



## Invited Review

# Health impact of climate change in cities of middle-income countries: the case of China

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## Abstract

**Background:** This review examines the human health impact of climate change in China. Through reviewing available research findings under four major climate change phenomena, namely extreme temperature, altered rainfall pattern, rise of sea level and extreme weather events, relevant implications for other middle-income population with similar contexts will be synthesized.

**Sources of data:** Sources of data included bilingual peer-reviewed articles published between 2000 and 2018 in PubMed, Google Scholar and China Academic Journals Full-text Database.

**Areas of agreement:** The impact of temperature on mortality outcomes was the most extensively studied, with the strongest cause-specific mortality risks between temperature and cardiovascular and respiratory mortality. The geographical focuses of the studies indicated variations in health risks and impacts of different climate change phenomena across the country.

**Areas of controversy:** While rainfall-related studies predominantly focus on its impact on infectious and vector-borne diseases, consistent associations were not often found.

**Growing points:** Mental health outcomes of climate change had been gaining increasing attention, particularly in the context of extreme weather events. The number of projection studies on the long-term impact had been growing.

**Areas timely for developing research:** The lack of studies on the health implications of rising sea levels and on comorbidity and injury outcomes warrants immediate attention. Evidence is needed to understand health impacts on vulnerable populations living in growing urbanized cities and urban enclaves, in particular migrant workers. Location-specific climate-health outcome thresholds (such as temperature-mortality threshold) will be needed to support evidence-based clinical management plans and health impact mitigation strategies to protect vulnerable communities.

**Key words:** climate change, China, health impact, temperature, extreme weather, urban

## Introduction

Climate change refers to ‘a change of climate which is attributable directly or indirectly to human activity that alters the composition of the global atmosphere and which is in addition to natural climate variability observed over comparable time periods’.<sup>1</sup> The 2015 Lancet Commission on Health and Climate Change concluded that the effects of climate change ‘represent an unacceptably high and potentially catastrophic risk to human health’.<sup>2</sup> The World Health Organization calls climate change ‘the defining issue for health systems in the 21st century’.<sup>3</sup> Through reviewing research findings of climate change-related health impact studies from China, a middle-income country that hosts a quarter of the global population, the findings will provide an overview of the current knowledge on the various health impacts of climate change on urban population, which may be applicable in other developing contexts.

The People’s Republic of China has a population of over 1.3 billion and is the second largest economy in the world, with urban population increased from 29% in 1995 to 56% in 2015.<sup>4</sup> By 2030, it is projected that over 1 billion people will be living in China’s urban areas.<sup>5</sup> The rapid urbanization and economic growth in China have brought not only significant reduction in poverty but also

huge challenges to sustainable development. The Tsinghua–Lancet Commission on Healthy Cities in China calls for urban health management as essential to China’s sustainable development, while acknowledging climate-related health risks as among the urban health challenges.<sup>6</sup> Climate change phenomena have been marked in China, with major implications for ecology and human health<sup>7</sup>:

- Annual average air temperature in China has increased by 0.5–0.8°C over the past 100 years, with the warming trend more marked in western, eastern and northern China than in the south;
- Altered rainfall pattern has been observed with different trends among regions: little change in overall annual rainfall, decrease in annual rainfall in northern China and significant increase in southern China and southwestern China;
- The sea level along China’s coasts during the past 50 years rose by 2.5 mm per year; and
- More severe floods have occurred in the middle and lower reaches of the Yangtze River and southeastern China, with increasing droughts in northern and northeastern China.

This article reviews published studies over the health impact of climate change in Chinese cities according to the following four climate change phenomena identified under the modified Watts

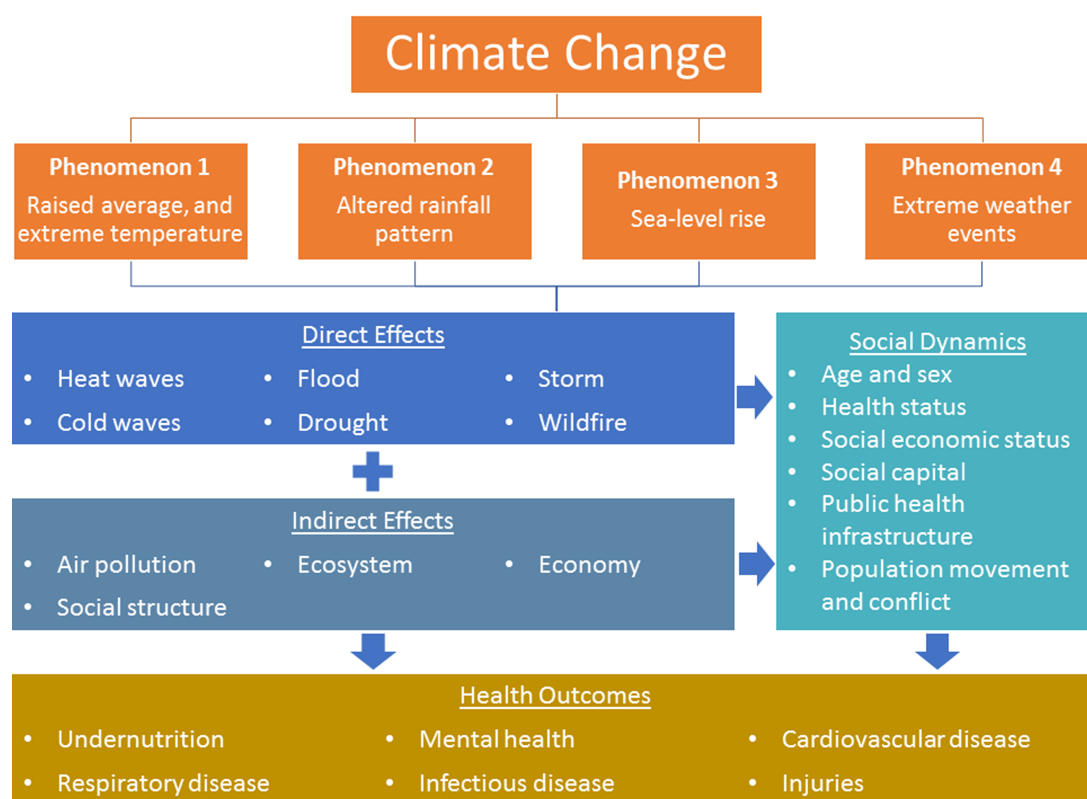


Fig. 1 Framework on climate change and its impact on health (adapted from Watts *et al.*, 2015<sup>2</sup>)

Framework 2015 (Fig. 1): (i) raised average and extreme temperature, (ii) altered rainfall pattern, (iii) sea-level rise and (iv) extreme weather events. Pathway of impacts and health outcomes will be discussed under each component. Given the vast area of China, there are marked regional climate variations and concerns, which will be covered in the review where appropriate. For a more focused and in-depth analysis, our review confines to the exposure, pathways and outcomes covered by the Framework and does not cover other related concepts including adaptation co-benefits.

Our review aims to answer the following questions:

- What health outcomes are commonly studied under each climate change phenomenon in the current literature in China?

- Where are the knowledge gaps related to CC-health in China?

## Search strategy

A bilingual literature review was conducted in February 2018 on PubMed, Google Scholar and China Academic Journals Full-text Database. Keywords including ‘human health’, ‘health impact’, ‘mortality’, ‘morbidity’, ‘hospital admission’, ‘physical health’, ‘mental health’ and ‘social health’; ‘climate change’, ‘extreme temperature’, ‘cold wave’, ‘heatwave’, ‘hot wave’, ‘rainfall’, ‘precipitation’, ‘sea level rise’, ‘extreme weather event’, ‘flood’, ‘drought’, ‘storm’ and ‘typhoon’; ‘China’ and ‘Chinese’; and ‘urban’, ‘city’, ‘cities’ and ‘metropolis’ were searched for peer-reviewed articles published between 2000 and January 2018. Original

research, reviews and meta-analyses were included and restricted to papers in the English and Chinese language.

## Results

We screened 900 of the best-match articles in both English and Chinese by title and abstract. Additionally, we searched for the latest relevant publications. A total of 196 papers were considered relevant with the full text reviewed. Our review indicated that majority of the published papers on health impact of climate change in Chinese cities are in English. These publications were mostly published after 2010 and were observation studies by nature. Most of the studies were ecological time-series studies, while there were several cross-sectional survey studies (particularly related to mental health) and a few spatial analysis studies. However, overall, there were very few cohort studies conducted on climate change and health in China. Table 1 shows that the typical length of studies was under 5 years. The maximum length of a study dataset was 46 years. Our review also found nine studies on future projections.

Table 2 indicates the geographical distribution of the studies included in this review. In general, published studies are largely concentrated in the regions of East and South China, and in major municipalities—Beijing, Tianjin, Shanghai, Chongqing and Hong Kong. Multiple-location comparison studies were conducted across China, particularly related to temperature-mortality studies. The most commonly studied exposures were temperature and meteorological factors, while the most commonly studied outcomes were mortality and infectious diseases. Hong Kong reported the highest number of temperature-morbidity studies.

Flooding studies were mostly located in Central China and East China, particularly Hunan province, while typhoon studies were conducted in East and South China. Vector-borne diseases were commonly studied in Guangdong province, Anhui province and the Southwest region. Studies on mental health were largely concentrated in Central China, particularly Hunan province following the 1998 Dongting lake flood.

## Climate phenomenon (1): elevated and extreme temperature

### Temperature-related mortality

#### All-cause mortality: general

The relationship between temperature and mortality has been studied globally, and in China, this is also the most frequently studied climate change and health outcome. Although increased mortality risk occurs in both cold and hot temperatures, larger proportion of temperature-related mortality attributed to cold rather than hot temperatures.<sup>8–10</sup> Overall, results indicated that mean temperature was a better predictor of mortality than maximum or minimum temperature, particularly in heat waves.<sup>11–13</sup> While heat effects were more immediate, cold effects were found to be more prolonged and long lasting.<sup>10,14,15</sup> Studies suggested that despite the projected temperature increase, decreasing cold-related mortality would not outweigh the overall mortality effects of increasing heat.<sup>15,16</sup>

Multi-city or multi-community comparisons were done to explore regional differences. Findings of temperature-mortality thresholds indicated that minimum mortality temperature was lower in northern areas<sup>8,17–20</sup> and identified to be around 75th–78th percentile of the temperature range.<sup>8,18</sup> Cold temperatures had larger effects in the warmer

**Table 1** Length of study datasets found in this review

Years	1–5	6–10	11–20	21+	Projection studies	Total
Number of articles	102	55	16	14	9	196

**Table 2** Geographical distribution of studies included in this review, by study exposure and outcome types

Location	Exposure types				Outcome types				
	Total	Temperature	Meteorological	Flood	Typhoon	Mortality	Vector-borne diseases	Other infectious diseases	Other morbidity types
Across China (multiple locations)	33	21	12	0	0	17	7	7	1
North China	21	11	10	0	0	9	0	9	3
Beijing*	16	8	8	0	0	7	0	7	2
Tianjin*	3	2	1	0	0	2	0	1	0
Hebei	2	1	1	0	0	0	0	1	1
Shanxi	0	0	0	0	0	0	0	0	0
Inner Mongolia	0	0	0	0	0	0	0	0	0
Northeast China	7	3	3	1	0	3	0	2	2
Heilongjiang	3	3	0	0	0	3	0	0	0
Jilin	0	0	0	0	0	0	0	0	0
Liaoning	4	0	3	1	0	0	0	2	2
East China	58	25	22	7	4	14	11	25	8
Shanghai*	11	10	1	0	0	5	0	3	3
Anhui	20	5	11	4	0	1	8	10	1
Fujian	2	0	0	0	2	0	0	1	1
Jiangsu	7	4	2	1	0	4	1	2	0
Jiangxi	0	0	0	0	0	0	0	0	0
Shandong	13	4	7	2	0	3	2	7	1
Zhejiang	5	2	1	0	2	1	0	2	2
South China	47	19	19	2	7	14	10	15	6
Guangdong	29	12	13	0	4	10	10	7	1
Guangxi	2	0	0	2	0	0	0	2	0
Hainan	2	0	0	0	2	0	0	1	0
Hong Kong SAR*	14	7	6	0	1	4	0	5	5
Macau SAR*	0	0	0	0	0	0	0	0	0

Continued

**Table 2** (continued)

Location	Exposure types				Outcome types						
	Total	Temperature	Meteorological	Flood	Typhoon	Mortality	Vector-borne diseases	Other infectious diseases	Mental health	Preterm birth	Other morbidities
Central China	24	3	5	16	0	4	4	8	8	0	0
Henan	6	0	3	3	0	0	3	3	0	0	0
Hubei	7	3	2	2	0	3	1	3	0	0	0
Hunan	11	0	0	11	0	1	0	2	8	0	0
Southwest China	23	8	15	0	0	5	13	2	0	0	3
Chongqing*	8	4	4	0	0	2	3	1	0	0	2
Sichuan	3	1	2	0	0	1	2	0	0	0	0
Guizhou	3	0	3	0	0	0	2	1	0	0	0
Yunnan	6	1	5	0	0	1	5	0	0	0	0
Tibet	3	2	1	0	0	1	1	0	0	0	1
Northwest China	4	0	3	0	0	0	1	3	0	0	0
Shaanxi	2	0	1	0	0	0	1	1	0	0	0
Gansu	1	0	1	0	0	0	0	1	0	0	0
Qinghai	1	0	1	0	0	0	0	1	0	0	0
Ningxia	0	0	0	0	0	0	0	0	0	0	0
Xinjiang	0	0	0	0	0	0	0	0	0	0	0
Total†	217	90	89	26	11	66	46	71	9	2	23

\* Indicates China's municipalities and special administrative regions that are not under any province.

<sup>†</sup> Some cross-provincial studies were double-counted.

southern regions,<sup>8,17–22</sup> possibly due to acclimatization in the north and lack of central heating in the south. Hot temperatures, however, had a mixed effect, with some reporting a higher effect in northern regions,<sup>8,17,18</sup> and others in southern regions.<sup>15,19</sup>

There is a general agreement on the relative impact of temperatures on mortality between urban and rural areas, i.e. a stronger heat-mortality effect in urban areas.<sup>23,24</sup> Studies on the urban heat island effect, although limited, have shown an increase in heat-related mortality in urban regions of Shanghai and Hong Kong.<sup>25,26</sup> Additionally, projection studies of climate change-mortality impacts were mostly focused on China's large cities,<sup>16,27–31</sup> but with very limited implications on growing urbanized communities. An excess of 25 800–37 800 heat-related deaths per year was projected in 51 Chinese cities by 2014–2060 under different climate change emission scenarios.<sup>29</sup>

#### All-cause mortality: heat waves

Several papers examined the relationship of prolonged extreme heat episodes, heat waves and mortality. As there is no universal definition of heat wave,<sup>32</sup> some papers used the Chinese Meteorological Administration's (CMA) official national heat wave definition of 'at least 3 consecutive days with maximum temperature exceeding 35°C',<sup>33–35</sup> while others defined heat wave with variations of criteria.<sup>23,36–39</sup> Several papers adopted their own best-fit regional definition and found a higher temperature threshold and longer duration of days in more southern cities, e.g. 97.5th percentile of daily mean temperature for  $\geq 2$  days in Beijing, 98th percentile for  $\geq 4$  consecutive days in Nanjing and 99th percentile for  $\geq 3$  days in Wuhan.<sup>12,13,40,41</sup> Their findings also revealed that the group-specific or cause-specific mortality risks were smaller in the best-fit definitions, when compared with the official CMA definition.<sup>12,13</sup> A nation-wide study on heat waves showed a larger effect of mortality on urban areas,<sup>23</sup> but a provincial-level study suggested otherwise.<sup>37</sup>

#### All-cause mortality: acute temperature variations

A number of studies identified temperature variation between neighboring days and diurnal temperature range (DTR) as independent risk factors for daily mortality. Temperature increases between neighboring days increased mortality risks in total and cardiovascular mortality, while temperature drops had a protective effect.<sup>42,43</sup> On the other hand, larger DTR were associated with increases in mortality risk in coastal<sup>44</sup> and plateau,<sup>45</sup> temperate<sup>46</sup> and subtropical<sup>47–49</sup> cities in China, with every 1°C DTR increase associated with a 0.42–1.37% increase in total non-accidental mortality.<sup>44,46–48</sup>

#### Cause-specific mortality: cardiovascular mortality

For cardiovascular mortality, strong associations were commonly observed at high temperatures,<sup>14,23,33,36,50</sup> DTR,<sup>44,46–48</sup> and specifically for ischemic heart,<sup>17</sup> coronary heart,<sup>41,51</sup> cardio-cerebrovascular diseases<sup>52,53</sup> and stroke mortality.<sup>30,38</sup> Projection studies in Beijing estimated a 10.2–74% increase of temperature-related cardiovascular deaths by 2050/2060.<sup>16,27</sup> Low temperatures and high humidity were found to be associated with larger burden and increased cardiovascular,<sup>8,17,39,54,55</sup> hypertensive-related<sup>56,57</sup> and stroke mortality.<sup>20</sup>

#### Cause-specific mortality: respiratory mortality

Studies on respiratory mortality were usually combined with other types of mortality, without a stand-alone analysis. Projections indicated that respiratory mortality was similar to cardiovascular mortality in a Beijing study.<sup>27</sup> Hot temperatures were found to be strongly associated with respiratory mortality,<sup>23,33,36,58</sup> including specifically chronic obstructive pulmonary disease.<sup>12,28</sup> In cold temperatures, respiratory mortality had greater effects compared with other cardiovascular/cerebrovascular mortality.<sup>21,57,59–62</sup> Respiratory mortality was associated with DTR only in cold days.<sup>44,46</sup>

#### Cause-specific mortality: other mortality

Diabetes and endocrine mortality has recently been included in the analysis of temperature-mortality relationship. Significant associations have been

observed on diabetes mortality with both extreme hot and cold temperatures,<sup>63–65</sup> with a slightly higher temperature threshold and a greater risk increase compared to other causes of mortality.<sup>66,67</sup> Studies on non-accidental years of life lost generally found greater associations with cold temperatures than hot.<sup>10,31,68</sup>

#### Demographic and socioeconomic vulnerability for temperature-related mortality

A greater effect of temperature on mortality has generally been identified on the elderly,<sup>14,20,21,59,69</sup> particularly for heatwaves,<sup>12,13,23,33,35,37,41</sup> acute temperature variations<sup>46–48</sup> and effects of air pollution.<sup>70</sup> The effects on gender were inconclusive. The impact of other socioeconomic variables was uncertain.

#### Temperature-related morbidity

Morbidity (all-cause and cause-specific) is much less frequently used as study outcome than mortality in examining the health impact of climate change in the reviewed studies. A number of studies examined the association between temperature variability (including maximum daily temperature, DTR, temperature change between neighboring days, heat waves, cold spells) and overall health impacts through proxy outcomes such as all-cause hospital admissions, emergency room visits and ambulance dispatches. Among those that measure cause-specific morbidities, cardiovascular diseases have been the main focus, with increasing attention on heat-related illnesses.

#### All-cause morbidities: hospital admissions, emergency room visits and ambulance dispatches

Studies conducted in two coastal cities found that extreme temperatures were associated with overall increase in all-cause hospital admissions, but different conclusions were reached as to whether hot or cold weather had a stronger effect.<sup>71,72</sup> A study conducted in the highland area of Lhasa reported no association between temperature and total hospital admission, although high temperature was associated with increase in total emergency room visit.<sup>73</sup> Interaction between temperature and relative humid-

ity was also reported in a study conducted in Beijing, suggesting a lower humidity at low temperature and higher humidity at high temperature were associated with higher emergency room visits.<sup>74</sup> It should be noted that different definitions of high temperature and heat wave/cold were adopted in these studies. As for ambulance dispatches, significant positive association was found with both intense heat waves<sup>75</sup> and temperature change between neighboring days.<sup>76</sup>

#### Cardiovascular diseases

Cardiovascular disease has been the most researched temperature-related morbidity among Chinese cities. Several studies conducted in Hong Kong found an association between cold weather and cardiovascular disease hospitalizations, including all-cause cardiovascular disease hospitalizations,<sup>72</sup> ischemic heart disease hospitalizations,<sup>77</sup> emergency circulatory hospitalizations<sup>78</sup> and hemorrhagic stroke hospitalization,<sup>79</sup> and such relationship was not observed for hot weather. This echoed with two studies in Shenyang, a provincial capital city in northeastern China, which identified a significant correlation between extreme low temperature and deep vein thrombosis hospital admission<sup>80</sup> and type B acute aortic dissection admission,<sup>81</sup> but not with extreme high temperature.

Given the rather consistent findings over the absence of, or relatively weak, relationship between high temperature and cardiovascular disease events, future research should consider other morbidities that are more likely to be associated with elevated temperature, as it is a major climate change phenomenon.

#### Heat-related illness and symptoms

Heat-related illnesses, e.g. heat stroke and heat cramp, are direct health consequences of high temperature, but they have received much less attention than cardiovascular-related morbidities among climate change studies in Chinese cities. The Chinese Centre of Diseases Control and Prevention put in place the Heat-Related Illness Surveillance System in 2007, and the relevant data have been analyzed in several studies conducted in the past few



years. Major cities including Chongqing, Wuhan, Shanghai and Ningbo reported the most number of cases, and strong association between maximum temperature and heat-related illness had been consistently found in studies conducted across China,<sup>82</sup> in Chongqing<sup>83</sup> and in Ningbo,<sup>84</sup> with 34°C estimated to be the threshold point for Chongqing.

#### Other morbidities

Other morbidity outcomes examined in the studies identified included respiratory diseases, preterm birth, Kawasaki disease and work-related injuries. Maximum temperature was found to be most closely correlated with respiratory disease incidence.<sup>85</sup> While morbidity increased in both cold and hot temperatures, heat waves were found to have an additional effect.<sup>86</sup> A study in Guangzhou found that extreme low temperature was associated with increased respiratory hospital admission, and the effect was stronger among communities with lower socioeconomic status.<sup>87</sup> A recent study found that extreme heat exposure increased the risk of preterm birth in hot areas, while extreme cold is a protective factor,<sup>88</sup> but a previous, smaller-scale study found both extreme heat and extreme cold risk factors.<sup>89</sup> A study on Kawasaki disease in Shanghai found an association with extreme hot temperatures.<sup>90</sup> One study conducted in Guangzhou found that an increase in temperature was significantly associated with work-related injuries.<sup>91</sup>

Several studies on the association between temperature and risk factors (rather than morbidities) were identified: fasting plasma glucose,<sup>92</sup> plasma lipid level<sup>93</sup> and children's blood pressure.<sup>94</sup>

### Climate phenomenon (2): altered rainfall (and other meteorological factors)

Rainfall has often been studied in combination with other meteorological factors, and almost all studies assessed infectious disease outcomes. Limited studies were published to understand how rainfall or other singular meteorological factors (except

temperature) affect health outcomes. Rainfall and humidity were the main focus for only several studies: on malaria,<sup>95</sup> hand-foot-mouth disease (HFMD)<sup>96,97</sup> and infectious diseases in general.<sup>98</sup> Our discussion below therefore covers studies that look at rainfall in combination with other meteorological factors, in line with the designs of the studies reviewed.

#### Vector-borne diseases

Most studies on mosquito-borne diseases examined malaria, with fewer on dengue fever<sup>99–104</sup> and Japanese encephalitis.<sup>105,106</sup> Malaria had an increased risk with temperature increases and an ~1- to 2-month lag,<sup>107–114</sup> while for rainfall, malaria generally increased at low levels, but decreased at high levels.<sup>95,108,111,112</sup> Relative humidity,<sup>111,114,115</sup> fog<sup>116</sup> and El Niño–Southern Oscillation index<sup>117</sup> were occasionally found associated. Studies projecting the environmentally suitable areas for malaria showed an increase northward and, particularly, northeast in the region above Democratic People's Republic of Korea.<sup>118–121</sup> A recent review on dengue highlighted inconsistent findings on the effects of temperature, relative humidity, wind velocity and rainfall on dengue.<sup>122</sup>

Other vector-borne diseases studies examined hemorrhagic fever with renal syndrome and a few on scrub typhus<sup>123–126</sup> and clonorchiasis.<sup>127</sup> Hemorrhagic fever with renal syndrome studies were largely located in the northern parts of China, and often considered combined effects of meteorological and non-meteorological factors.<sup>128,129</sup> A 2015 review on hemorrhagic fever with renal syndrome found 21 studies showing a mainly positive influence of temperature and humidity. Yet, an inconclusive association was found with rainfall. The review also highlighted the importance of distinguishing the different effects between the Seoul virus (mainly urban) and Hantaan virus (rural), which are associated with different rodent hosts.<sup>130</sup> Increased scrub typhus, which is endemic in southern China and carried by infected mites,<sup>126</sup> was associated with temperature and rainfall increases.<sup>123–126</sup>

#### Respiratory-related infectious diseases

Studies on respiratory-related infectious diseases were limited and generally focused on influenza and other general respiratory tract infections, with one study on tuberculosis in Qinghai.<sup>131</sup> Among other meteorological factors, only temperature had a consistent relationship for respiratory tract infections<sup>132–135</sup> and various influenza, inclusive of H5N1 and H7N9.<sup>136–140</sup> In a hypothetical scenario of 2°C increase in average temperatures, a greater increase in favorable days was projected for influenza A rather than B.<sup>141</sup> Other studies also looked at the meteorological patterns of respiratory syncytial virus, parainfluenza viruses 1–3, adenovirus and human metapneumovirus.<sup>142,143</sup>

#### Other infectious diseases

The association of HFMD with meteorological factors was most frequently studied, with several large multi-city/regional studies.<sup>144–148</sup> The effect of meteorological factors was modified by different locations (altitude or climate types), but the combined temperature–HFMD relationship of multiple locations displayed a consistent inverted V-shaped curve,<sup>144,146,147</sup> particularly in the summer.<sup>148</sup> Moderate rainfall and humidity levels above 80% provided favorable conditions,<sup>97,149–151</sup> but these findings were not always consistent.<sup>151–154</sup> Neighboring provinces of Jiangsu and Shandong identified HFMD peaks during April–June.<sup>147,152,155</sup> Non-meteorological factors such as child population density, annual household income and number of healthcare institutions were found to have strong association with HFMD.<sup>147,156</sup>

While the relationship of bacillary dysentery varied with precipitation and relative humidity, its risk increased with temperature<sup>157–164</sup> and was more pronounced in urban areas.<sup>165</sup> A DTR above 8°C also increased the risk of bacillary dysentery.<sup>166</sup> Projection to 2050 estimated an increase in years lost due to disabilities for bacillary dysentery, and this was greater for a temperate city in northern China compared with a subtropical city in southern China.<sup>167</sup>

Studies on other infectious diseases and their associations with meteorological variables were also

identified: mumps,<sup>168</sup> varicella (or chickenpox),<sup>169,170</sup> typhoid fever,<sup>171</sup> scarlet fever<sup>172</sup> and infectious diarrhea with temperature.<sup>173</sup>

### Climate phenomenon (3): sea-level rise

While over 11% of the people in China live in coastal areas,<sup>174</sup> the research team was unable to identify any study on the health impact of sea-level rise in Chinese cities.

### Climate phenomenon (4): extreme weather events

Extreme weather events refer to disasters involving hydrological hazard (e.g. flood), meteorological hazard (e.g. storm) and climatological hazard (e.g. drought) and cause a number of health outcomes. For China, flood is the weather-related disaster that causes the highest number of mortality and the largest amount of economic loss, with inland river flood along the Yangtze River region particularly relevant, while storm/typhoon has the most number of occurrences.<sup>175</sup>

#### Floods

Health outcomes of floods are the most well researched among extreme weather events in China, focusing mostly on infectious diseases, in particular infectious diarrhea. Mortality was much less seen as the outcome measure.<sup>176</sup>

Hepatitis A virus, malaria and infectious diarrhea were found to be significantly related to the 2007 flood in Anhui.<sup>177</sup> Viral hepatitis was found as most commonly reported infectious disease after the flood in Hubei province, followed by tuberculosis and mumps.<sup>178</sup> For infectious diarrhea, there had been consistent findings in a number of studies on floods,<sup>179,180</sup> with most of the studies focusing on dysentery<sup>181,182,183</sup> and bacillary dysentery.<sup>184–188</sup> One study suggested that the strong association between bacillary dysentery and floods existed only in relation to men,<sup>185</sup> which was not noted in other studies. Another infectious disease that was analyzed as the health outcome of flood was schistosomiasis

japonica, and the study conducted in Anhui, Hubei and Jiangsu found that the number of reported cases was 2.8 times higher when compared to non-flood years.<sup>189</sup>

Only one projection study was identified in relation to health outcomes of flood. The study found a significant association between severe flood and hepatitis A virus and projected the incidence of hepatitis A virus infection to increase.<sup>190</sup>

Mental health is an under-researched health outcome in climate change studies, and climate change-related impact on mental health is most often associated with extreme weather events. Only a handful of research papers were identified for Chinese cities, and they were mostly related to the flood in Hunan province in 1998. The research covered mainly post-traumatic stress disorder (PTSD): from its prevalence, risk factors and recovery. Data from various researches suggested the prevalence of PTSD to be around 10% among the victims.<sup>191,192,193,194</sup> One paper suggested female sex, older age, flood type (flash flood) and flood severity (intermediate) as risk factors,<sup>191</sup> and one suggested social support as a protective factor.<sup>192</sup> Several studies were conducted to examine the long-term effect of PTSD: studies conducted 15 years after the flood suggested that ~15 to 20% of PTSD flood victims continued to have the condition,<sup>195,196,197</sup> while the latest study established the figure to be 9.5% by 2015.<sup>198</sup> Risk factors for the long-term effect of PTSD include trauma-related stressors (e.g. loss of relatives, bodily injury) and negative coping style, with social support again as a protective factor. The findings however disagreed over whether female sex was a risk factor.<sup>196,198</sup>

#### Typhoons/cyclones

Typhoons mostly occur in southeast China and are much less researched on than floods, likely because of the relatively less significant human and economic loss. Research findings on typhoons are similar to those for floods, with association with infectious diarrhea found,<sup>199,200,201</sup> except for one study in Guangdong,<sup>202</sup> and with PTSD.<sup>203,204</sup> A study in Guangzhou found that typhoon could increase the

all-cause mortality, particularly among female, very young and old population.<sup>205</sup> Other health outcomes examined include injuries<sup>206</sup> and related risk factors,<sup>207</sup> emergency room visits as proxy.<sup>208</sup>

#### Extreme temperature events

Research in China related to extreme temperature events, i.e. heatwaves and cold spells, are reviewed in the section on temperature.

## Conclusions

Our findings indicated that the temperature–mortality association is the most extensively researched issue in China and found both hot and cold temperatures increased mortality risk. Yet, most studies tend to focus on one indicator and typically under a 5- or 10-year timeframe. Temperature-related morbidities are much less understood and should be given more attention, particularly as cause-specific morbidity studies are important for informing targeted interventions for vulnerable populations. There is currently a lack of literature that examines how climate variation may affect comorbidities, injuries, mental health and allergies. Understanding on both mortality and morbidity is critical as the former can be applied to warning thresholds and policy planning, and the latter for health and related service planning. Building on the existing findings on temperature–mortality association, researchers should also consider conducting longer time trends and scenario-based projection studies on the health impacts of extreme temperatures to facilitate public health planning and risk reduction efforts.

The effect of rainfall and other meteorological variables were assessed on a wide range of infectious diseases in China. While diseases such as malaria and scrub typhus were found to have more consistent associations with rainfall, the associations with other infectious diseases such as dengue, hemorrhagic fever with renal syndrome and HFMD have been less consistent. However, studies on rainfall and other meteorological factors have rarely examined other health impacts such as non-communicable diseases

and injury. As typical rainfall distribution patterns vary regionally, the generalizability of each health outcome's study conclusions may be limited. Yet, changing rainfall patterns and the occurrence of extreme weather events like flooding and drought will continue to impact the trends of infectious diseases and other health outcomes. It is critical to develop further knowledge on the regional effects of rainfall variability on health for regional and community planning.

We were not able to identify any research on the health impact of sea-level rise in Chinese cities. According to the latest official data, sea-level rise occurred at an average rate of 3.2 mm per year between 1980 and 2016, and the average sea level along the Chinese coast in 2016 was 38 mm higher than that of 2015.<sup>209</sup> Major Chinese coastal cities including Shanghai and those in the river deltas like Hong Kong are facing inevitable challenge from a rising sea level, and it is imminent to understand its health impact and implications on lifeline infrastructure support and fresh water supply.

Flooding is the extreme weather event that is highly relevant to China in terms of mortality, morbidity and economic loss. Existing understanding on the health impact of floods is mainly limited to certain regions and a few types of infectious diseases. Other outcomes should be considered, e.g. hepatitis A virus infection, malaria, injuries, mental health consequences (including anxiety and depression) and chronic disease complications. More attention should also be paid to the health impact of typhoon, especially in the context of rising sea level for the coastal cities. Projection studies for extreme weather events are also highly recommended.

As limited reviews have been conducted in the developing context, our review highlights a wide range of topics and provides evidence to understand the development of climate and health research after the millennium. Rapid urbanization is taking place in many developing countries in Asia, and the experience of urban China is of significant reference for other places of similar latitude and socioeconomic development. Our review is presented in a frame-

work that allows readers to see the links between climate change and its health impacts. The findings will probably serve as good reference for other developing context to build their climate change and health outcome models, to better support health and medical needs and service planning. However, this was not a systematic review and out of the scope of this review were related topics such as air pollution, co-benefits, acclimatization, adaptation, behavioral change and other indirect impacts of climate change. These are highly important topics as some of these issues involve protective factors like social support and help-seeking behaviors, which could improve the health outcomes.

Based on the current gaps of knowledge in our review findings, future climate change and health research in China or urban communities of middle-income countries should pay special attention to the following:

1. Health studies with sea-level rise, rainfall or extreme weather events as the main exposures;
2. More studies located outside of main municipalities and the Eastern and Southern China regions;
3. Research on the specific climate change-related health needs among special vulnerable populations in the urban areas in China, e.g. among urban migrant workers (percentage of urban employment rose from 28 to 52% between 1995 and 2015);
4. Studies focused on health outcomes such as comorbidities, mental health, allergy and injuries patterns; and
5. More long-term studies (at least over 10 years) over the health impact of climate change, inclusive of potential acclimatization, are warranted.

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## Conflict of interest statement

The authors have no potential conflicts of interest.

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