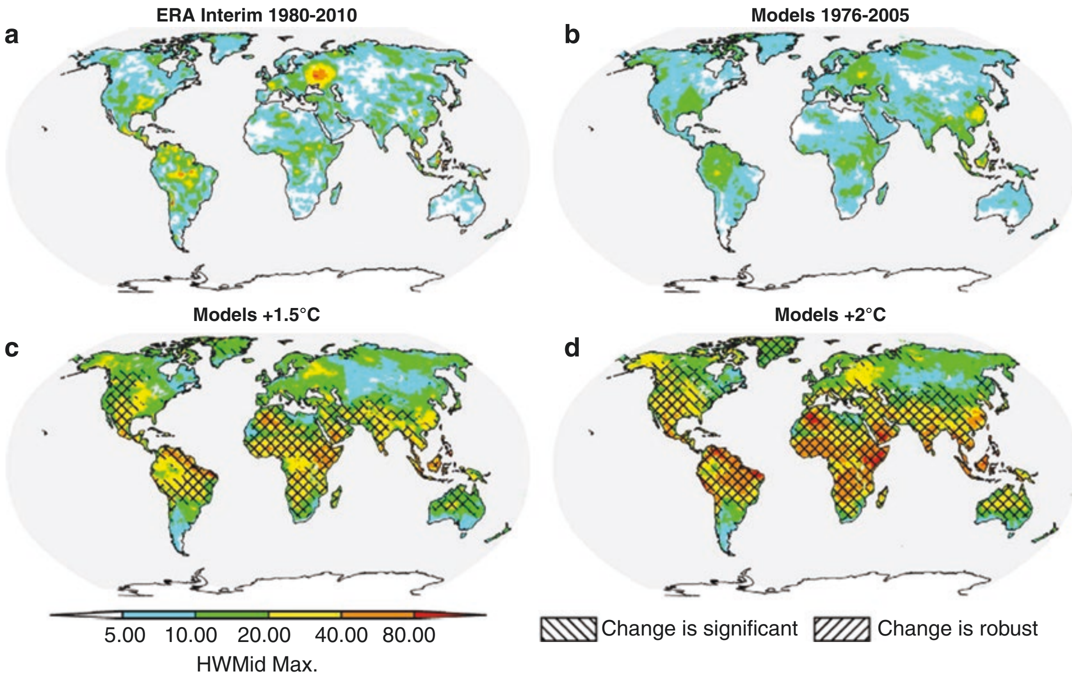


Fig. 11.3 Present and future distribution of heat waves. (**a**) Heat Wave Magnitude Index daily (HWMId) observed during 1980–2010. (**b**) Modeled maximum magnitude during 1976–2005. (**c**) Projected maximum magnitude in a 1.5 °C warming world and (**d**) a 2 °C warming world. Source from an Open Access article: [49]. (https://iopscience.iop.org/article/10.1088/1748-9326/aab827/meta)

warming. The majority of population in China lives in mid- and low-latitude areas, which are expected to experience more heat waves. Sun et al. [50] found that current probability of extreme warm summer in China has increased by 60 times compared to historical level of the 1950s and projected that about 50% of summers in the next two decades will be hotter than that in 2013 under the moderate emissions scenario (RCP4.5), which will pose severe health threats.

11.4.2 Rapid Urbanization

There is about 54.7% of population living in urban areas globally in 2018, and this figure will reach 68.4% by 2050 [51]. The rapid urbanization has influenced our environment profoundly. Buildings absorb more solar radiation, greenhouse effect reduces heat escaping into space, and these make urban areas warmer than surrounding areas. The extra heat could exacerbate health impacts of heat waves. A study in the UK found that urban heat islands (UHI) contributed half of heat-related deaths, and health impact assessments ignoring regional difference of temperature resulted in a 20% underestimation in mortality [52]. China has observed a huge migration from rural to urban since the reform and opening-up policy in 1978. The number of cities increased from 193 in 1978 to 657 in 2016. This transformation not only manifested in the expending of built-up area but also the proportion of urban residents, as in Fig. 11.4. The proportion of urban population rose from 17.9% in 1978 to 58.5% in 2016 and is estimated to reach 80%, with the urban population increasing to 1.09 billion by 2050. The continuous growth of urban residents may increase the exposed population and present severe challenge to health sector [51].

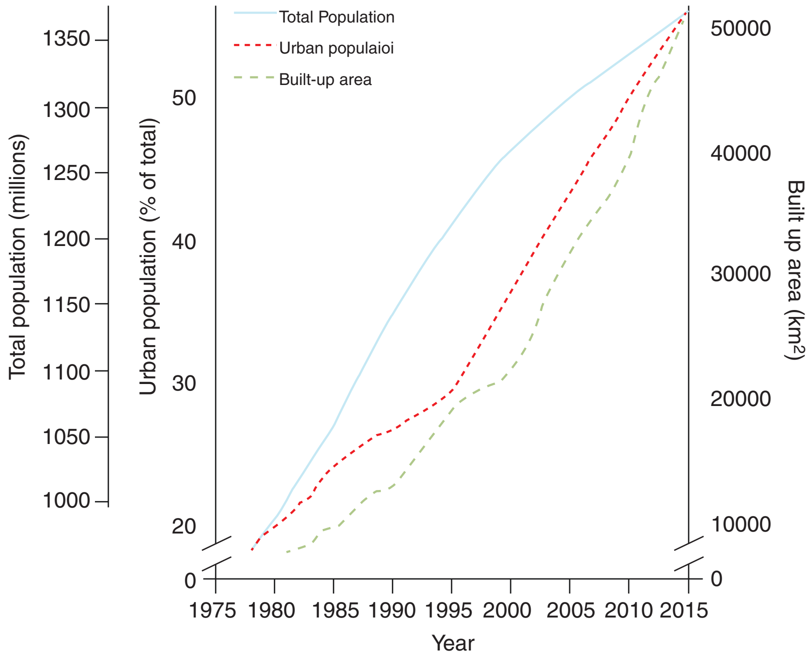


Fig. 11.4 Total population, urban population, and built-up area in China, 1978–2015. Adapted from Yang et al. [53]

11.4.3 Population Aging

Population aging is the case for most countries. Advanced age represents one of the most significant risk factors for heat-related health effects. According to the United Nations [54], China is one of the fastest aging countries, and one-tenth of its total population is aged 65 years and above in 2017. It is also projected that by 2050, population aged 65 years and older will reach 359 million, or 26.3% of total population in China (Fig. 11.5). Elderly people usually have diminished physiological heat adaptation ability due to poorer thermoregulation and suffer from underlying diseases, such as coronary heart disease and chronic lung disease. The elderly are more likely to live alone and have reduced social contacts. Therefore, the social and physiological vulnerabilities to heat waves will increase greatly because of a larger proportion of elderly people in the near future.

11.5 Acclimatization Limits

Considering that humans have already tolerated a wide range of climate, many people are optimistic that humans will simply adapt to future increasing temperature. Previous studies indicated that heat-related mortality varied among different regions [8, 9]. It usually attributes to behavioral and technological adaptation as well as physiological acclimatization. Taking the time horizon into consideration, it has aroused intense discussion in academia if humans can acclimatize to future increased heat exposures due to climate change.

Sherwood and Huber [55] concluded that when global mean temperature increases by 7 °C, metabolic heat dissipation would become impossible in some regions due to the human limits to heat tolerance. When the mean global temperature increases by about 11–12 °C, these regions would expand to encompass most of today's human habitation. Since it becomes difficult to dissipate metabolic heat, it would induce hyperthermia in humans and other warm-blooded animals when body temperature exceeds 35 °C for extended periods. Sherwood and Huber [55] pay much attention to the variation of mean temperature conditions and the relevant variation of maximum temperatures distribution during a few centuries. They found that, though the variation of mean global temperature is little, it is more likely to exceed physiologically tolerable thermal

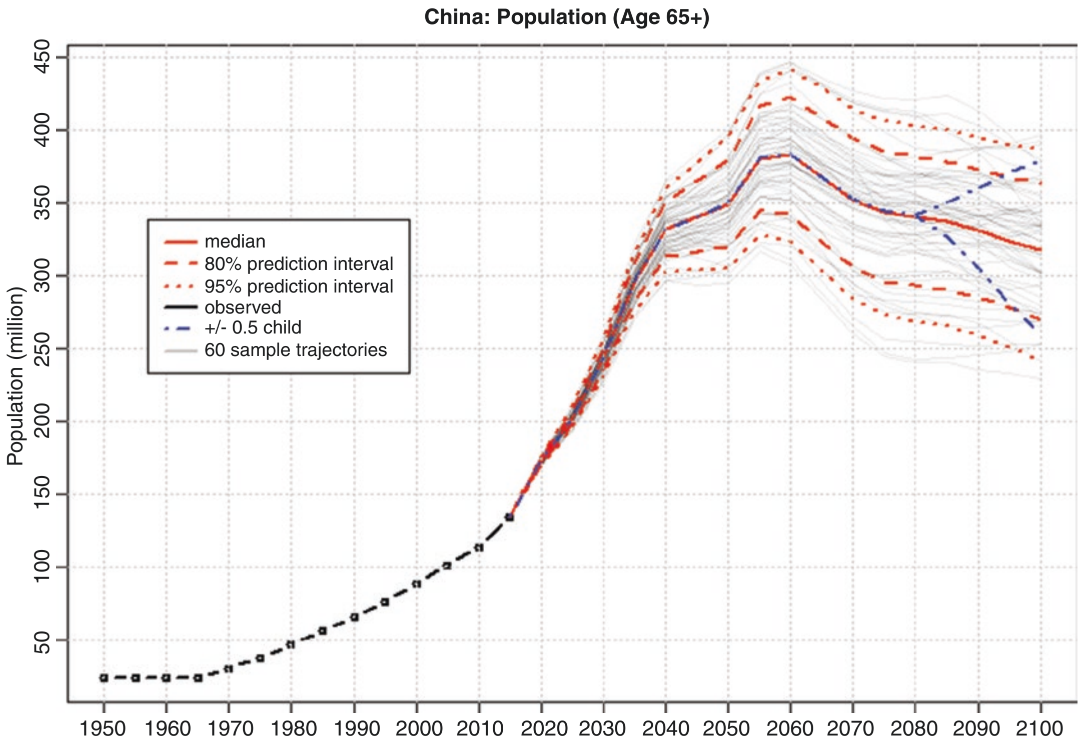


Fig. 11.5 Projections of population aged 65 and over in China. Source from an Open Access article: [54]. (http://esa.un.org/unpd/wpp/)

limits when mean temperature is higher. If mean global temperature increases above 4–6 °C, human biology may be physiologically maladaptive to the new thermal environment.

From an evolutionary perspective, biological evolution is a long process. Fossil records indicate that the slow undulatory processes of global cooling during the past 65 million years have led to the increased body size of warm-blooded mammalian. Thus, they could reduce heat dissipation to the external environment. During the evolution of nanoseconds over the next few centuries, it would be impossible for human mammals to go through useful genetic acclimatization. There is no denying that the population has experienced an exponential increase from millions to billions. When gene pool is larger, it is faster to respond to the variation in environment and interbreeding between regional genetic strains will increase. Nevertheless, many scientists warned that it will not be possible for biological evolutionary adaptation to a warmer climate in a few hundred years [56].

Apart from the perspective of physiology or evolution, a hotter world will not only be less livable, it will also reduce productivity, which will become an obstacle to acclimatization in return. It is due to the interruption of the production process in nature that we rely on and because of the impaired work capacity in overheated conditions [57]. Zander et al. [58] analyzed estimates of job absences and performance degradation of about 2000 workers resulting from heat during 2013–2014 in Australia [58]. Around 75% respondents said that heat exposure in the workplace had affected their work efficiency. The authors then conducted further research and found that the cost for one person was about annual 655 US dollars. Through speculation, this study shows that the cost for the Australian economy is about 6.2 billion US dollars (accounted for 0.4% of GDP in 2014). Until now, however, many governments have not fully realized that heat exposure had a profound impact on work ability and economy productivity nor take them into consideration of future projections and plans for social and economic development [59].

11.6 Public Health Response and Adaptation Strategies

Public health adaptation aims to reduce undesirable health impacts or enhance resilience to heat waves through short- and long-term actions [60]. However, adaptation strategies may fall into autonomous and planned actions [61]. Although autonomous adaptations can occur without coordinated scheming in individual or community levels, and are usually reactive by nature, well-planned adaptations will involve deliberate policy actions with conscious intervention basing on anticipated risks. Thus, planning ahead is more important for public health communities to cope with the adverse effects of heat waves.

11.6.1 Adaptation Policies

Many government authorities have developed multiagency and intersectoral policies or regulations in response to heat events. Among these policies, heat-health action plans (HAPs) are core policy elements in public health adaptation to heat waves. Developing an effective HAP requires a lead agency which coordinates with all participating or supporting agencies and sets criteria to determine the threshold for HAP's activation and deactivation in city-specific setting. This lead agency also sets a risk communication and public education plan to deliver heat-related health information, detects high-risk populations, and determines ways to reach most vulnerable groups [62, 63].

Developing and participating HAPs among agencies and public could help decrease adverse health impacts of heat and heat-related mortality [64–66]. For example, public health authorities in Montreal city of Canada developed a heat-health action plans in 2004, which would be activated when forecast temperatures exceeding 30 °C (86 °F). After a revision in 2012, the current Montreal heat response plan (MHRP) comprises five levels, including *normal*, *seasonal watch*, *active watch*, *alert*, and *intervention*. Different actions such as public advisories, risk information transmission, intensified surveillance, and air-conditioned shelter opening will be taken depending on different alert levels [67]. Benmarhnia et al. [68] reported that the actions of MHRP have been proved effective in reducing heat-related mortality by 2.5 deaths per day when extreme heat occurred (Fig. 11.6).

In 2012, the Chinese state government has released the *Administrative Measures on Heatstroke Prevention* (AMHP2012) to address intensive heat events. Some critical countermeasures in this regulation include applying new materials and technologies, constructing protective equipment, and monitoring and examining health status of labors. In addition, this regulation requires the employers to adjust shift time on the basis of weather forecasting and pay high-temperature subsidies to workers during hot days. More importantly, once diagnosed as occupational disease due to occupational heat exposure, labors have every right to enjoy the treatments of industrial injury insurance regulations. However, to the best of our knowledge, until now there is no research on how AMHP2012 is implemented and whether it has an effect on protecting occupational health.

11.6.2 Heat-Health Warning Systems

Heat-health warning systems (HHWSs) were developed to cope with impending hazardous hot weather and to provide advice on protecting health from extreme heat evens [70]. The HHWSs have been widely deployed in many areas around the world [71, 72]. The operation of an HHWS involves local weather forecasting and extreme weather identification, the determination of specific and sensitive trigger threshold, risk communication, and action recommendation [61, 73, 74].

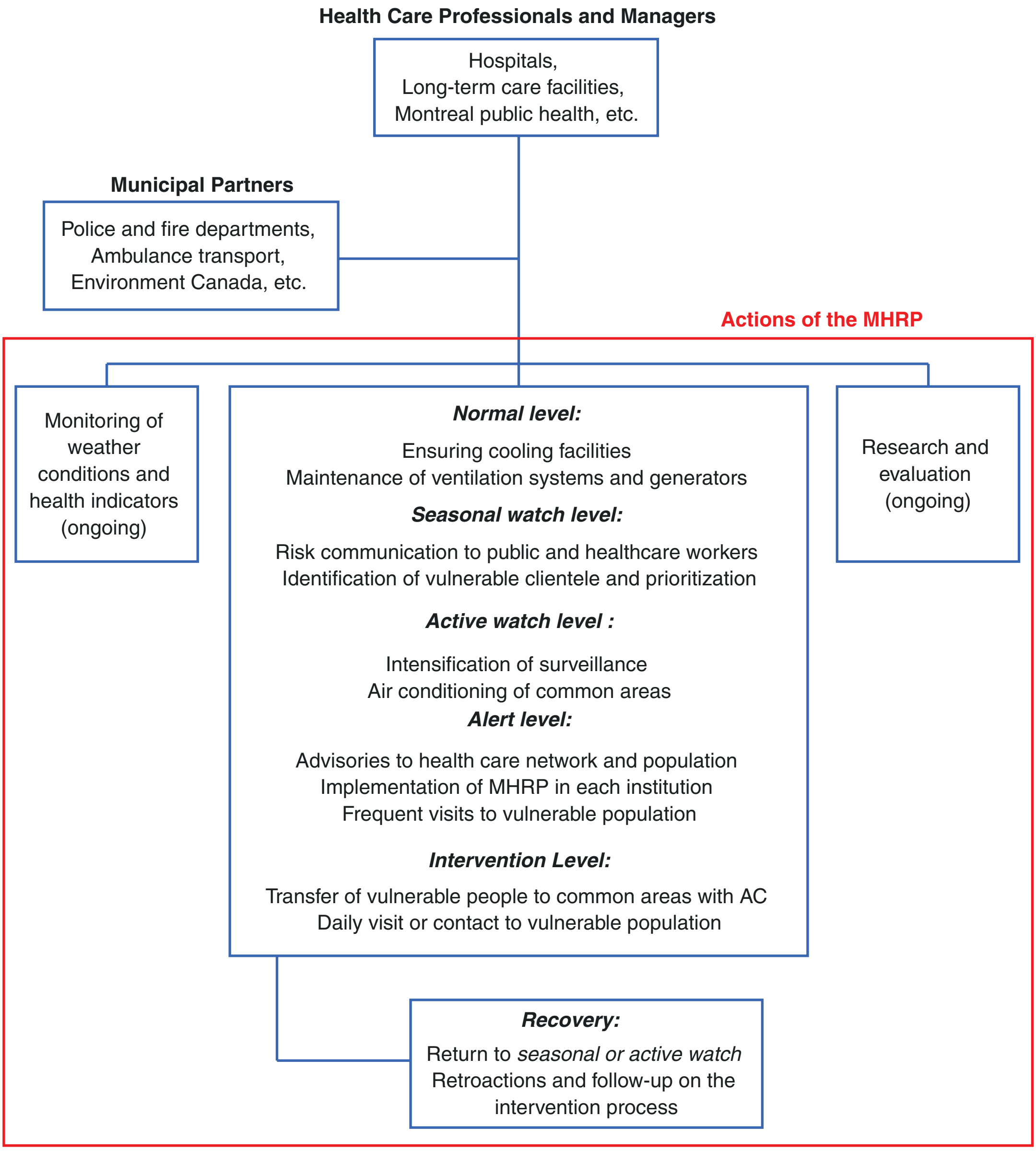


Fig. 11.6 Logic model for the Montreal heat response plan (MHRP). Adapted from Price et al. [69]

Figure 11.7 shows the typical process within an HHWS. The standard for triggering warnings varies based upon differential nature of heat-health relationships in different local scales. Defining accurate locally specific temperature thresholds is particularly significant for issuing heat warnings, as well as timely risk communication and public health interventions [70]. In many settings, prediction of health consequence due to heat waves is feasible basing on developed associations between extreme heat events and adverse health outcomes [76]. An effective HHWS would inform the public on how to achieve health protection and stay safe during extremely hot days.

In China, HHWSs have been set up in several cities such as Shanghai, Nanjing, and Harbin. According to the stipulations of the National Emergency Response Plan for Public Health Emergencies released by the State Council of China in 2006, China has a four-tier warning

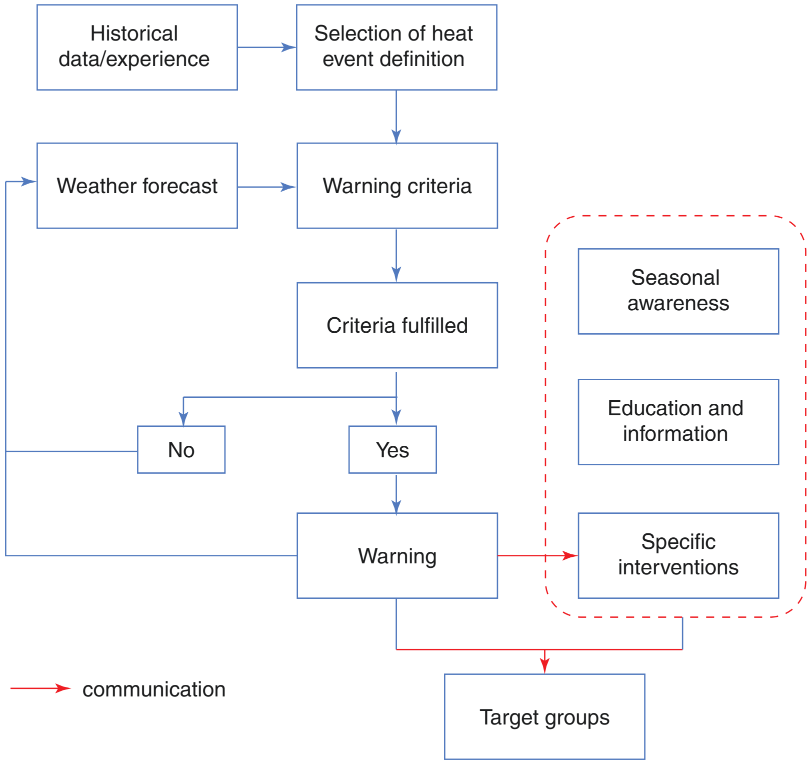


Fig. 11.7 Flow diagram displaying the operation of a typical heat-health warning systems. Adapted from Kalkstein [75]

including extremely serious, serious, major, and ordinary levels. Red alert represents the most severe, followed by orange, yellow, and blue alert. In Shanghai, HHWS was established in 2001 and is triggered when air mass with higher mortality level is predicted [77]. A series of operations, such as risk dissemination through various media, health education, mobilization of medical and public services, and maintenance of water and cooling facilities, are performed by the Shanghai Municipal Health Bureau, in collaboration with other supporting agencies. Compared with 1998 heat wave, it is suggested that the successful implementation of HHWS in Shanghai was responsible for lower mortality in the 2003 heat wave [66].

11.6.3 Risk Communication and Behavior Change

It is difficult for institutional arrangement to achieve an effective response to heat events without individual participation. The public should know what heat waves are, which health effects of heat waves they may be sensitive to, and what actions they can take to protect themselves from heat events [61]. However, a unique challenge in risk communication about heat waves exists in public health campaign due to the following reasons [34]. First, unlike other disasters, heat waves are less sudden and dramatic. Second, the hazards posed by heat waves gradually aggravate as the exposure duration extends, because the ability of a person to tolerate excessive high temperature will gradually diminish. Moreover, one's perceived threats to heat waves also gradually diminish with the duration of heat waves, and this will lead to demotivation of adaptive behaviors.

Fundamentally, whether risk communication and other interventions lead to changes in individual behavior is the key to determining whether public health can successfully prevent heat-related mortality and morbidity [34]. Although extremely high temperatures could be lethal, the public is not well aware of the dangers of heat exposure. Many people at risk do not know their dangerous situation or are reluctant to take coun-

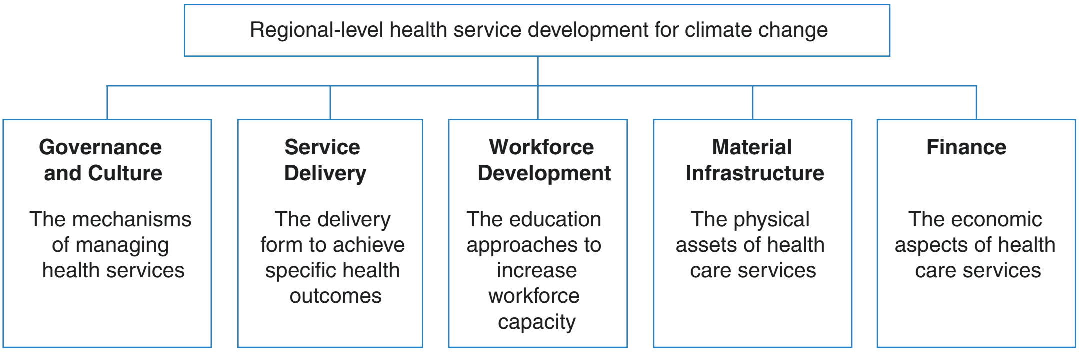


Fig. 11.8 Definition of a whole-of-systems approach to developing health services for climate change. Adapted from Bell [84]

termeasures [78]. Some people might have knowledge about heat risks, but their knowledge of adaptive behavior is limited [79]. Additionally, economic factors can hinder adaptive behaviors. For those who live on a fixed income or with low social economic status, air-conditioning cooling during high temperatures means a big economic burden, and many of them would rather tolerate with heat waves than pay for air-conditioning. Worse still, some of them do not even have any cooling facilities in their home [80].

Therefore, a sound and concrete risk communication and public education program are necessary, especially in transforming risk perception into behavioral adaptation. Public health activities should not only raise general awareness of heat waves but also offer practical advice and indeed help [61]. The World Health Organization recommends that risk communication should actively reach out to vulnerable groups, constantly pay attention to their health status, and provide them with advice on heatstroke prevention and cooling, instead of just distributing brochures [74].

11.6.4 Provision of Healthcare and Social Services

A heat warning system alone will not save lives without effective interventions and services that are prompted by the warning. The delivery of healthcare services is challenged in summer especially during extreme heat events, when it is necessary to achieve maximum coverage of the population, reaching the poor and socially vulnerable [61]. Working in hot environments can potentially threat the health of workforces as well. Health workers may be reluctant to work when a severe heat wave comes, although the situations will harm their own health and safety. Such reluctance will further exert pressure on healthcare system, which is already overcrowded and stretched [81]. Therefore, hospitals, emergency centers, and public health system should consider to hiring more health workers and increase their work shifts during hot days.

Social isolation and other adverse social factors can further deteriorate vulnerability to heat [82, 83], and the health sector should take them into consideration. Healthcare delivery should match to the demands of the most vulnerable populations by the collaboration among health sectors, social departments, and other community-based organizations. The most appropriate plan is to recognize the most advisable and suitable choices on the basis of the structure of local healthcare and social service systems [61, 74]. Bell [84] suggested a whole-of-systems approach for climate change including five areas or domains of health services: governance and culture, service delivery, workforce development, material infrastructure, and finance (Fig. 11.8). This approach may provide a useful framework in terms of involving a wide range of health and community services that could feasibly be part of government or community responses to heat waves.

11.6.5 Heat Exposure Reduction

Reducing personal heat exposure is an important protection measure during extreme hot days. Due to the limitation of physiological adaption capacities, there is a limit to the extent of heat exposure that one can bear with [74, 83, 85]. Staying in cool place can strongly protect population from heat-related illnesses and deaths [34]. Strategies include access to natural ventilation, air-conditioning, and cooling centers.

Natural ventilation, including using fans or opening window, is a long-standing strategy to reduce heat exposure. However, Ravanelli et al. [86] suggested that working fans are less effective and even harmful when the ambient temperature or relative humidity (RH) exceeds a certain limit (e.g., upper limits were 80% relative humidity at 37 °C or 50% relative humidity at 42 °C in the USA). This might because without air-conditioning, fans were actually circulating hot air rather than cool air. Beyond the threshold, fans may increase heat stress by evaporating sweat and blowing hot air over the skin.

Air-conditioning has been proved to reduce heat-related mortality effectively. Previous studies revealed that heat mortality decreased with household air-conditioning widespread in Chinese cities [66, 87]. However, some researchers oppose the frequently use of air-conditioning. For one reason, air-conditioners emit waste heat to outdoor environment during operation. Ohashi et al. [88] estimated the waste heat causing a higher temperature in Tokyo office areas by 1–2 °C or more on weekdays. For the other reason, relying on air-conditioners may actually increase population vulnerability. Once blackout occurs and air-conditioning is not available, individuals who have come to depend on it may have trouble getting through heat waves by other means. Lin et al. [89] found a stronger adverse effect of the blackout in New York City in 2003 than on comparable hot days.

Access to cooling centers is another efficient way to reduce heat exposure [48]. In China, cooling centers have been set up by the Office of Civil Air Defense since the twenty-first century. A total of 153 cooling centers built in Henan Province can accommodate 210,000 people at a time. Centers will open from July to September during daytime or be available to the public when daily temperature exceeds the maximum daytime temperature of 35 °C or the minimum nighttime temperature of 28 °C. Centers are equipped with air-conditioning, drinking water, first aid medicines, recreational facilities, and even Wi-Fi in certain centers. However, there are barriers to access cooling centers, including concerns about pet care issues, inconvenient or unaffordable transportation, and loneliness of leaving home [29]. Among these concerns, transportation is raised as both resource and barrier to cooler places. An underlying concern is that public transportation may fail to send people to centers directly; waiting at bus stop outside can even increase heat exposure, thus acting as a barrier to reaching cooling sites.

11.6.6 Urban Planning for Cool City

The urban heat island is a phenomenon that urban regions experience warmer temperatures than surrounding areas due to the rapid urbanization. However, appropriate planning, such as "cool city" initiatives, could assist in reducing vulnerability, establishing resilience and promoting health [90]. The cool city initiatives are drawing more attention for their potentialities to decrease morbidity and mortality of heat-related diseases; lower energy consumption, greenhouse gas emissions, and air-conditioner use; and potentially enhance population health status. Strategies include optimizing building design, building parks, and green spaces.

Optimizing building construction is one of the main strategies to achieve cool city initiatives. Strategies for better building construction include two categories: increasing evapotranspiration and albedo. Increasing evapotranspiration is accomplished through green roofs to cool inside by the evaporation of water from vegetations. Increasing albedo is usually achieved by high reflectivity and light-colored materials on roofs, which can increase building reflectivity, acting as a barrier to outside heat [61].

Tree planting is commonly used to build shaded space in urban areas. Seeking shade is one of the main adaptive behaviors that people take when they are outdoor [91, 92]. Trees have multiple roles, for example, blocking solar radiation, purifying the air, and providing venues of outdoor sports and social and cultural activities [93, 94]. Yan et al. [95] demonstrated the significant cooling effects of a large urban park, and the cooling effects could expand to surrounding areas (Fig. 11.9). Besides improving thermal comfort, providing access to green spaces can

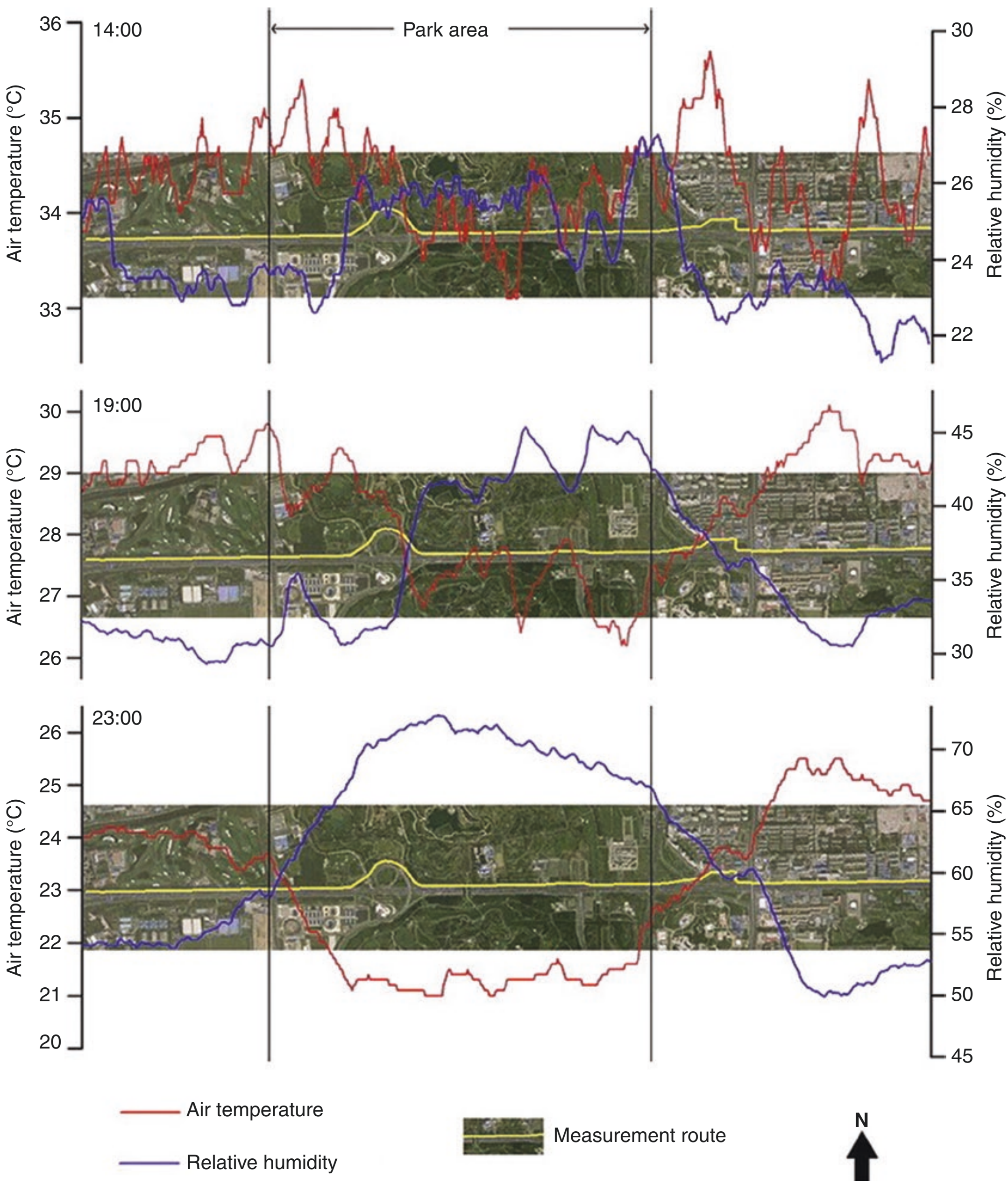


Fig. 11.9 Distribution pattern of temperature and humidity inside and outside the park in Beijing, China (Reproduced with permission from Yan et al. [95] (https://doi.org/10.1016/j.scitotenv.2017.11.327))

help promote public physical activity and social communications [96, 97]. Moderate-intensity physical activities have been demonstrated to decrease all-cause mortality; morbidity of chronic noncommunicable diseases such as cardio-cerebral vascular disease, diabetes, overweight, and obesity; as well as mortality and morbidity of cancer [98, 99].

11.6.7 Vulnerability Mapping

Vulnerability to heat is conceptualized to reflect population heat exposure and their sensitivity. Vulnerability mapping is an emerging research field to characterize the population vulnerability, aiming at preventing heat-related health effects among vulnerable groups. Since not all populations have the same health risk from heat exposure, it is necessary to highlight areas with elevated vulnerability and identify the location of vulnerable people. Specific interventions can then be designed, which can help the government target their resources more efficiently and effectively. Recognizing community-level heat vulnerability not only gathers evidence from epidemiological studies on individual-level susceptibility factors, it also provides information about neighborhood characteristics, thereby enabling more informed preventive actions. A national map of district-level heat vulnerability allows the government to situate vulnerable people to heat exposure and identify areas most in need of intervention.

Wolf et al. [100] suggested four steps to develop a vulnerability map. First, vulnerability values are calculated through a variance-weighted approach. Second, values are mapped at a fine spatial scale. Third, classify and identify the spatial cluster regions where vulnerability may occur. Last, it is necessary to assess the degree to which areas of high heat vulnerability coincide with possible areas of high heat exposure. In China, 1 previous study reported the spatial heterogeneity of social vulnerability to heat waves among 124 counties/districts of Guangdong Province [101]. Even a small-scale district shows a great variation in vulnerability, which is inconsistent with the general distribution of vulnerability index in the whole province. This inconsistency would be due to the differences in economic development levels in different districts, where well-developed economy region shows low social vulnerability to heat waves (Fig. 11.10). This finding indicates the importance and necessity of taking city-specific social and economic characteristics into consideration for vulnerability evaluation.

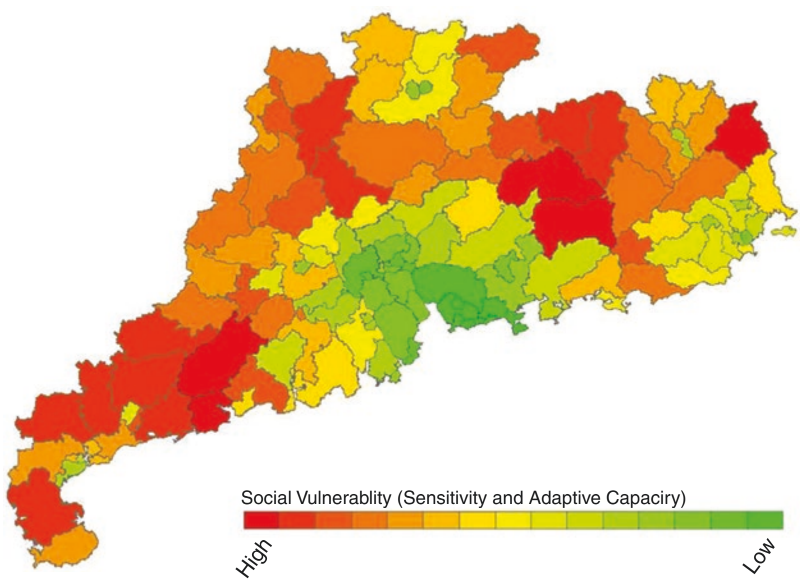


Fig. 11.10 Social vulnerability to heat waves in Guangdong Province, China. Sourced from an Open Access article: [101]. (https://doi.org/10.3402/gha.v7.25051)

11.6.8 Surveillance, Monitoring, and Evaluation

Real-time surveillance systems can be used to detect heat-related health threats in early stage and inform health policy-makers about upcoming outbreaks of adverse health impacts due to the heat waves. The most useful real-time data are mortality data, ambulance calls, emergency department visits, and general practitioner records. Among these, mortality data can provide detailed information about the impacts of heat events, acting as an important source. The lesson learned from heat wave in Europe during the 2003 indicated that timely feedback is essential for health sectors. Emergency department data may provide information about the nonfatal diseases that are susceptible to the heat. Ambulance calls can provide the most timely information, because of their sensibility to extreme heat [74, 102]. There is also a demand to design efficient syndromic surveillance systems to promoting public health responses to heat events [103]. Syndromic surveillance is the procedure of near real-time collection, analysis, interpretation, and communication of health-related data. However, health data for surveillance need to be readily available because the mortality and morbidity may increase rapidly after heat exposure [103]. These indicators could be taken into account as a public health "sentinel" indicator for triggering suitable interventions and eventually preventing adverse outcomes [12]. Long-term records of syndromic surveillance data can contribute to the development and improvement of interventions focused on vulnerable populations.

Monitoring and evaluation can promote identification of the most efficient interventions, both in country and local scale and barriers to implementation. For the adjustment of existing adaptation strategies, the iterative process can be followed based on continuous monitoring and evaluation (Fig. 11.11). Epidemiology is a key approach to build the knowledge base for developing, implementing, and evaluating the effectiveness of public health adaptation to heat. However, evaluation of existing policies or measures is difficult because of the following reasons. Firstly, it may be due to the regional disparity and time variation. Secondly, it is impossible to design a perfect study that takes all potential confounders into consideration. Randomized trials are usually infeasible for ethical and organizational reasons. In the meanwhile, observational studies have vital limitations because it is difficult to identify an appropriate control population and assess the appropriate type of intervention. Nevertheless, from both epidemiological and public health viewpoints, it is necessary to describe the changes occurring in the heat-health relationship over time. This information would assist policy-makers in making evidence-based choices, in order to better allocate available resources and direct future research questions.

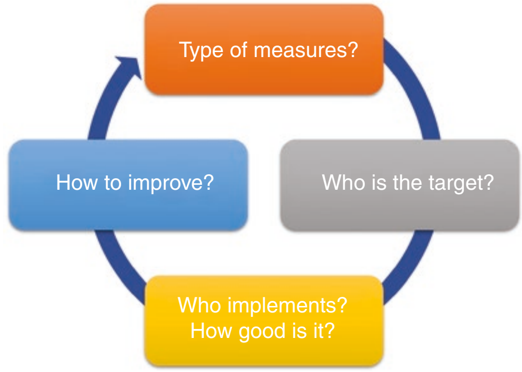


Fig. 11.11 The iterative process for the development and assessment of public health adaptation strategies. Adapted from WHO [74]

11.7 Conclusions

With more severe heat waves projected in the near future, evidence-based health protection measures by the general public and health professionals will play an important role in reducing heat-related disease burden. Planned adaptation strategies are becoming an increasing necessity for China to address the adverse health effects of extreme heat events. Heat vulnerability and adaptation assessments can highlight the significant gaps in understanding and managing the health impacts of heat waves in a changing climate.

Acknowledgement This work was supported by the National Key R&D Program of China (grant number 2018YFA0606200), the Natural Science Foundation of Guangdong Province (grant number 2016A030313216), the Asia-Pacific Network for Global Change (grant number CRRP2016-10MYSG02-Huang), and the Natural Science Foundation of Guangdong Province, China (grant number 2017A030310249).

References

1. Horton RM, Mankin JS, Lesk C, Coffel E, Raymond C. A review of recent advances in research on extreme heat events. Curr Clim Change Rep. 2016;2:242–59.
2. Steadman RG. A universal scale of apparent temperature. J Clim Appl Meteorol. 1984;23:1674–87.
3. IPCC. Climate change 2014: synthesis report. In: Contribution of working groups I, II and III to the fifth assessment report of the intergovernmental panel on climate change. Geneva: IPCC; 2014.
4. Fischer EM, Knutti R. Anthropogenic contribution to global occurrence of heavy-precipitation and high-temperature extremes. Nat Clim Chang. 2015;5:560.
5. Vimal M, Auroop RG, Bart N, Dennis PL. Changes in observed climate extremes in global urban areas. Environ Res Lett. 2015;10:024005.
6. Luo Y, Qin D, Zhang R, Wang S, Zhang D. Climatic and environmental changes in China. In: Qin D, Ding Y, Mu M, editors. Climatic and environmental change in China: 1951-2012. New York: Springer Environmental Science and Engineering; 2016.
7. Bailey M, Esposito C, Clark B, Foster C, Goeken D, Hanel J, Johnson E, Schmitt S. Colorado's climate and Colorado's health examining the connection. Denver: Courtesy of the Colorado Health Institute; 2017.
8. Gasparrini A, Guo Y, Hashizume M, Lavigne E, Zanobetti A, Schwartz J, Tobias A, Tong S, Rocklöv J, Forsberg B, Leone M, De Sario M, Bell ML, YLL G, Wu CF, Kan H, Yi SM, de Sousa Zanotti Stagliorio Coelho M, PHN S, Honda Y, Kim H, Armstrong B. Mortality risk attributable to high and low ambient temperature: a multicountry observational study. Lancet. 2015;386:369–75.
9. Gasparrini A, Guo Y, Hashizume M, Lavigne E, Zanobetti A, Schwartz J, Tobias A, Tong S, Rocklov J, Forsberg B, Leone M, De Sario M, Bell ML, Guo YL, Wu CF, Kan H, Yi SM, de Sousa Zanotti Stagliorio Coelho M, Saldiva PH, Honda Y, Kim H, Armstrong B. Mortality risk attributable to high and low ambient temperature: a multicountry observational study. Lancet. 2015;386:369–75.
10. Margolis HG. Heat waves and rising temperatures: human health impacts and the determinants of vulnerability. In: Pinkerton KE, Rom WN, editors. Global climate change and public health. New York: Springer; 2014. p. 85–120.
11. Huang C, Barnett AG, Wang X, Tong S. Effects of extreme temperatures on years of life lost for cardiovascular deaths: a time series study in Brisbane, Australia. Circ Cardiovasc Qual Outcomes. 2012;5:609–14.
12. Kravchenko J, Abernethy AP, Fawzy M, Lyerly HK. Minimization of heatwave morbidity and mortality. Am J Prev Med. 2013;44:274–82.
13. Li M, Gu S, Bi P, Yang J, Liu Q. Heat waves and morbidity: current knowledge and further direction-a comprehensive literature review. Int J Environ Res Public Health. 2015;12:5256–83.
14. Basu R, Pearson D, Malig B, Broadwin R, Green R. The effect of high ambient temperature on emergency room visits. Epidemiology. 2012;23:813–20.
15. Kovats RS, Hajat S, Wilkinson P. Contrasting patterns of mortality and hospital admissions during hot weather and heat waves in greater London, UK. Occup Environ Med. 2004;61:893–8.
16. Ye X, Wolff R, Yu W, Vaneckova P, Pan X, Tong S. Ambient temperature and morbidity: a review of epidemiological evidence. Environ Health Perspect. 2012;120:19–28.
17. Gu S, Huang C, Bai L, Chu C, Liu Q. Heat-related illness in China, summer of 2013. Int J Biometeorol. 2016;60:131–7.
18. Kan H. Climate change and human health in China. Environ Health Perspect. 2011;119:A60–1.
19. Petkova EP, Morita H, Kinney PL. Health impacts of heat in a changing climate: how can emerging science inform urban adaptation planning? Curr Epidemiol Rep. 2014;1:67–74.
20. Gronlund CJ. Racial and socioeconomic disparities in heat-related health effects and their mechanisms: a review. Curr Epidemiol Rep. 2014;1:165–73.
21. Kjellstrom T, Briggs D, Freyberg C, Lemke B, Otto M, Hyatt O. Heat, human performance, and occupational health: a key issue for the assessment of global climate change impacts. Annu Rev Public Health. 2016;37:97–112.
22. Charbotel B, Fervers B, Droz JP. Occupational exposures in rare cancers: a critical review of the literature. Crit Rev Oncol Hematol. 2014;90:99–134.
23. Beck N, Balanay JAG, Johnson T. Assessment of occupational exposure to heat stress and solar ultraviolet radiation among groundskeepers in an eastern North Carolina university setting. J Occup Environ Hyg. 2018;15:105–16.
24. Gubernot DM, Anderson GB, Hunting KL. Characterizing occupational heat-related mortality in the United States, 2000-2010: an analysis using the census of fatal occupational injuries database. Am J Ind Med. 2015;58:203–11.
25. Bartlett S, Larrieu S, Carcaillon L, Lefranc A, Helmer C, Dartigues J, Tavernier B, Ledrans M, Filleul L, Bonauto D, Anderson R, Rauser E, Burke B. Climate change and urban children: impacts and implications for adaptation in low- and middle-

income countries factors associated with morbidity during the 2003 heat wave in two population-based cohorts of elderly subjects: Paquid and three city occupational heat illness in Washington state, 1995-2005. Environ Urban. 2008;20:501–19.
26. Knowlton K, Rotkin-Ellman M, King G, Margolis HG, Smith D, Solomon G, Trent R, English P. The 2006 California heat wave: impacts on hospitalizations and emergency department visits. Environ Health Perspect. 2009;117:61–7.
27. Lee S, Lee H, Myung W, Kim EJ, Kim H. Mental disease-related emergency admissions attributable to hot temperatures. Sci Total Environ. 2018;616–617:688–94.
28. Thomas CL. Fatal isolation: the devastating Paris heat wave of 2003, by Richard C. Keller. Psychiatry. 2016;79:180–3.
29. Sampson NR, Gronlund CJ, Buxton MA, Catalano L, White-Newsome JL, Conlon KC, O'Neill MS, McCormick S, Parker EA. Staying cool in a changing climate: reaching vulnerable populations during heat events. Glob Environ Chang. 2013;23:475–84.
30. Crandall CG, Gonzalez-Alonso J. Cardiovascular function in the heat-stressed human. Acta Physiol (Oxf). 2010;199:407–23.
31. Arbuthnott KG, Hajat S. The health effects of hotter summers and heat waves in the population of the United Kingdom: a review of the evidence. Environ Health. 2017;16:119.
32. Hopp S, Dominici F, Bobb JF. Medical diagnoses of heat wave-related hospital admissions in older adults. Prev Med. 2018;110:81–5.
33. Wang Q, Li C, Guo Y, Barnett AG, Tong S, Phung D, Chu C, Dear K, Wang X, Huang C. Environmental ambient temperature and blood pressure in adults: a systematic review and meta-analysis. Sci Total Environ. 2017;575:276–86.
34. Luber G, McGeehin M. Climate change and extreme heat events. Am J Prev Med. 2008;35:429–35.
35. Stollberger C, Lutz W, Finsterer J. Heat-related side-effects of neurological and non-neurological medication may increase heatwave fatalities. Eur J Neurol. 2009;16:879–82.
36. Sommet A, Durrieu G, Lapeyre-Mestre M, Montastruc JL, Ctr AFP. A comparative study of adverse drug reactions during two heat waves that occurred in France in 2003 and 2006. Pharmacoepidemiol Drug Saf. 2012;21:285–8.
37. Zhao L, Lee X, Smith RB, Oleson K. Strong contributions of local background climate to urban heat islands. Nature. 2014;511:216–9.
38. Laaidi K, Zeghnoun A, Dousset B, Bretin P, Vandentorren S, Giraudet E, Beaudeau P. The impact of heat islands on mortality in Paris during the august 2003 heat wave. Environ Health Perspect. 2012;120:254–9.
39. Madrigano J, Ito K, Johnson S, Kinney PL, Matte T, Parsons K. A case-only study of vulnerability to heat wave-related mortality in New York city (2000-2011) human thermal environments: the effects of hot, moderate, and cold environments on human health, comfort, and performance. Environ Health Perspect. 2015;123:672–8.
40. Sheng R, Li C, Wang Q, Yang L, Bao J, Wang K, Ma R, Gao C, Lin S, Zhang Y, Bi P, Fu C, Huang C, Liu X, Song Y, Yi W, Wang X, Zhu J. Does hot weather affect work-related injury? A case-crossover study in Guangzhou, China comparing the random forest with the generalized additive model to evaluate the impacts of outdoor ambient environmental factors on scaffolding construction productivity. Int J Hyg Environ Health. 2018;221:423–8.
41. Zhou L, Dickinson RE, Tian Y, Fang J, Li Q, Kaufmann RK, Tucker CJ, Myneni RB. Evidence for a significant urbanization effect on climate in China. Proc Natl Acad Sci U S A. 2004;101:9540–4.
42. Curriero FC, Heiner KS, Samet JM, Zeger SL, Strug L, Patz JA. Temperature and mortality in 11 cities of the eastern United States. Am J Epidemiol. 2002;155:80–7.
43. Chan EYY, Goggins WB, Kim JJ, Griffiths SM. A study of intracity variation of temperature-related mortality and socioeconomic status among the Chinese population in Hong Kong. J Epidemiol Community Health. 2012;66:322–7.
44. Zhang Y, Nitschke M, Krackowizer A, Dear K, Pisaniello D, Weinstein P, Tucker G, Shakib S, Bi P. Risk factors of direct heat-related hospital admissions during the 2009 heatwave in Adelaide, Australia: a matched case–control study. BMJ Open. 2016;6:e010666.
45. Xu Y, Dadvand P, Barrera-Gomez J, Sartini C, Mari-Dell'Olmo M, Borrell C, Medina-Ramon M, Sunyer J, Basagana X. Differences on the effect of heat waves on mortality by sociodemographic and urban landscape characteristics. J Epidemiol Community Health. 2013;67:519–25.
46. Larrieu S, Carcaillon L, Lefranc A, Helmer C, Dartigues JF, Tavernier B, Ledrans M, Filleul L. Factors associated with morbidity during the 2003 heat wave in two population-based cohorts of elderly subjects: Paquid and three city. Eur J Epidemiol. 2008;23:295–302.
47. Zanobetti A, O'Neill MS, Gronlund CJ, Schwartz JD. Susceptibility to mortality in weather extremes: effect modification by personal and small-area characteristics. Epidemiology. 2013;24:809–19.
48. Bouchama A, Dehbi M, Mohamed G, Matthies F, Shoukri M, Menne B. Prognostic factors in heat wave related deaths: a meta-analysis. Arch Intern Med. 2007;167:2170–6.
49. Dosio A, Mentaschi L, Fischer EM, Wyser K. Extreme heat waves under 1.5 °C and 2 °C global warming. Environ Res Lett. 2018;13:054006.
50. Sun Y, Zhang X, Zwiers FW, Song L, Wan H, Hu T, Yin H, Ren G. Rapid increase in the risk of extreme summer heat in eastern China. Nat Clim Chang. 2014;4:1082–5.

51. United Nations DoEaSA, Population Division (2018). 2018. World urbanization prospects: the 2018 revision.
52. Heaviside C, Vardoulakis S, Cai XM. Attribution of mortality to the urban heat island during heatwaves in the west midlands, UK. Environ Health. 2016;15(Suppl 1):27.
53. Yang J, Siri JG, Remais JV, Cheng Q, Zhang H, Chan KKY, Sun Z, Zhao Y, Cong N, Li X, Zhang W, Bai Y, Bi J, Cai W, Chan EYY, Chen W, Fan W, Fu H, He J, Huang H, Ji JS, Jia P, Jiang X, Kwan M-P, Li T, Li X, Liang S, Liang X, Liang L, Liu Q, Lu Y, Luo Y, Ma X, Schwartländer B, Shen Z, Shi P, Su J, Wu T, Yang C, Yin Y, Zhang Q, Zhang Y, Zhang Y, Xu B, Gong P. The Tsinghua—Lancet Commission on healthy cities in China: unlocking the power of cities for a healthy China. Lancet. 2018;391:2140–84.
54. United Nations DoEaSA, Population Division (2017). 2017. World population prospects: the 2017 revision.
55. Sherwood SC, Huber M. An adaptability limit to climate change due to heat stress. Proc Natl Acad Sci U S A. 2010;107:9552–5.
56. Hawks J, Wang ET, Cochran GM, Harpending HC, Moyzis RK. Recent acceleration of human adaptive evolution. Proc Natl Acad Sci U S A. 2007;104:20753–8.
57. Kjellstrom T, Holmer I, Lemke B. Workplace heat stress, health and productivity—an increasing challenge for low and middle-income countries during climate change. Glob Health Action. 2009;2:46–51.
58. Zander KK, Botzen WJW, Oppermann E, Kjellstrom T, Garnett ST. Heat stress causes substantial labour productivity loss in Australia. Nat Clim Chang. 2015;5:647.
59. McMichael AJ, Dear KB. Climate change: heat, health, and longer horizons. Proc Natl Acad Sci U S A. 2010;107:9483–4.
60. Huang C, Vaneckova P, Wang X, Fitzgerald G, Guo Y, Tong S. Constraints and barriers to public health adaptation to climate change: a review of the literature. Am J Prev Med. 2011;40:183–90.
61. Huang C, Barnett AG, Xu Z, Chu C, Wang X, Turner LR, Tong S. Managing the health effects of temperature in response to climate change: challenges ahead. Environ Health Perspect. 2013;121:415–9.
62. Bernard SM, McGeehin MA. Municipal heat wave response plans. Am J Public Health. 2004;94:1520–2.
63. Matthies F, Menne B. Prevention and management of health hazards related to heatwaves. Int J Circumpolar Health. 2009;68:8–22.
64. Chau PH, Chan KC, Woo J. Hot weather warning might help to reduce elderly mortality in Hong Kong. Int J Biometeorol. 2009;53:461–8.
65. Fouillet A, Rey G, Wagner V, Laaidi K, Empereur-Bissonnet P, Le Tertre A, Frayssinet P, Bessemoulin P, Laurent F, De Crouy-Chanel P, Jougla E, Hemon D. Has the impact of heat waves on mortality changed in France since the European heat wave of summer 2003? A study of the 2006 heat wave. Int J Epidemiol. 2008;37:309–17.
66. Tan J, Zheng Y, Song G, Kalkstein LS, Kalkstein AJ, Tang X. Heat wave impacts on mortality in Shanghai, 1998 and 2003. Int J Biometeorol. 2007;51:193–200.
67. Price K, Perron S, King N. Implementation of the Montreal heat response plan during the 2010 heat wave. Can J Public Health. 2013;104:e96–100.
68. Benmarhnia T, Bailey Z, Kaiser D, Auger N, King N, Kaufman JS. A difference-in-differences approach to assess the effect of a heat action plan on heat-related mortality, and differences in effectiveness according to sex, age, and socioeconomic status (Montreal, Quebec). Environ Health Perspect. 2016;124:1694–9.
69. Price K, Benmarhnia T, Gaudet J, Kaiser D, Sadoine ML, Perron S, Smargiassi A. The Montreal heat response plan: evaluation of its implementation towards healthcare professionals and vulnerable populations. Can J Public Health. 2018;109:108–16.
70. Hajat S, Sheridan SC, Allen MJ, Pascal M, Laaidi K, Yagouti A, Bickis U, Tobias A, Bourque D, Armstrong BG, Kosatsky T. Heat-health warning systems: a comparison of the predictive capacity of different approaches to identifying dangerously hot days. Am J Public Health. 2010;100:1137–44.
71. O'Neill MS, Ebi KL. Temperature extremes and health: impacts of climate variability and change in the United States. J Occup Environ Med. 2009;51:13–25.
72. Toloo GS, Fitzgerald G, Aitken P, Verrall K, Tong S. Are heat warning systems effective? Environ Health. 2013;12:27.
73. Lowe D, Ebi KL, Forsberg B. Heatwave early warning systems and adaptation advice to reduce human health consequences of heatwaves. Int J Environ Res Public Health. 2011;8:4623–48.
74. WHO. Improving public health responses to extreme weather/heat-waves: Euroheat: technical summary. Copenhagen: WHO Regional Office for Europe; 2009.
75. Kalkstein L. Heat health warning systems: definition and methodology. Geneva: WHO; 2012.
76. Gosling SN, Lowe JA, McGregor GR, Pelling M, Malamud BD. Associations between elevated atmospheric temperature and human mortality: a critical review of the literature. Clim Chang. 2009;92:299–341.
77. Tan J, Kalkstein LS, Huang J, Lin S, Yin H, Shao D. An operational heat/health warning system in Shanghai. Int J Biometeorol. 2004;48:157–62.
78. Lane K, Wheeler K, Charles-Guzman K, Ahmed M, Blum M, Gregory K, Graber N, Clark N, Matte T. Extreme heat awareness and protective behaviors in New York city. J Urban Health. 2014;91:403–14.
79. Sheridan SC. A survey of public perception and response to heat warnings across four North American cities: an evaluation of municipal effectiveness. Int J Biometeorol. 2007;52:3–15.

80. Stuart K, Mahmood MA, Clark L, Pace R. Health education and a co-ordinated response system to support vulnerable people during heat waves. Aust N Z J Public Health. 2011;35:394–5; discussion 395.
81. Smith E, Morgans A, Qureshi K, Burkle FM, Archer F. Paramedics' perceptions of risk and willingness to work during disasters. Aust J Emerg Manag. 2009;24(3):21–7.
82. Hajat S, Kosatky T. Heat-related mortality: a review and exploration of heterogeneity. J Epidemiol Community Health. 2010;64:753–60.
83. Kovats RS, Hajat S. Heat stress and public health: a critical review. Annu Rev Public Health. 2008;29:41–55.
84. Bell E. Readying health services for climate change: a policy framework for regional development. Am J Public Health. 2011;101:804–13.
85. Hajat S, O'Connor M, Kosatsky T. Health effects of hot weather: from awareness of risk factors to effective health protection. Lancet. 2010;375:856–63.
86. Ravanelli NM, Hodder SG, Havenith G, Jay O. Heart rate and body temperature responses to extreme heat and humidity with and without electric fans. JAMA. 2015;313:724.
87. Ma W, Chen R, Kan H. Temperature-related mortality in 17 large Chinese cities: how heat and cold affect mortality in China. Environ Res. 2014;134:127–33.
88. Ohashi Y, Genchi Y, Kondo H, Kikegawa Y, Yoshikado H, Hirano Y. Influence of air-conditioning waste heat on air temperature in Tokyo during summer: numerical experiments using an urban canopy model coupled with a building energy model. J Appl Meteorol Climatol. 2007;46:66–81.
89. Lin S, Fletcher BA, Luo M, Chinery R, Hwang SA. Health impact in New York city during the northeastern blackout of 2003. Public Health Rep. 2011;126:384–93.
90. Stone B, Hess JJ, Frumkin H. Urban form and extreme heat events: are sprawling cities more vulnerable to climate change than compact cities? Environ Health Perspect. 2010;118:1425–8.
91. Ahmed KS. Comfort in urban spaces: defining the boundaries of outdoor thermal comfort for the tropical urban environments. Energ Buildings. 2003;35:103–10.
92. Lin TP. Thermal perception, adaptation and attendance in a public square in hot and humid regions. Build Environ. 2009;44:2017–26.
93. Boone-Heinonen J, Casanova K, Richardson AS, Gordon-Larsen P. Where can they play? Outdoor spaces and physical activity among adolescents in U.S. urbanized areas. Prev Med. 2010;51:295–8.
94. van den Berg AE, Maas J, Verheij RA, Groenewegen PP. Green space as a buffer between stressful life events and health. Soc Sci Med. 2010;70:1203–10.
95. Yan H, Wu F, Dong L. Influence of a large urban park on the local urban thermal environment. Sci Total Environ. 2018;622–623:882–91.
96. Hunter RF, Christian H, Veitch J, Astell-Burt T, Hipp JA, Schipperijn J. The impact of interventions to promote physical activity in urban green space: a systematic review and recommendations for future research. Soc Sci Med. 2015;124:246–56.
97. Schipperijn J, Bentsen P, Troelsen J, Toftager M, Stigsdotter UK. Associations between physical activity and characteristics of urban green space. Urban For Urban Gree. 2013;12:109–16.
98. Monninkhof EM, Elias SG, Vlems FA, van der Tweel I, Schuit AJ, Voskuil DW, van Leeuwen FE, TFPAC. Physical activity and breast cancer: a systematic review. Epidemiology. 2007;18:137–57.
99. Woodcock J, Edwards P, Tonne C, Armstrong BG, Ashiru O, Banister D, Beevers S, Chalabi Z, Chowdhury Z, Cohen A, Franco OH, Haines A, Hickman R, Lindsay G, Mittal I, Mohan D, Tiwari G, Woodward A, Roberts I. Public health benefits of strategies to reduce greenhouse-gas emissions: urban land transport. Lancet. 2009;374:1930–43.
100. Wolf T, McGregor G. The development of a heat wave vulnerability index for London, United Kingdom. Weather Clim Extrem. 2013;1:59–68.
101. Zhu Q, Liu T, Lin H, Xiao J, Luo Y, Zeng W, Zeng S, Wei Y, Chu C, Baum S, Du Y, Ma W. The spatial distribution of health vulnerability to heat waves in Guangdong province, China. Glob Health Action. 2014;7:25051.
102. Turner LR, Connell D, Tong S. Exposure to hot and cold temperatures and ambulance attendances in Brisbane, Australia: a time-series study. BMJ Open. 2012;2:e001074.
103. Leonardi GS, Hajat S, Kovats RS, Smith GE, Cooper D, Gerard E. Syndromic surveillance use to detect the early effects of heat-waves: an analysis of NHS direct data in England. Soz Praventivmed. 2006;51:194–201.

12 Perspectives and Future Research Directions on Climate Change and Health in China

Wenjun Ma, Jianpeng Xiao, Xing Li, Tao Liu, Weilin Zeng, and Ruoxi Zhong

Abstract

Currently climate change is becoming a significant threat to human health. Though increasing evidence about climate change or variation has shown an adverse impact on human health in China, more deep researches are needed for climate change adaption in the future. Some research recommendations were identified in this chapter: (1) to identify health risk scope of climate change, (2) to investigate spatial heterogeneity of health risk from climate change, (3) to strengthen studies on health risk of climate-related disasters, (4) to explore mechanism of health risk caused by climate change, (5) to improve early warning capacity to climate change, (6) to enhance co-benefit assessment of climate change mitigation, and (7) to strengthen adaptation research of climate change.

Keywords

Climate change · Temperature · Human health · Further research · China

12.1 Introduction

The climate has certainly changed globally. The global temperature has raised by approximately 0.85 °C compared with 130 years ago [1]. The World Meteorological Organization reported that the average global temperature from 2013 to 2017 is the highest 5-year average on record, which is close to 1 °C above that from 1850 to 1900 [2]. It was projected that the global temperature could increase 1.5 °C by the end of the twenty-first century [1]. According to a report of the China Meteorological Administration, the surface temperature of China has risen by 0.24 °C every decade from 1951 to 2017, exceeding the global average temperature increase rate [3].

Global warming, precipitation changing, increasing frequency or intensity of extreme weather events, and sea level rising are one of the climate change impacts, which bring about direct and indirect impacts on the population health by affecting the elements necessary for living around us including food, water, air, and also the weather. In the past decade, rich evidence indicates that climate change or variation has threatened human health in China, including the increasing risks of mortality and morbidity from high temperatures,

W. Ma (✉) · T. Liu
Guangdong Provincial Institute of Public Health, Guangdong Provincial Center for Disease Control and Prevention, Guangzhou, China

General Practice Center, Nanhai Hospital, Southern Medical University, Foshan, China
e-mail: mawj@gdiph.org.cn

J. Xiao · X. Li · W. Zeng · R. Zhong
Guangdong Provincial Institute of Public Health, Guangdong Provincial Center for Disease Control and Prevention, Guangzhou, China

H. Lin et al. (eds.), *Ambient Temperature and Health in China*,
https://doi.org/10.1007/978-981-13-2583-0_12

extreme weather events happen more often, the air and water pollution become worse, and the ecology of infectious diseases may change [4]. The most vulnerable population such as children, the elderly, people living in poverty, outdoor workers, and those with underlying health conditions are at an increased health risk of climate change. Furthermore, several studies found that with the increase of aging population, the adverse health impacts from climate change may increase much in the future in China [5].

Although the studies on health impact assessment of climate change increase rapidly in China in recent years, most of them focus on the association of meteorological factors and few health outcomes such as mortalities. There are few studies that involved future health risk assessment, adaptation measure evaluation and co-benefits of climate mitigation, etc. Therefore, it is necessary to conduct deeper and wider researches to develop effective response strategies and measures to reduce the disease burden from climate change. Based on literature review and current research situation, future research directions in China are suggested as the following.

12.2 To Comprehensively Identify Health Risk of Climate Change in China

Human physical, mental, and community health are influenced by climate change [6]. In China, the health impact assessments of climate change are limited to some kinds of climate-sensitive diseases including cardiovascular diseases, respiratory diseases, and some infectious diseases [4]. Recent study found that the increasing heat stress has significant negative effects on occupational health [7]. For example, heat exposure may induce serious diseases (such as heatstroke, kidney disease, cardiovascular disease, and mental illness) among workers and reduce human performance and work capacity. Some studies indicated that extreme hot or cold temperatures experienced during pregnancy can increase the risks of gestational hypertension, preterm births, or low birth weight [8]. Several studies also reported that climate change may affect fresh and marine water resources, which could increase human exposure to waterborne diseases caused by bacteria or viruses [6]. In addition, some studies reported that rising temperature and extreme weather could not only limit our access to safe food but also impact the nutritional value of wheat and rice and other crops [9]. Threatened by climate change, many people may experience adverse mental health outcomes and social impacts, while people with mental illness can get higher risks for other diseases by extreme heat rising [9]. As there is still limited knowledge about the risk of these climate-sensitive diseases or health events in China, more large-scale studies based on multi-health outcomes are necessary to comprehensively identify the health risk scope of climate change in China.

12.3 To Investigate Spatial Heterogeneity of Health Risk from Climate Change in China

Climate change is a global phenomenon, but its impacts are quite heterogeneous across regions of the world. Climate change affects much on certain groups of population than others, depending on where they live and their ability to cope with different climate hazards. The varied and complicated terrain, climate, socioeconomic status, living habits, and local medical conditions [10] lead to a high spatial heterogeneity of climate health impact in China [11]. One example could be a rapid population growth in coastal areas and southern and eastern regions in China happened in recent years. These areas are more sensitive to heat wave, coastal storms, and flooding [12].

Previous study also found that minimum mortality temperature (MMT) increased from north to south in China, and there was a larger cold effect in southern China, while a significantly hot effect was identified in northern China [13]. However, most previous researches focused only on a single city or a small number of cities in China, and few studies have been conducted in economically underdeveloped regions such as western China where the population may get a higher risk of adverse health effects from climate change. Therefore, regional heterogeneity of health risks caused by climate variations or projected climate changes remains unclear in China, which will restrict climate change adaptation plan or measures implementation. Further health risk assessments and vulnerability studies based on multicenters to quantify the spatial distribution of health risk resulting from climate change or variation at the national level are urgently required.

12.4 To Strengthen Studies on the Health Risk of Climate-Related Disasters in China

In the past decades, the frequencies of extreme climate events have increased significantly [10, 14]. It was predicted that the occurrence and severity of extreme climate events including droughts and floods led by the extreme precipitation and tropical cyclone will continue to increase under different climate change scenarios [14]. Several types of extreme climate events can cause infrastructure disruption including power outage, water supply cutoff, and traffic congestion. The power, water, and transportation are essential to maintain people access to health care and emergency response services [9]. These extreme climate events may increase the risk of deaths, injuries, and diseases, exacerbate potential medical conditions, and aggravate impacts on mental health including post-traumatic stress disorder (PTSD) and depression [9]. Children, the elderly, women, the economically disadvantaged, and the homeless are vulnerable groups for these climate-related disasters.

China is one of the most natural disaster-affected countries [15]. However, most previous studies focused on the associations between climate variation and health outcome, and there are few studies on the health impact of extreme climate events such as droughts, floods, and typhoon in China. We suggest that more studies should have been encouraged to explore the health risk, vulnerable populations, and vulnerable regions of climate-related disasters in China.

12.5 To Explore the Mechanism of Health Risk Caused by Climate Change in China

At present, concerning the relationship between climate variables and health outcomes, most of the studies were conducted using ecological research methods [16]. Based on time series data, generalized additive model, case crossover design, distribution lag nonlinear model, and other statistical techniques are mostly used to investigate the association between weather factors and extreme weather events and multiple health outcomes such as mortality, morbidity, and infectious diseases [17, 18]. The future health risk assessment of climate change should be based on the dose-response relationship between existing meteorological factors and health outcomes. Therefore, the health risks of climate change will be estimated based on changes in meteorological factors under different climate change scenarios in the future [19].

The associations between climate variation and change and health outcomes could be estimated using ecological research designs, but these studies are limited to address the mechanism between exposure and response. What are the key elements, social process, or vulnerable factors of the health risks caused by climate variation or change? What is the driving force or transmission process of infectious disease outbreak? These are all the issues remaining unsolved. It is clear that the mechanisms can lay the foundation for the development of a spatiotemporal warning system to help in timely implementation of response measures for vulnerable groups in vulnerable areas, thereby reducing the health risk of extreme climate events and climate change.

12.6 To Improve Early Warning Capacity to Climate Change in China

Abnormal temperature fluctuations and prolonged maintenance often lead to high health risks [20, 21], such as increased frequency and intensity of extreme heat (heat wave) in summer, strong and persistent cold (cold spell) in winter, and sudden temperature fluctuation during the alternation of seasons. An accurate forecasting of extreme meteorological events or health weather index can greatly mitigate the human health risks. However, there are few studies on the early warning of the abnormality of the health-related meteorological factors. It would be a challenge to identify the key meteorological factors and their risk thresholds related to health. It is also not easy to capture the anomalous precursor signals of these meteorological factors at an early stage for climate response [22].

Previous studies demonstrated the association between diseases and climate variations, emphasizing the potential for climate-based early warning systems development [23]. However, the relationship between climate and diseases is likely to interact with many other factors. For example, the association between climate and infectious disease may include how pathogens adapt and change, the availability of hosts, changing ecosystems and land use, demographics, human behaviors, adaptive capacity, etc. [24]. Many previous studies on prediction were conducted without consideration of non-climatic confounding factors, limited geographical/temporal resolution, or insufficient evaluation of predictive validity. Involving more fine-scale data from various data sources (such as remote satellite, mobile cell and social network, and developing a feasible spatial-temporal prediction models for climate-sensitive diseases) could be a research direction in the future in China. For example, increasing daytime temperatures, reducing nighttime cooling, and exacerbating heat wave associated with urban heat islands could affect human health [25]. Fine spatiotemporal scale studies integrating demographics, environmental factors, and socioeconomic factors into prediction model are potential for developing an early warning system.

12.7 To Enhance Co-Benefit Assessment of Climate Change Mitigation in China

Assessing the health risks of climate change is an important step for public health institutes to cope with climate change. Although it can be done by using either qualitative or quantitative method, quantitative projections may provide more useful information [26]. In general, quantitative risk assessment requires prediction of (1) physical climate changes, (2) future socioeconomic features, and (3) the association between these factors and health outcome of interest [9]. Even though uncertainty occurs, the development of health risk assessment modeling technology strengthens our understanding of the quantitative climate change risks, such as the risk of temperature-related mortality [19] and vector-borne diseases [27] under climate change scenarios. However, most previous studies focused on present health impact assessment of climate variation based on historical data, and a limited number of studies are involved in the health risk projection of climate change in China because projection research is relatively complex [9]. Interdisciplinary research related to climate change projections to potential people health vulnerabilities needs to be further investigated.

Climate change was called as "the biggest global health threat in the twenty-first century," while adding that climate change response could be the greatest global opportunity of this century [28]. Research should concern about the estimating of the long-term health benefits from climate change mitigation [29]. In future decades, the anticipated benefits of successful climate change mitigation can tend to become important globally. These benefits may include (1) improving the air quality, especially reducing indoor or outdoor air pollution by popularizing clean energy generation, (2) promoting safe public transportation systems, and (3) reducing chronic diseases in the community by encouraging healthy lifestyles like walking and cycling. Except for health risk assessment of climate change, more resources should be motivated to focus on co-benefit research of mitigation measures of climate change.

12.8 To Strengthen Adaptation Research to Climate Change in China

Climate adaptation is crucial to help local communities to response extreme weather conditions and relative climatic variations [28]. Researchers need to provide more evidence for governments to build strategies and develop program against climate impact [30]. We need to develop, disseminate, and supervise the adaptation plan implementation and assess the effectiveness of current adaptation measures, including the costs and benefits of interventions. Research is warranted to enhance the public health system to respond to the threats of climate change, including maintenance of the water supplies and sanitation security; control of vector-borne diseases; and health education and health promotion, especially in the fields of thermal stress [28]. Furthermore, research on health risk communication of climate change should be strengthened [31]. Risk communication is one essential lifesaving action in public health emergencies. Effective risk communication could not only save lives but also reduce diseases. It can produce several great effects by developing suitable materials for risk communication and identifying the best way for communication during a climate-related emergency.

Acknowledgment This work was supported by the National Key Research and Development Program (2018YFA0606202).

References

1. Flato G, Marotzke J, Abiodun B, Braconnot P, Chou SC, Collins WJ, Cox P, Driouech F, Emori S, Eyring V. Evaluation of climate models. In: climate change 2013: the physical science basis. Contribution of working group I to the fifth assessment report of the intergovernmental panel on climate change. Clim Change. 2013;5:741–866.
2. World Meteorological Organization. WMO Statement on the State of the Global Climate 2017. 2018. https://library.wmo.int/opac/doc_num.php?explnum_id=4453.
3. China Meteorological Administration. China blue book on climate change. 2018. http://www.cma.gov.cn/2011xwzx/2011xqxxw/2011xqxyw/201804/t20180404_465788.html.
4. Kan H, Chen R, Tong S. Ambient air pollution, climate change, and population health in China. Environ Int. 2012;42:10–9.
5. Liang P, Xu W, Ma Y, Zhao X, Qin L. Increase of elderly population in the rainstorm hazard areas of China. Int J Environ Res Public Health. 2017;14(9):963.
6. USEPA. Climate impacts on human health. 2018. https://19january2017snapshot.epa.gov/climate-impacts/climate-impacts-human-health_.html.
7. Kjellstrom T, Briggs D, Freyberg C, Lemke B, Otto M, Hyatt O. Heat, human performance, and occupational health: a key issue for the assessment of global climate change impacts. Annu Rev Public Health. 2016;37:97–112.
8. Strand LB, Barnett AG, Tong S. The influence of season and ambient temperature on birth outcomes: a review of the epidemiological literature. Environ Res. 2011;111(3):451–62.
9. Crimmins A, Balbus J, Gamble J, Beard C, Bell J, Dodgen D, Eisen R, Fann N, Hawkins M, Herring S. The impacts of climate change on human health in the United States: a scientific assessment. Washington, DC: Global Change Research Program; 2016.
10. Zhou Y, Liu Y, Wu W, Li N. Integrated risk assessment of multi-hazards in China. Nat Hazards. 2015;78(1):257–80.
11. Ma W, Zeng W, Zhou M, Wang L, Rutherford S, Lin H, Liu T, Zhang Y, Xiao J, Zhang Y. The short-term effect of heat waves on mortality and its modifiers in China: an analysis from 66 communities. Environ Int. 2015;75:103–9.
12. Luo M, Lau N-C. Heat waves in southern China: synoptic behavior, long-term change, and urbanization effects. J Climate. 2017;30(2):703–20.
13. Ma W, Wang L, Lin H, Liu T, Zhang Y, Rutherford S, Luo Y, Zeng W, Zhang Y, Wang X. The temperature–mortality relationship in China: an analysis from 66 Chinese communities. Environ Res. 2015;137:72–7.
14. Thomas V, López R. Global increase in climate-related disasters. Asian Development Bank Economics Working Paper Series. 2015:466.
15. Gong D, Han H. Extreme climate events in northern China over the last 50 years. Acta Geogr Sin Chin. 2004;59(2):230–8.
16. Gasparrini A, Guo Y, Hashizume M, Lavigne E, Zanobetti A, Schwartz J, Tobias A, Tong S, Rocklöv J, Forsberg B. Mortality risk attributable to high and low

ambient temperature: a multicountry observational study. Lancet. 2015;386(9991):369–75.
17. Wu W, Xiao Y, Li G, Zeng W, Lin H, Rutherford S, Xu Y, Luo Y, Xu X, Chu C. Temperature–mortality relationship in four subtropical Chinese cities: a time-series study using a distributed lag non-linear model. Sci Total Environ. 2013;449:355–62.
18. Xiao J, Liu T, Lin H, Zhu G, Zeng W, Li X, Zhang B, Song T, Deng A, Zhang M. Weather variables and the El Niño Southern Oscillation may drive the epidemics of dengue in Guangdong Province, China. Sci Total Environ. 2018;624:926–34.
19. Gasparrini A, Guo Y, Sera F, Vicedo-Cabrera AM, Huber V, Tong S, Coelho MDSZS, Saldiva PHN, Lavigne E, Correa PM. Projections of temperature-related excess mortality under climate change scenarios. Lancet Planet Health. 2017;1(9):e360–7.
20. Luo Y, Zhang Y, Liu T, Rutherford S, Xu Y, Xu X, Wu W, Xiao J, Zeng W, Chu C. Lagged effect of diurnal temperature range on mortality in a subtropical megacity of China. PLoS One. 2013;8(2):e55280.
21. Xie H, Yao Z, Zhang Y, Xu Y, Xu X, Liu T, Lin H, Lao X, Rutherford S, Chu C. Short-term effects of the 2008 cold spell on mortality in three subtropical cities in Guangdong Province, China. Environ Health Perspect. 2013;121(2):210.
22. Tan J, Yuan D. A research perspective on weather-climate based health meteorological forecast. Huanjing yu Zhiye Yixue. 2012;29(3):129–31.
23. Sang S, Gu S, Bi P, Yang W, Yang Z, Xu L, Yang J, Liu X, Jiang T, Wu H. Predicting unprecedented dengue outbreak using imported cases and climatic factors in Guangzhou, 2014. PLoS Negl Trop Dis. 2015;9(5):e0003808.
24. Heesterbeek H, Anderson RM, Andreasen V, Bansal S, De Angelis D, Dye C, Eames KT, Edmunds WJ, Frost SD, Funk S. Modeling infectious disease dynamics in the complex landscape of global health. Science. 2015;347(6227):aaa4339.
25. USEPA. Heat island impacts. 2018. https://www.epa.gov/heat-islands/heat-island-impacts.
26. World Health Organization. Quantitative risk assessment of the effects of climate change on selected causes of death, 2030s and 2050s. Geneva: World Health Organization; 2014.
27. Ebi KL, Nealon J. Dengue in a changing climate. Environ Res. 2016;151:115–23.
28. Watts N, Adger WN, Agnolucci P, Blackstock J, Byass P, Cai W, Chaytor S, Colbourn T, Collins M, Cooper A. Health and climate change: policy responses to protect public health. Lancet. 2015;386(10006):1861–914.
29. Shahab S, Ghaffar A, Stearns B, Woodward A. Strengthening the base: preparing health research for climate change. Geneva: Global Forum for Health Research; 2008.
30. Marinucci GD, Luber G, Uejio CK, Saha S, Hess JJ. Building resilience against climate effects—a novel framework to facilitate climate readiness in public health agencies. Int J Environ Res Public Health. 2014;11(6):6433–58.
31. DeBono R, Vincenti K, Calleja N. Risk communication: climate change as a human-health threat, a survey of public perceptions in Malta. Eur J Publ Health. 2010;22(1):144–9.