

Open Research Online

The Open University's repository of research publications and other research outputs

Direct and indirect health impacts of climate change on the vulnerable elderly population in East China

Journal Item

How to cite:

Kinay, Pelin; Morse, Andrew P.; Villanueva, Elmer V.; Morrissey, Karyn and Staddon, Philip L. (2019). Direct and indirect health impacts of climate change on the vulnerable elderly population in East China. *Environmental Reviews*, 27(3) pp. 295–303.

For guidance on citations see [FAQs](#).

© [not recorded]



<https://creativecommons.org/licenses/by-nc-nd/4.0/>

Version: Accepted Manuscript

Link(s) to article on publisher's website:
<http://dx.doi.org/doi:10.1139/er-2017-0095>

Copyright and Moral Rights for the articles on this site are retained by the individual authors and/or other copyright owners. For more information on Open Research Online's data [policy](#) on reuse of materials please consult the policies page.

oro.open.ac.uk

1 **Direct and indirect health impacts of climate change on the vulnerable elderly population in East China**

2 PelinKinay^{a,b*}, Andrew P Morse^b, Elmer V Villanueva^c, KarynMorrissey^d, and Philip L Staddon^{a,d,e}

3 ^aDepartment of Environmental Science, Xi'an Jiaotong-Liverpool University, Suzhou, People's Republic of China;^bDepartment of
4 Geography and Planning, University of Liverpool, Liverpool, United Kingdom; ^cDepartment of Public Health, Xi'an Jiaotong-
5 Liverpool University, Suzhou, People's Republic of China; ^dMedical School, University of Exeter, Exeter, United Kingdom;^eSchool
6 of Environment, Earth and Ecosystem Sciences, The Open University, Milton Keynes, United Kingdom.

7 *PelinKinay, Department of Environmental Science, Xi'an Jiaotong-Liverpool University, 111 Ren'ai Road, Suzhou Industrial Park,
8 Suzhou, Jiangsu 215123, People's Republic of China. Email: Kinay.Pelin@xjtlu.edu.cn. Telephone: +86 15850232571

9 Word count: 3967 excluding abstract.

10

11 **ABSTRACT**

12

13 The latest scientific advances on the impacts of climate change on the health of the elderly in East China were reviewed consulting
14 peer-reviewed publications from 2000-2017. The direct impacts of climate change result from rising temperatures, heatwaves, and
15 increases in the frequency of complex extreme weather events such as windstorms, floods, and droughts. The health and social

16 consequences of these events are far-reaching, ranging from reduced labour productivity and heat-related deaths, through to direct
17 physical injury during extreme weather events, the spread of infectious diseases, and mental health effects following widespread
18 flooding or prolonged drought. Research has indicated that climate change will have the greatest impact on vulnerable groups of
19 people, including the elderly population. However, there is a dearth of empirical evidence, a lack of focus on vulnerable segments of
20 the population (especially elderly), limited understanding of how health status will change in the future, and lack of acknowledgement
21 of how different regions in China vary in terms of the consequences of climate change. The main risk in East China that climate
22 change may exacerbate is flooding (sea level rise, coastal and riverine, flood risk). However in some regions of East China such as in
23 the provinces of Anhui, Jiangsu, Hebei and Shandong the biggest climate change risk is considered to be drought. Main health risks
24 linked to climate change are evident as cardiovascular and respiratory diseases (heat stroke, exhaustion, and asthma), often caused by
25 interactions between heatwave episodes and concurrent poor air quality.

26

27 **Key words:** Climate change, East China, elderly, health impacts, flooding, heatwaves.

28

29 **I. Introduction**

30 Many prevalent human diseases respond to climatic conditions (Liang and Gong 2017). Links between weather and climate exist for
31 cardiovascular diseases (Kim et al. 2015), respiratory illnesses (Hopkinson et al. 2017) and infectious diseases, including water-, food-
32 and vector-borne, are well established (Patz et al. 2005). Climate change is one of the greatest challenges currently facing humanity

33 and it is considered to be the biggest global threat to public health this century (Costello et al. 2009). *The Lancet* Commission on
34 Climate Change and Human Health note that the impacts of climate change, through rising temperatures, heatwaves, and increases in
35 the frequency of complex extreme weather events such as windstorms, floods, and droughts are already being felt and through these
36 events climate change impacts will have substantial costs to human health (Costello et al. 2009; Portier et al. 2013). Climate change
37 will affect human health via multiple pathways of direct and indirect impacts (Frumkin et al. 2008; Massad et al. 2011). The effects of
38 climate change on human health will include health problems linked to heat stress, flooding, and increased frequency and intensity of
39 storms (Easterling et al. 2000). For example, cardiovascular and respiratory diseases, may be induced by heatwaves and air quality
40 interactions (Kan et al. 2012). Climate change also indirectly threatens human health through adverse changes in temperature (Peel et
41 al. 2013), vector borne infectious diseases (Epstein 2001) and via food and water quality and security (Myers et al. 2017). Forced
42 migration and shortage of resources can also be predicted as indirect impacts of climate change on human health (Watts et al. 2015).

43 The climate in China and East China have already experienced significant changes in recent years (Qin et al. 2015). This review
44 focuses on the impacts of climate change on health in the elderly in East China, which is home to 408 million people, and is one of the
45 key economic areas in China. Demographically, population projections predict that by 2050 one third of the Chinese population will
46 be elderly (aged older than 65) (Yao-Dong et al. 2013). The elderly are a population group that has been identified as being
47 particularly vulnerable and susceptible to the wide range of environmental and societal impacts of climate (Zeng et al. 2010). Thus,
48 the future health profile and needs of this population needs to be a key consideration for Chinese policymakers. Several studies have
49 been carried out in China related to the health concerns of climate change and some have quantified the direct impacts of climate

50 change in the health on elderly population (McMichael et al. 2006; Wu et al. 2016; Zhou et al. 2017). Most studies focuses on health
51 impacts of extreme heat and highlights the health risks to the elderly population (cardiovascular, respiratory, stroke, ischemic heart
52 disease) (Chen et al. 2017; Zhang et al. 2017). Given the large size of the affected population, the climate and environmental diversity
53 across regions and the diverse socio-economic status across East China, it is considered timely to review and summarize the latest
54 scientific advances in understanding the likely future health impacts of climate change. Here, a broad range of studies on the potential
55 risks of climate change impacts in China are reviewed, and the current state of knowledge on the health impacts of climate change in
56 the elderly Chinese population is presented and methods and limitations of previous research are examined.

57 **II. Approach**

58 Peer-reviewed publications that reported the impact of future climate scenarios on risks to health are reviewed. Web of Science,
59 Environment Complete (EBSCO), Google Scholar and Science Direct databases were used for the research. The review is based on a
60 structured literature search, but did not include a formal meta-analysis, as too few studies reported suitable effect size for meaningful
61 comparison. The search terms were used in combination and included ‘climate change’, ‘health’, ‘China’, and ‘elderly’, ‘East China’
62 were used to filter the resources. This search returned many off-topic articles, as evidenced by their titles and abstracts. Due to the
63 large number of publications we cannot give an exhaustive overview of all studies. Instead, the most important, relevant and novel
64 publications were considered to form the main body of review. Overall, since 2000, 970 full articles were identified including 940
65 confirmed as peer reviewed. Within these results a further search was performed with the term ‘health impacts’ and this filter resulted

66 in 361 articles. The final search identified 163 studies and 114 studies were chosen for this review as they were highly relevant (Figure
67 1).

68

69 <<Insert Figure 1 Here>>

70

71 **III. Recent and Future Climate Change in China**

72 Future predictions indicate that climate change may exacerbate a wide range of extreme weather events in China, including typhoons,
73 floods, and droughts (Kan 2011). For China different emission scenarios estimate that, by the year 2020 averaged annual mean
74 temperature will increase by 1.5–2.1°C, by the year 2050 by 2.3–3.3°C, and by year 2100 by 3.9–6°C (Ding et al. 2007). Across
75 most of China future temperatures are expected to rise another 1.3 to 5 °C by the end of the century, in comparison to the global
76 average predicted rise of 1 to 3.7°C (Ding et al. 2007; Guoju et al. 2005).

77 Studies have shown recent trends in annual and summer total precipitation, and the large regional precipitation variability in China
78 (Shi et al. 2003; Zhai et al. 2005). In the last decade China has suffered a series of extreme droughts, including the spring-summer
79 drought in northern China in 2000 and 2001, the spring drought in Yunnan in 2005, the spring-summer drought in Sichuan and
80 Chongqing in 2006, the summer drought in southern China in 2007, the summer drought in Chongqing in 2008, and the spring-
81 summer drought in five southwest provinces in 2010 (Barriopedro et al. 2012). Indeed, data on droughts and floods in the Yangtze and
82 Yellow Rivers over the last 2000 years found that while the intensity of flooding in the 20th century was comparable to historical

83 events, previous drought events were less intense (Zheng et al. 2006). Between 1876 and 1878 a drought occurred in China which was
84 considered as an extreme climate event after the cold climate at the end of the Little Ice Age (this is a period between about 1300 and
85 1870) (De'er and Youye 2010).

86 Sea level rise in East China is another further concern (Wellner and Bartek 2003). China Meteorological Administration states that a
87 sea level rise of 60 cm by 2050 could make economic growth in Shanghai vulnerable, and also poses risks to health for vulnerable
88 segments of the population (Hu 2017).

89

90 **IV. Vulnerability to Climate Change**

91 The concept of vulnerability is defined as an important extension of traditional risk analysis, which is focused primarily on natural
92 hazards (Kok and Jäger 2009; Leichenko and O'Brien 2002; Otto et al. 2017; Turner et al. 2003). Table 1 presents various concepts of
93 vulnerability (Füssel 2007).

94

95 <<Table 1 Here>>

96

97 Vulnerabilities may vary greatly from those associated with human health to built infrastructure (Heltberg et al. 2009). Human
98 vulnerability factors can be divided into five groups: natural vulnerability, human vulnerability, social vulnerability, financial

99 vulnerability and physical vulnerability (Thow and de Blois 2008) (Figure 2). The vulnerability level of human populations vary
100 depending on conditions (McMichael 2003). For example, some population subgroups may have difficulty adapting to climate change
101 because of scarce resources, lack of information, poor public health infrastructure, as well as a lack of effective guidance and help
102 (Corvalan et al. 2005).

103

104 <<Insert Figure 2 Here>>

105

106 Population groups including the elderly, children, and disabled people are considered particularly vulnerable to climate change (Watts
107 et al. 2015). Age is a well-known risk factor for heat related illness and death and the elderly are under the greatest risk (Basu and
108 Samet 2002).

109 Increased human health vulnerability to climate change is associated with many factors including rapid population growth, (as in the
110 case of China) poverty and hunger, poor health, low levels of education, and lack of access to information on climate change
111 (Demirkesen and Evrendilek 2017; Füssel and Klein 2006). It has been shown that the elderly (people who are 65 years or older) are
112 particularly vulnerable to the impacts of heat waves (Li et al. 2017b). For example, the 2003 heatwave in Shanghai was reported to
113 have caused a 12 percent increase in total deaths and a 19 percent increase in cardiovascular mortality amongst the elderly (Huang et
114 al. 2010). It has also been reported that high temperature mortality risks were highest for women over 65 years old in Jinan, China (Li

115 et al. 2017a). A recent study established a social vulnerability index at the county level with a composite index to climate change
116 focusing on urbanized cities on the Chinese east coast (54 cities govern 407 county-level divisions containing counties, county-level
117 cities, and city districts) and found that more work on health and social care should be put toward this sensitive elderly group (Ge et al.
118 2017).

119 These findings indicate that human health interventions aimed at mitigating the climate change health impacts require an in-depth
120 understanding of vulnerable populations (Berrang-Ford et al. 2011). Improving understanding of vulnerability to climate change
121 health impacts is a clear research gap in China that requires urgent attention from public health researchers.

122 **V. Uncertainty on Climate Impacts and Human health**

123 Uncertainty defined in the context of risk, restricts our ability to measure the risks associated with different events (Hillen et al. 2017).
124 In China much of the climate change uncertainty has focused on crop yields and scarcity in water resources which are two of the
125 biggest indirect impacts of climate change on health (Kang et al. 2017). The uncertainty of the direct impacts of climate change on
126 human health has received very little attention in China. However, some research has examined climate change issues that will
127 indirectly impact on human health, including precipitation, temperature, weather variability and water management. Research has
128 found that the uncertainty in predictions of future precipitation (Piao et al. 2010), future temperature trends (Wang et al. 2012b),
129 weather variability (Piao et al. 2010), and water security of the responses of crops to changes in climate, diseases, pests and
130 atmospheric constituents all of which can have an important impact on human health (Pahl-Wostl 2007). Climate change challenges

131 on existing water resources management practices should be considered amongst the factors that have additional uncertainty in future
132 (Pahl-Wostl 2007). For adaptation to change, integrated water resources management must therefore take climate change impacts
133 under full consideration to enhance the potential of the resources (Guo et al. 2002). On water management uncertainty, there are still
134 many gaps in the climate change assessment methodologies and many uncertainties in the climate health projections (Yong-Jian et al.
135 2013). Some studies have focused on the potential uncertainty of the effect of climate change, and mathematical methods have been
136 employed for model constructions (Piao et al. 2010). On temperature extremes, uncertainty ranges were completed as $0.084^{\circ}\text{C}/\text{decade}$
137 and $0.037^{\circ}\text{C}/\text{decade}$ for the minimum and maximum temperature trends, respectively (Wang et al. 2012b). Due to the lack of reliable
138 observations, there are uncertainties on tropical cyclones in the exploration of results (Zou and Zhao 2010). In a study which
139 focused on rich range of uncertainties related to heat related climate change impacts, population demographics and adaptation,
140 however in this study modeling future adaptation is still considered as a big challenge (Li et al. 2016).

141 **VI. Impacts of Climate Change on Health**

142 The WHO (2016) estimated that, in 2012, 12.6 million deaths (23% of all deaths worldwide) were attributable to modifiable
143 environmental factors, many of which could be influenced by climate change or are related to the driving forces of climate change
144 (Neira and Prüss-Ustün 2016). Links between weather and climate exist for cardiovascular diseases (Kim et al. 2015), respiratory
145 illnesses (Hopkinson et al. 2017) and a number of infectious diseases (Patz et al. 2005). As noted above, many prevalent human
146 diseases respond to climatic conditions (Liang and Gong 2017). Human health in China will also be affected by climate change in

147 numerous ways such as mortality from extreme weather events; changes in quality of air and water; and changes in the ecology of
148 infectious disease vectors (Kan et al. 2012). Indeed, some of the most common infectious diseases including malaria and dengue, are
149 those transmitted by mosquitoes, many of which have exhibited changes to their species range in the last decade (Liang and Gong
150 2017; Tian et al. 2015; Yu et al. 2015). *The Lancet* Commission (Costello, 2009) identified six factors that connect climate change to
151 adverse health outcomes: changing patterns of disease and mortality, food, water and sanitation, shelter and human settlements,
152 extreme events, and population and migration. The following sections will focus on the impact of increased extreme events linked to
153 climate change will have on human health (Figure 3).

154

155 <<Insert Figure 3 Here>>

156 <<Insert Table 2 Here>>

157

158 **a. Climate Change Impacts on Health: Storms and Typhoons**

159 Climate change is expected to lead to an increased number of storms and typhoons and East China is one of the regions seriously
160 affected by tropical storms (Lu and Zhao 2013). Previous research in Guangdong, South China, found that the landing of tropical
161 cyclones not only causes substantial direct economic losses but also threatens human health (Kang et al. 2015). Research has found
162 that tropical cyclones increase the risk of transmitted infectious diseases (Zheng et al. 2017). Study in Guangdong city between years

163 2005-2011 concluding that there is an increase on the infectious diarrhea incidents after tropical cyclones (Kang et al. 2015). An
164 assessment on the public health risks and impacts of a tornado in Funing, East China concluded that elderly (75-84 year group) was at
165 the highest risk death (RR (relative risk) = 82.16; 95% CI (confidence interval) = 19.66, 343.33) and injury (RR = 31.80; 95% CI =
166 17.26, 58.61), and females were at 53% higher risk of death than males (RR = 1.53; 95% CI = 1.02, 2.29) (Wang et al. 2017).

167 **b. Climate Change Impacts on Health: Heatwaves and Cold Spells**

168 Heat waves are increasing in frequency (Luber and McGeehin 2008; Robinson 2001). Population groups with high vulnerability to
169 heatwaves and cold spells (Davídkovová et al. 2014) include the elderly, children and/or people with chronic diseases who are more
170 susceptible to extreme temperatures, both hot and cold (Tian et al. 2012). Being exposed to extreme heat can cause heat stroke and
171 dehydration, as well as cardiovascular, respiratory, and cerebrovascular disease risks which may cause insomnia, fatigue, clinical
172 exacerbation, or death from heatstroke (Yao-Dong et al. 2013; Zeng et al. 2014). It is estimated that the heat waves will cause severe
173 health impacts on the metropolitan areas in the Pearl River Delta as heat waves become more intense and longer in duration (Yao-
174 Dong et al. 2013). Many studies that have investigated heat wave related mortality (Li et al. 2017b; Luo and Lau 2017; Yin and Wang
175 2017; Zhou et al. 2017) but less attention has been given to the health effects of cold spells (Staddon et al. 2014) in the context of
176 global climate change (Zhou et al. 2014). It is important to note that climate change may lead to warmer winters but with greater
177 weather variability leading to the counter intuitive effect of more cold spells occurring. A recent study shows that a total of 5 % excess
178 deaths were associated with heat waves in 66 Chinese communities, with the highest excess deaths in North China, followed by East
179 China and South China (Ma et al. 2015). In Beijing research on the elderly found that ignoring adaptation and demographic changes
180 among elderly who are most susceptible to heat leads to differences in estimations on future heat-related mortality (Li et al. 2016).
181 Increased mortality rates are associated also with cold waves in populations around the world (Ryti et al. 2016). Both extremely cold
182 and hot temperatures increase heart disease mortality in China (Guo et al. 2012). The elderly are more vulnerable to low temperatures

183 than young people which can trigger some chronic diseases (De'Donato et al. 2013). Also, cold spells lead to increases in patients
184 with fractures from the possible injuries of icy ground (Yao-Dong et al. 2013). In Shanghai a study done on the elderly showed that
185 cold spells had a significant impact in elderly people with increasing mortality rates (age greater than 65) (Ma et al. 2013).

186 **c. Climate Change Impacts on Health: Flooding**

187 *River Flooding*

188 Flooding events are generally considered among the deadliest natural disasters, and have led to the highest number of mortalities in
189 the 20th century (O'Connor and Costa 2004). Flood disasters have been recognized as the most severe natural hazard in China since
190 the country frequently experiences natural disasters, of which flooding is of great concern to the different levels of Chinese
191 government (Zhang and Liu 2006). For East China disastrous flooding in several river valleys across East China in 1755, serious
192 flooding occurred in the middle and lower reaches of the Yellow River in 1756 and 1757, a rarely seen precipitation pattern of north-
193 flood and south-drought in China for two successive years (Zhang 2012). In 1931 in Central China there were a series of floods that
194 occurred and these floods took the lives of nearly 4 million people (Zong and Chen 2000). In the summer of 1991, an area in the East
195 of China measuring 130,000km² was flooded and 3 million houses were damaged or destroyed resulting in health impacts including
196 injuries (for those who sustained open wounds etc.) (Gautam and Van Der Hoek 2003). After, China suffered extensive flooding in
197 three areas during the 1998 summer: along the Yangtze River in South Central China (Ye and Glantz 2005). East China also
198 experienced a series of severe floods during the summer of 1998 and these floods adversely affected the human population, directly

199 and indirectly (Jonkman 2005). Regions most at risk are: central North China, the Huaihe River (provinces: Henan, Anhui, Jiangsu),
200 the middle and lower reaches of the Yangtze River, and the Pearl River Basin (cities around Shanghai, Nantong, Zhenjiang, Nanjing,
201 Tongling, Wuhu, Jingzhou) (Shao-Hong et al. 2012). Drowning, injuries, hypothermia are amongst the immediate direct health
202 impacts of floods (Du et al. 2010). All populations affected by a flood are at direct or indirect risk of health impacts during and after
203 the event, but the literature also mentions the certain groups are at higher risk than others. People with limited physical capacity or
204 limited mobility, who require home care or regular visits to health care facilities, and who have weak social networks, poor flood
205 awareness, few resources and little access to flood warnings are at particularly high risk (Galea et al. 2005). Information on risk
206 factors for flood-related death remains limited, and those drowning in their own homes are largely the elderly as they are less mobile
207 (Jonkman and Kelman 2005).

208

209 *Coastal Flooding*

210 Under future climate change, altered patterns of precipitation and sea level rise are expected to increase in frequency and intensity of
211 floods in many coastal regions (Ahern et al. 2005). China's coastal region is physically vulnerable to sea-level rise and associated
212 coastal flooding because of its low topography (Wang et al. 2011). The East Sea, South Sea and East China regions with high
213 population density have the greatest exposure to coastal flooding risk from sea level rise (Fang et al. 2017; Zhang et al. 2002). Xiamen
214 is proposing an integrated assessment approach to sea-level rise and storm tide-induced flood risks on a coastal urban system (Lilai et
215 al. 2016). Half of Shanghai is projected to be at risk of flooding by the year 2100, and 46% of the seawalls and levees would be

216 breached, and sea level rise projections show 86.6 mm, 185.6 mm, and 433.1 mm rise by 2030, 2050, and 2100, respectively (Wang
217 et al. 2012a).

218

219 **d. Climate Change Impacts on Health: Drought**

220 Drought is a major natural hazard determined by water availability being significantly below normal conditions for a region (Sheffield
221 et al. 2012). For the period of 1900-2012, China was amongst the countries with the greatest number of people affected by drought
222 (Stanke et al. 2013). During the three most recent decades Northwest, North, and Northeast of China have seen an increase in droughts
223 frequency (Yu et al. 2014). Drought impacts on health are generally indirect and include: malnutrition and mortality due to decreased
224 crop yields, water-related diseases due to increasing concentrations of pollutants and algae, airborne and dust-related diseases, vector
225 borne diseases; mental health effects (Stanke et al. 2013). Although information on droughts' health impacts is available globally,
226 specifically in East China, related elderly population, the information in the literature is very limited.

227 **e. Climate Change Impacts on Health: Air Quality Interactions**

228 There is a considerable literature on the relationship between air quality and numerous health problems, including respiratory
229 infections, cardiovascular diseases, and lung cancer (Arceo et al. 2016; Currie and Neidell 2005; Currie et al. 2009). Air quality is
230 strongly dependent on weather and is therefore sensitive to climate (Jacob and Winner 2009). Changes in the climate will impact air
231 quality, for example by increasing formation of ozone during heatwaves (Stedman 2004). Most air pollutants significantly increase the
232 risk of coronary heart disease mortality especially particular matter (PM₁₀, PM_{2.5}) (Zhao et al. 2017). Due to climate change, patterns
233 of air pollution are changing in urban areas, and this brings a huge threat to respiratory health (D'Amato et al. 2013). Other air
234 contaminants of relevance to human health, including smoke from wildfires and airborne pollens and molds, may be influenced by
235 climate change (Kinney 2008).

236 Studies related PM₁₀ induced health losses are evident, covering most of the large and medium-sized cities in China (Zhang et al.
237 2008). PM_{2.5} is known for its harm to the human respiratory system, and is positively related to daily mortality of people especially of
238 older adults (RR =1.5%, 95% CI: 1.1–1.9%) (RR: Relative risk, CI: Confidence interval) (Schwartz 2000). According to the Chinese
239 disease surveillance report, mortality due to respiratory diseases, cardiovascular diseases and neoplasm is higher in the over 60 age
240 group (Zhou et al. 2016). In Beijing some severe haze events were studied, studies about the quantification of PM₁₀ health effects can
241 help in policy making if they are revealed (Gao et al. 2015; Yin et al. 2015). Dust storms have also been positively associated with
242 excess mortality in China (Wang et al. 2004). Respiratory and cardiovascular hospitalization are associated with the dust events after
243 adjusting the effect of sulphur dioxide and/or nitrogen dioxide (Pan and Liu 2011). Although literature provides information on the

244 interaction between air quality and climate change impacts, more research is needed in this area. Research should focus on air quality
245 interactions with climate change and what the consequences will be for population health.

246 **Conclusions**

247 The impact of climate change on human health is beginning to receive more attention, however except for heatwave impacts; specific
248 information on how climate change will impact the health of the ageing Chinese population is sparse. This review highlights the broad
249 range of health risks linked to climate change and identifies where more research effort is needed. In particular, more quantitative and
250 epidemiological studies are required to better understand the likely impact of climate change on the health of the growing elderly
251 populations affected. This research gap requires further investment if we are to have an evidence-based adaptation strategy to climate
252 change. Furthermore, research is urgently required on the indirect pathways by which climate change will impact the health of elderly
253 Chinese and other segments of the population. China, with its ageing population, rapid development and likely climate change
254 impacts, has a great challenge in safeguarding the health of its population in the face of demographic and environmental changes of a
255 magnitude rarely seen. Hence, this research gap on quantitative and epidemiological studies must be addressed if we are to have an
256 evidence-based adaptation strategy to climate change.

257

258

259

260 **REFERENCES**

- 261 Ahern, M., Kovats, R.S., Wilkinson, P., Few, R., and Matthies, F. 2005. Global health impacts of floods: epidemiologic evidence. *Epidemiol. Rev.*
262 **27**(1): 36-46.
- 263 Arceo, E., Hanna, R., and Oliva, P. 2016. Does the effect of pollution on infant mortality differ between developing and developed countries?
264 Evidence from Mexico City. *Econ. J.* **126**(591): 257-280.
- 265 Barriopedro, D., Gouveia, C.M., Trigo, R.M., and Wang, L. 2012. The 2009/10 drought in China: possible causes and impacts on vegetation. *J.*
266 *Hydrometeorol.* **13**(4): 1251-1267.
- 267 Basu, R., and Samet, J.M. 2002. Relation between elevated ambient temperature and mortality: a review of the epidemiologic evidence.
268 *Epidemiol. Rev.* **24**(2): 190-202.
- 269 Berrang-Ford, L., Ford, J.D., and Paterson, J. 2011. Are we adapting to climate change? *Glob. Environ. Chang.* **21**(1): 25-33.
- 270 Chen, K., Horton, R.M., Bader, D.A., Lesk, C., Jiang, L., Jones, B., Zhou, L., Chen, X., Bi, J., and Kinney, P.L. 2017. Impact of climate change on heat-
271 related mortality in Jiangsu Province, China. *Environmental pollution* **224**: 317-325.
- 272 Corvalan, C., Hales, S., and McMichael, A.J. 2005. Ecosystems and human well-being: health synthesis. World Health Organization.
- 273 Costello, A., Abbas, M., Allen, A., Ball, S., Bell, S., Bellamy, R., Friel, S., Groce, N., Johnson, A., and Kett, M. 2009. Managing the health effects of
274 climate change. *Lancet* **373**(9676): 1693-1733.
- 275 Currie, J., and Neidell, M. 2005. Air pollution and infant health: what can we learn from California's recent experience? *Q. J. Econ* **120**(3): 1003-
276 1030.
- 277 Currie, J., Neidell, M., and Schmieder, J.F. 2009. Air pollution and infant health: lessons from New Jersey. *J. Health Econ.* **28**(3): 688-703.
- 278 D'Amato, G., Baena-Cagnani, C.E., Cecchi, L., Annesi-Maesano, I., Nunes, C., Ansotegui, I., D'Amato, M., Liccardi, G., Sofia, M., and Canonica,
279 W.G. 2013. Climate change, air pollution and extreme events leading to increasing prevalence of allergic respiratory diseases. *Multidiscip Respir*
280 *Med.* **8**(1): 12.
- 281 Davidkovová, H., Plavcová, E., Kynčl, J., and Kyselý, J. 2014. Impacts of hot and cold spells differ for acute and chronic ischaemic heart diseases.
282 *BMC Public Health* **14**(1): 480.
- 283 De'Donato, F.K., Leone, M., Noce, D., Davoli, M., and Michelozzi, P. 2013. The impact of the February 2012 cold spell on health in Italy using
284 surveillance data. *PLoS One* **8**(4).
- 285 De'er, Z., and Youye, L. 2010. A long lasting and extensive drought event over China during 1876-1878. *Adv. Clim. Change Res.* **2**: 009.
- 286 Demirkesen, A.C., and Evrendilek, F. 2017. Compositing climate change vulnerability of a Mediterranean region using spatiotemporally dynamic
287 proxies for ecological and socioeconomic impacts and stabilities. *Environ. Monit. Assess.* **189**(1): 29.
- 288 Ding, Y., Ren, G., Zhao, Z., Xu, Y., Luo, Y., Li, Q., and Zhang, J. 2007. Detection, causes and projection of climate change over China: an overview of
289 recent progress. *Adv. Atmos. Sci.* **24**(6): 954-971.
- 290 Du, W., FitzGerald, G.J., Clark, M., and Hou, X.-Y. 2010. Health impacts of floods. *Prehosp. Disaster Med.* **25**(3): 265-272.
- 291 Easterling, D.R., Evans, J., Groisman, P.Y., Karl, T.R., Kunkel, K.E., and Ambenje, P. 2000. Observed variability and trends in extreme climate
292 events: a brief review. *Bulletin of the American Meteorological Society* **81**(3): 417-425.

293 Epstein, P.R. 2001. Climate change and emerging infectious diseases. *Microbes and infection* **3**(9): 747-754.

294 Fang, J., Liu, W., Yang, S., Brown, S., Nicholls, R.J., Hinkel, J., Shi, X., and Shi, P. 2017. Spatial-temporal changes of coastal and marine disasters
295 risks and impacts in Mainland China. *Ocean Coast Manag.* **139**: 125-140.

296 Frumkin, H., Hess, J., Luber, G., Malilay, J., and McGeehin, M. 2008. Climate change: the public health response. *Am. J. Public Health* **98**(3): 435-
297 445.

298 Füssel, H.-M. 2007. Vulnerability: A generally applicable conceptual framework for climate change research. *Global Environmental Change* **17**(2):
299 155-167. doi: <https://doi.org/10.1016/j.gloenvcha.2006.05.002>.

300 Füssel, H.-M., and Klein, R.J. 2006. Climate change vulnerability assessments: an evolution of conceptual thinking. *Clim. Change* **75**(3): 301-329.

301 Galea, S., Nandi, A., and Vlahov, D. 2005. The epidemiology of post-traumatic stress disorder after disasters. *Epidemiol. Rev.* **27**(1): 78-91.

302 Gao, M., Guttikunda, S.K., Carmichael, G.R., Wang, Y., Liu, Z., Stanier, C.O., Saide, P.E., and Yu, M. 2015. Health impacts and economic losses
303 assessment of the 2013 severe haze event in Beijing area. *Sci. Total Environ.* **511**: 553-561.

304 Gautam, K., and Van Der Hoek, E. 2003. Literature study on environmental impact of floods. DC1-233-13.

305 Ge, Y., Dou, W., and Liu, N. 2017. Planning Resilient and Sustainable Cities: Identifying and Targeting Social Vulnerability to Climate Change.
306 *Sustainability* **9**(8): 1394.

307 Guo, S., Wang, J., Xiong, L., Ying, A., and Li, D. 2002. A macro-scale and semi-distributed monthly water balance model to predict climate change
308 impacts in China. *J. Hydrol.* **268**(1): 1-15.

309 Guo, Y., Jiang, F., Peng, L., Zhang, J., Geng, F., Xu, J., Zhen, C., Shen, X., and Tong, S. 2012. The association between cold spells and pediatric
310 outpatient visits for asthma in Shanghai, China. *PLoS One* **7**(7).

311 Guoju, X., Weixiang, L., Qiang, X., Zhaojun, S., and Jing, W. 2005. Effects of temperature increase and elevated CO₂ concentration, with
312 supplemental irrigation, on the yield of rain-fed spring wheat in a semiarid region of China. *Agricultural Water Management* **74**(3): 243-255.

313 Heltberg, R., Siegel, P.B., and Jorgensen, S.L. 2009. Addressing human vulnerability to climate change: toward a 'no-regrets' approach. *Glob.*
314 *Environ. Chang.* **19**(1): 89-99.

315 Hillen, M.A., Gutheil, C.M., Strout, T.D., Smets, E., and Han, P.K. 2017. Tolerance of uncertainty: conceptual analysis, integrative model, and
316 implications for healthcare. *Soc. Sci. Med.* **180**(C): 62-75.

317 Hopkinson, N., Hart, N., Jenkins, G., Kaminski, N., Rosenfeld, M., Smyth, A., and Wilkinson, A. 2017. Climate change and lung health: the
318 challenge for a new president. *Thorax* **72**(4): 295-296.

319 Hu, G. 2017. China's cost of handling climate change. *In* *The Cost of Development in China*. Springer. pp. 489-506.

320 Huang, W., Kan, H., and Kovats, S. 2010. The impact of the 2003 heat wave on mortality in Shanghai, China. *Sci. Total Environ.* **408**(11): 2418-
321 2420.

322 Jacob, D.J., and Winner, D.A. 2009. Effect of climate change on air quality. *Atmos. Environ.* **43**(1): 51-63.

323 Jonkman, S.N. 2005. Global perspectives on loss of human life caused by floods. *Nat. Hazards* **34**(2): 151-175.

324 Jonkman, S.N., and Kelman, I. 2005. An analysis of the causes and circumstances of flood disaster deaths. *Disasters* **29**(1): 75-97.

325 Kan, H. 2011. Climate change and human health in China. *Environ. Health Perspect.* **119**(2): A60.

326 Kan, H., Chen, R., and Tong, S. 2012. Ambient air pollution, climate change, and population health in China. *Environ. Int.* **42**: 10-19.

327 Kang, R., Xun, H., Zhang, Y., Wang, W., Wang, X., Jiang, B., and Ma, W. 2015. Impacts of Different Grades of Tropical Cyclones on Infectious
328 Diarrhea in Guangdong, 2005-2011. *PLoS One* **10**(6): e0131423.

329 Kang, S., Hao, X., Du, T., Tong, L., Su, X., Lu, H., Li, X., Huo, Z., Li, S., and Ding, R. 2017. Improving agricultural water productivity to ensure food
330 security in China under changing environment: from research to practice. *Agric Water Manag.* **179**: 5-17.

331 Kim, K.-H., Kabir, E., and Kabir, S. 2015. A review on the human health impact of airborne particulate matter. *Environ. Int.* **74**: 136-143.

332 Kinney, P.L. 2008. Climate change, air quality, and human health. *Am. J. Prev. Med.* **35**(5): 459-467.

333 Kok, M., and Jäger, J. 2009. Vulnerability of people and the environment: challenges and opportunities: background report on Chapter 7 of the
334 Fourth Global Environment Outlook (GEO-4). Netherlands Environment Assessment Agency.

335 Leichenko, R.M., and O'Brien, K.L. 2002. The dynamics of rural vulnerability to global change: the case of southern Africa. *Mitig. adapt. strategies*
336 *glob. chang.* **7**(1): 1-18.

337 Li, J., Xu, X., Yang, J., Liu, Z., Xu, L., Gao, J., Liu, X., Wu, H., Wang, J., and Yu, J. 2017a. Ambient high temperature and mortality in Jinan, China: A
338 study of heat thresholds and vulnerable populations. *Environ. Res.* **156**: 657-664.

339 Li, T., Horton, R., Bader, D., Zhou, M., Liang, X., Ban, J., Sun, Q., and Kinney, P. 2016. Aging will amplify the heat-related mortality risk under a
340 changing climate: projection for the elderly in Beijing, China. *Sci. Rep.* **6**: 28161.

341 Li, Y., Li, C., Luo, S., He, J., Cheng, Y., and Jin, Y. 2017b. Impacts of extremely high temperature and heatwave on heatstroke in Chongqing, China.
342 *Environ. Sci. Pollut. Res.* **24**(9): 8534-8540.

343 Liang, L., and Gong, P. 2017. Climate change and human infectious diseases: a synthesis of research findings from global and spatio-temporal
344 perspectives. *Environ. Int.* **103**: 99-108.

345 Lilai, X., Yuanrong, H., and Wei, H. 2016. A multi-dimensional integrated approach to assess flood risks on a coastal city, induced by sea-level rise
346 and storm tides. *Environ. Res. Lett.* **11**(1): 014001.

347 Lu, X., and Zhao, B. 2013. Analysis of the climatic characteristics of landing tropical cyclones in East China. *J Trop Meteorol* **19**(2).

348 Luber, G., and McGeehin, M. 2008. Climate change and extreme heat events. *Am. J. Prev. Med.* **35**(5): 429-435.

349 Luo, M., and Lau, N.-C. 2017. Heat waves in southern China: synoptic behavior, long-term change, and urbanization effects. *J. Clim.* **30**(2): 703-
350 720.

351 Ma, W., Yang, C., Chu, C., Li, T., Tan, J., and Kan, H. 2013. The impact of the 2008 cold spell on mortality in Shanghai, China. *Int. J. Biometeorol.*
352 **57**(1): 179-184.

353 Ma, W., Zeng, W., Zhou, M., Wang, L., Rutherford, S., Lin, H., Liu, T., Zhang, Y., Xiao, J., and Zhang, Y. 2015. The short-term effect of heat waves
354 on mortality and its modifiers in China: an analysis from 66 communities. *Environ. Int.* **75**: 103-109.

355 Massad, E., Coutinho, F.A.B., Lopez, L.F., and Da Silva, D.R. 2011. Modeling the impact of global warming on vector-borne infections. *Phys. Life*
356 *Rev* **8**(2): 169-199.

357 McMichael, A.J. 2003. Global climate change and health: an old story writ large. *Climate change and human health: Risks and responses*. Geneva,
358 Switzerland: World Health Organization.

359 McMichael, A.J., Woodruff, R.E., and Hales, S. 2006. Climate change and human health: present and future risks. *Lancet* **367**(9513): 859-869.

360 Myers, S.S., Smith, M.R., Guth, S., Golden, C.D., Vaitla, B., Mueller, N.D., Dangour, A.D., and Huybers, P. 2017. Climate change and global food
361 systems: Potential impacts on food security and undernutrition. *Annu. Rev. Public Health* **38**: 259-277.

362 Neira, M., and Prüss-Ustün, A. 2016. Preventing disease through healthy environments: A global assessment of the environmental burden of
363 disease. *Toxicol. Lett.*(259): S1.

364 O'Connor, J.E., and Costa, J.E. 2004. The world's largest floods, past and present: their causes and magnitudes. *US Geological Survey*
365 *Circular*(1254): 1-13.

366 Otto, I.M., Reckien, D., Reyer, C.P., Marcus, R., Le Masson, V., Jones, L., Norton, A., and Serdeczny, O. 2017. Social vulnerability to climate
367 change: a review of concepts and evidence. *Reg. Environ. Chang.* **17**(6): 1651-1662.

368 Pahl-Wostl, C. 2007. Transitions towards adaptive management of water facing climate and global change. *Water Resour Manag* **21**(1): 49-62.

369 Pan, X.-C., and Liu, J. 2011. Study on health effects of dust storms (Asian dusts) in China. *Epidemiology* **22**(1): S26-S27.

370 Patz, J.A., Campbell-Lendrum, D., Holloway, T., and Foley, J.A. 2005. Impact of regional climate change on human health. *Nature* **438**(7066): 310-
371 317.

372 Peel, J.L., Haeuber, R., Garcia, V., Russell, A.G., and Neas, L. 2013. Impact of nitrogen and climate change interactions on ambient air pollution
373 and human health. *Biogeochemistry* **114**(1-3): 121-134.

374 Piao, S., Ciais, P., Huang, Y., Shen, Z., Peng, S., Li, J., Zhou, L., Liu, H., Ma, Y., Ding, Y., Friedlingstein, P., Liu, C., Tan, K., Yu, Y., Zhang, T., and Fang,
375 J. 2010. The impacts of climate change on water resources and agriculture in China. *Nature* **467**(7311): 43-51.

376 Portier, C.J., Tart, K.T., Carter, S.R., Dilworth, C.H., Grambsch, A.E., Gohlke, J., Hess, J., Howard, S., Luber, G., and Lutz, J. 2013. A human health
377 perspective on climate change: a report outlining the research needs on the human health effects of climate change. *Journal of Current Issues in*
378 *Globalization* **6**(4): 621.

379 Qin, D., Ding, Y., and Mu, M. 2015. *Climate and environmental change in China: 1951–2012*. Springer.

380 Robinson, P.J. 2001. On the definition of a heat wave. *J. Appl. Meteorol.* **40**(4): 762-775.

381 Rytty, N.R., Guo, Y., and Jaakkola, J.J. 2016. Global association of cold spells and adverse health effects: a systematic review and meta-analysis.
382 *Environ. Health Perspect.* **124**(1): 12.

383 Schwartz, J. 2000. Harvesting and long term exposure effects in the relation between air pollution and mortality. *Am. J. Epidemiol.* **151**(5): 440-
384 448.

385 Shao-Hong, W., Tao, P., and Shan-Feng, H. 2012. Climate change risk research: a case study on flood disaster risk in China. *Adv. Clim. Change Res.*
386 **3**(2): 92-98.

387 Sheffield, J., Wood, E.F., and Roderick, M.L. 2012. Little change in global drought over the past 60 years. *Nature* **491**(7424): 435-438.

388 Shi, Y., Shen, Y., Li, D., Zhang, G., Ding, Y., Hu, R., and Kang, E. 2003. Discussion on the present climate change from warm-dry to warm-wet in
389 northwest China. *J. Quaternary Sci.* **23**(2): 152-164.

390 Staddon, P.L., Montgomery, H.E., and Depledge, M.H. 2014. Climate warming will not decrease winter mortality. *Nature Climate Change* **4**(3):
391 190-194.

392 Stanke, C., Kerac, M., Prudhomme, C., Medlock, J., and Murray, V. 2013. Health effects of drought: a systematic review of the evidence. *PLoS*
393 *Currents* **5**.

394 Stedman, J.R. 2004. The predicted number of air pollution related deaths in the UK during the August 2003 heatwave. *Atmos. Environ.* **38**(8):
395 1087-1090.

396 Thow, A., and de Blois, M. 2008. Climate change and human vulnerability: Mapping emerging trends and risk hotspots for humanitarian actors.
397 Report to the UN Office for Coordination of Humanitarian Affairs by Maplecroft, Bath.

398 Tian, H., Zhou, S., Dong, L., Van Boeckel, T.P., Cui, Y., Newman, S.H., Takekawa, J.Y., Prosser, D.J., Xiao, X., and Wu, Y. 2015. Avian influenza H5N1
399 viral and bird migration networks in Asia. *Proc. Natl. Acad. Sci.* **112**(1): 172-177.

400 Tian, Z., Li, S., Zhang, J., Jaakkola, J.J., and Guo, Y. 2012. Ambient temperature and coronary heart disease mortality in Beijing, China: a time
401 series study. *Environ. Health* **11**(1): 56.

402 Turner, B.L., Kasperson, R.E., Matson, P.A., McCarthy, J.J., Corell, R.W., Christensen, L., Eckley, N., Kasperson, J.X., Luers, A., and Martello, M.L.
403 2003. A framework for vulnerability analysis in sustainability science. *Proc. Natl. Acad. Sci.* **100**(14): 8074-8079.

404 Wang, J., Gao, W., Xu, S., and Yu, L. 2012a. Evaluation of the combined risk of sea level rise, land subsidence, and storm surges on the coastal
405 areas of Shanghai, China. *Climatic change* **115**(3-4): 537-558.

406 Wang, J., Gao, W., Xu, S., and Yu, L. 2012b. Evaluation of the combined risk of sea level rise, land subsidence, and storm surges on the coastal
407 areas of Shanghai, China. *Clim. Change* **115**(3-4): 537-558.

408 Wang, J., Ye, M., Liu, Y., and Xu, S. 2011. Design of integrated toolkit for coastal natural disaster risk assessment based on GIS technology. *In*
409 *Geoinformatics, 2011 19th International Conference on*. IEEE. pp. 1-6.

410 Wang, K., Zhong, S., Wang, X., Wang, Z., Yang, L., Wang, Q., Wang, S., Sheng, R., Ma, R., and Lin, S. 2017. Assessment of the public health risks
411 and impact of a tornado in Funing, China, 23 June 2016: a retrospective analysis. *Int. J. Environ. Res. Public Health* **14**(10): 1201.

412 Wang, X., Dong, Z., Zhang, J., and Liu, L. 2004. Modern dust storms in China: an overview. *J. Arid Environ.* **58**(4): 559-574.

413 Watts, N., Adger, W.N., Agnolucci, P., Blackstock, J., Byass, P., Cai, W., Chaytor, S., Colbourn, T., Collins, M., and Cooper, A. 2015. Health and
414 climate change: policy responses to protect public health. *Lancet* **386**(10006): 1861-1914.

415 Wellner, R.W., and Bartek, L.R. 2003. The effect of sea level, climate, and shelf physiography on the development of incised-valley complexes: a
416 modern example from the East China Sea. *J. Sediment. Res.* **73**(6): 926-940.

417 Wu, X., Lu, Y., Zhou, S., Chen, L., and Xu, B. 2016. Impact of climate change on human infectious diseases: empirical evidence and human
418 adaptation. *Environ. Int.* **86**: 14-23.

419 Yao-Dong, D., Xian-Wei, W., Xiao-Feng, Y., Wen-Jun, M., Hui, A., and Xiao-Xuan, W. 2013. Impacts of climate change on human health and
420 adaptation strategies in South China. *Adv. Clim. Change Res.* **4**(4): 208-214.

421 Ye, Q., and Glantz, M. 2005. The 1998 Yangtze floods: The use of short-term forecasts in the context of seasonal to interannual water resource
422 management. *Mitig. adapt. strategies glob. chang.* **10**(1): 159-182.

423 Yin, H., Xu, L., and Cai, Y. 2015. Monetary Valuation of PM10-Related Health Risks in Beijing China: The Necessity for PM10 Pollution Indemnity.
424 *Int. J. Environ. Res. Public Health* **12**(8): 9967-9987.

425 Yin, Q., and Wang, J. 2017. The association between consecutive days' heat wave and cardiovascular disease mortality in Beijing, China. *BMC*
426 *Public Health* **17**(1): 223.

427 Yong-Jian, R., Jiang-Xue, C., Su-Qin, W., Min, L., Zheng-Hong, C., Yu-Fang, L., and Ji-Jun, W. 2013. Climate change impacts on central China and
428 adaptation measures. *Adv. Clim. Change Res.* **4**(4): 215-222.

429 Yu, M., Li, Q., Hayes, M.J., Svoboda, M.D., and Heim, R.R. 2014. Are droughts becoming more frequent or severe in China based on the
430 standardized precipitation evapotranspiration index: 1951–2010? *Int. J. Climatol.* **34**(3): 545-558.

431 Yu, P., Tian, H., Ma, C., Ma, C., Wei, J., Lu, X., Wang, Z., Zhou, S., Li, S., and Dong, J. 2015. Hantavirus infection in rodents and haemorrhagic fever
432 with renal syndrome in Shaanxi province, China, 1984–2012. *Epidemiol. Infect.* **143**(2): 405-411.

433 Zeng, W., Lao, X., Rutherford, S., Xu, Y., Xu, X., Lin, H., Liu, T., Luo, Y., Xiao, J., and Hu, M. 2014. The effect of heat waves on mortality and effect
434 modifiers in four communities of Guangdong Province, China. *Sci. Total Environ.* **482**: 214-221.

435 Zeng, Y., Gu, D., Purser, J., Hoenig, H., and Christakis, N. 2010. Associations of environmental factors with elderly health and mortality in China.
436 *Am. J. Public Health* **100**(2): 298-305.

437 Zhai, P., Zhang, X., Wan, H., and Pan, X. 2005. Trends in total precipitation and frequency of daily precipitation extremes over China. *Journal of*
438 *climate* **18**(7): 1096-1108.

439 Zhang, D.-E. 2012. A study of the large scale flooding over eastern China in 1755. *Adv. Clim. Change Res.* **3**(3): 128-137.

440 Zhang, J., and Liu, Z. 2006. Hydrological monitoring and flood management in China. *IAHS Publications-Series of Proceedings and Reports* **305**:
441 93-102.

442 Zhang, J., Zhou, C., Xu, K., and Watanabe, M. 2002. Flood disaster monitoring and evaluation in China. *Global Environmental Change Part B:*
443 *Environmental Hazards* **4**(2): 33-43.

444 Zhang, M., Song, Y., Cai, X., and Zhou, J. 2008. Economic assessment of the health effects related to particulate matter pollution in 111 Chinese
445 cities by using economic burden of disease analysis. *J. Environ. Manage.* **88**(4): 947-954.

446 Zhang, Y., Feng, R., Wu, R., Zhong, P., Tan, X., Wu, K., and Ma, L. 2017. Global climate change: impact of heat waves under different definitions
447 on daily mortality in Wuhan, China. *Global Health Research and Policy* **2**(1): 10.

448 Zhao, Y., Cheng, Z., Lu, Y., Chang, X., Chan, C., Bai, Y., Zhang, Y., and Cheng, N. 2017. PM10 and PM2.5 particles as main air pollutants
449 contributing to rising risks of coronary heart disease: a systematic review. *Environmental Technology Reviews* **6**(1): 174-185.

450 Zheng, J.-Y., Wang, W.-C., Ge, Q.-S., Man, Z.-M., and Zhang, P.-Y. 2006. Precipitation variability and extreme events in eastern China during the
451 past 1500 years. *Terr Atmos Ocean Sci* **17**(3): 579-592.

452 Zheng, J., Han, W., Jiang, B., Ma, W., and Zhang, Y. 2017. Infectious Diseases and Tropical Cyclones in Southeast China. *Int. J. Environ. Res. Public*
453 *Health* **14**(5): 494.

454 Zhou, L., Chen, K., Chen, X., Jing, Y., Ma, Z., Bi, J., and Kinney, P.L. 2017. Heat and mortality for ischemic and hemorrhagic stroke in 12 cities of
455 Jiangsu Province, China. *Sci. Total Environ.* **601**: 271-277.

456 Zhou, M., Wang, H., Zhu, J., Chen, W., Wang, L., Liu, S., Li, Y., Wang, L., Liu, Y., and Yin, P. 2016. Cause-specific mortality for 240 causes in China
457 during 1990–2013: a systematic subnational analysis for the Global Burden of Disease Study 2013. *Lancet* **387**(10015): 251-272.

458 Zhou, M.G., Wang, L.J., Liu, T., Zhang, Y.H., Lin, H.L., Luo, Y., Xiao, J.P., Zeng, W.L., Zhang, Y.W., and Wang, X.F. 2014. Health impact of the 2008
459 cold spell on mortality in subtropical China: the climate and health impact national assessment study (CHINAs). *Environ. Health* **13**(1): 60.

460 Zong, Y., and Chen, X. 2000. The 1998 flood on the Yangtze, China. *Nat. Hazards* **22**(2): 165-184.

461 Zou, Y., and Zhao, P. 2010. Comparison of some tropical cyclone datasets and correction of yearbook data. 熱帶氣象學報 (英文版) **16**(2): 109-
462 114.

463

464 **LIST OF FIGURES AND TABLES**

465 Figure 1:Prisma flow chart for literature review

466 Figure 2: Vulnerability factors (Based on Thow and De Blois, 2008).

467 Figure 3: Health impacts of climate change

468

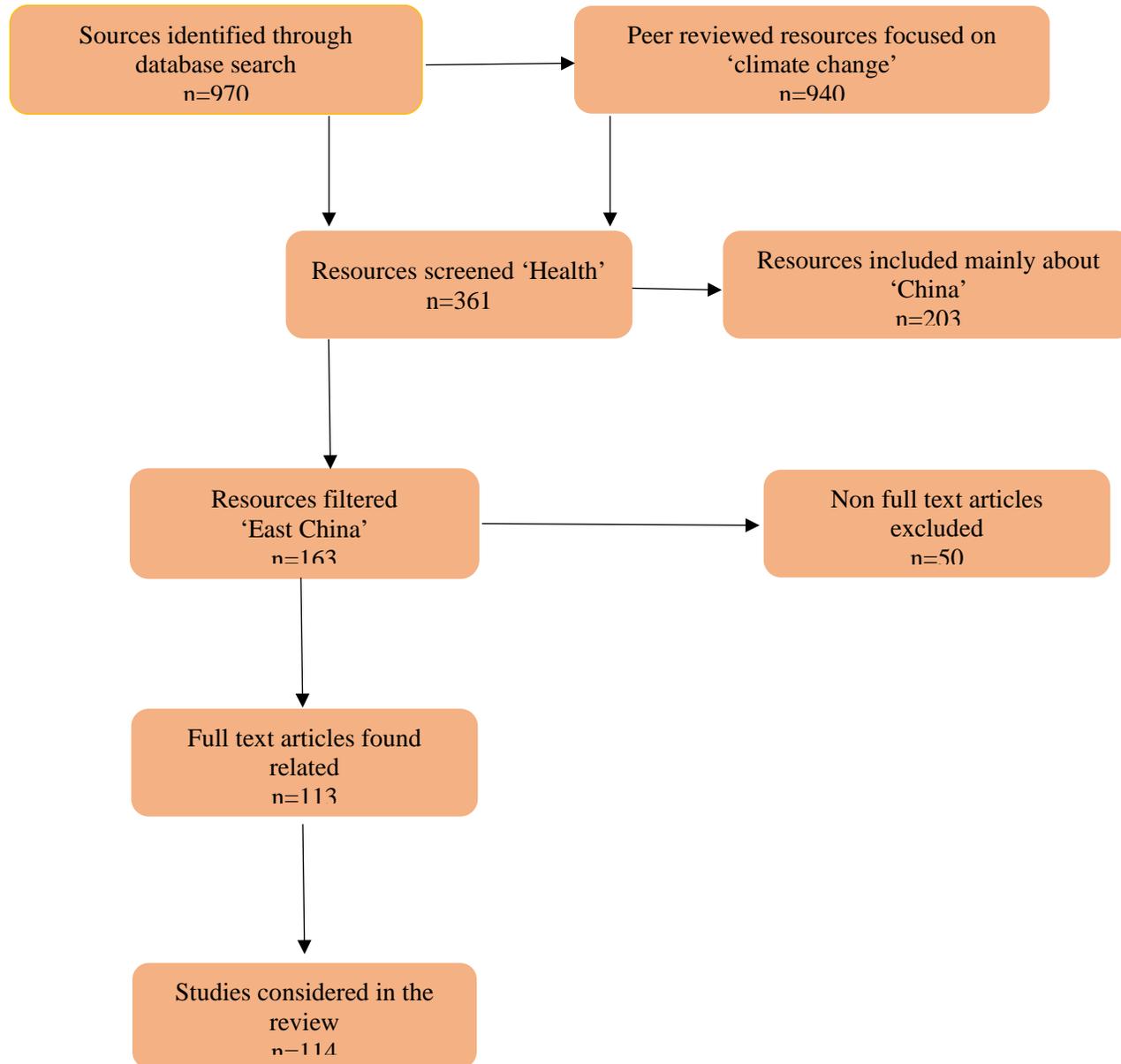
469 Table 1: Various concepts of vulnerability (Based on Füssel 2007)

470 Table 2: Climate change impacts and impacts on health

471

472 Figure 1:Prisma flow chart for literature review

473
474
475
476
477
478
479
480
481
482
483
484
485



486 Table 1: Various concepts of vulnerability (Based on Füssel 2007)

System

(The system or region and/or population group and/or sector of concern.)

- Human Environment System
- Geographical Region
- Economic Sector
- Natural System

Attribute of Concerns (The valued attribute (or variables of concern) of the vulnerable system that are threatened by its exposure to the hazard.)

- Human Health and Life
- Existence and Natural Identity
- Biodiversity and Ecosystem Services
- Income and Livelihood

Hazards

(The external stressor (or set of stressors) of concern.)

- External- Floods
- Internal- Unsustainable Farming Practices

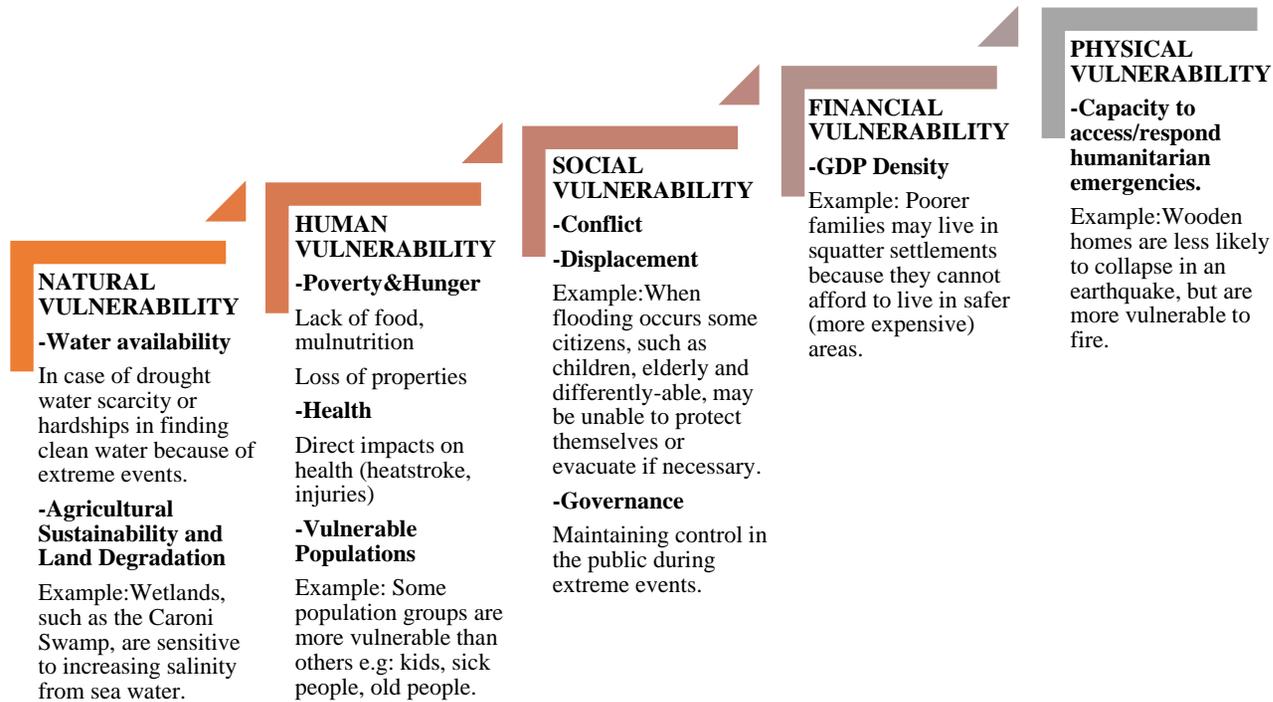
Temporal Reference

(The time period of interest.)

- Current
- Future

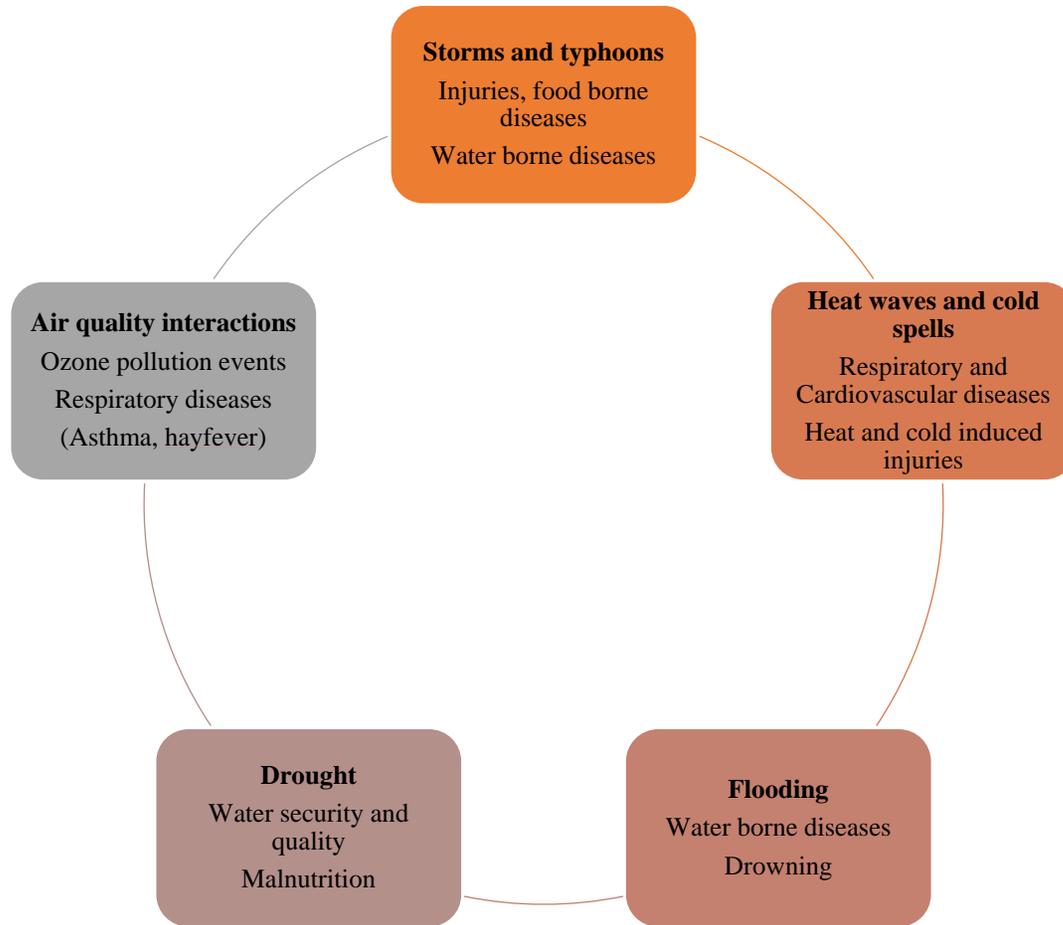
487

488 Figure 2: Vulnerability factors (Based on Thow and De Blois, 2008).



489

490 Figure 3: Health impacts of climate change



491

492

493 Table 2: Climate change impacts and impacts on health

494

Climate Change Impacts on Health				
Storms and Typhoons	Heatwaves and Cold Spells	Flooding	Drought	Air Quality Interactions
Increased number of storms and typhoons, East China is strictly affected (Lu and Zhao 2013)	Increase in frequency (Luber and McGeehin 2008; Robinson 2001), less attention given to cold spells (Staddon et al. 2014)	Have led to the highest number of mortalities in the 20th century (O'Connor and Costa 2004)	1900-2012, people in China severely affected by drought (Stanke et al. 290 2013)	Respiratory infections, cardiovascular diseases, and lung cancer (Arceo et al. 300 2016; Currie and Neidell 2005; Currie et al. 2009)
Guangdong, potential loss in economy and health(Kang et al. 2015)	Vulnerable population groups susceptible to extreme temperatures, both hot and cold (Davídkovová et al. 2014; Tian et al. 2012; Li et al. 2016; De'Donato et al. 2013; Ma et al. 2013)	Flooding is of great concern to the different levels of Chinese government (Zhang and Liu 2006)	Malnutrition and mortality, water-related diseases, airborne and dust-related diseases, vector borne diseases; mental health effects (Stanke et al. 2013)	Air pollutants-increase the risk of coronary heart disease mortality and respiratory problems (PM10, PM2.5) (Zhao et al. 2017; D'Amato et al. 2013)
Increased risk of transmitted infectious diseases (Zheng et al. 2017; Kang et al. 2015)	Extreme heat can cause heat stroke and dehydration, as well as cardiovascular, respiratory, and cerebrovascular disease risks (Yao-Dong et al. 2013; Zeng et al. 2014).	East China is severely affected by floods throughout the history (Zhang 2012)	Northwest, North, and Northeast of China -increase in droughts frequency (Yu et al. 2014)	PM ₁₀ induced health losses are evident in China (Zhang et al. 2008)
Public health risks and impacts of a tornado in Funing, East China elderly (75-84 year group) with highest risk of death (Wang et al. 2017)	Metropolitan areas in the Pearl River Delta are at risk of extreme heat (Yao-Dong et al. 2013)	East China-measuring 130,000km ² was flooded resulting in health impacts including injuries (Gautam and Van Der Hoek 2003; Ye and Glantz 2005; Jonkman 2005; Shao-Hong et al. 2012)		PM _{2.5} is positively related to daily mortality of people especially of older adults (Schwartz 2000)
	5 % excess deaths were linked with heat waves in 66 Chinese communities, with the highest excess deaths in North East and South China (Ma et al. 2015)	Drowning, injuries, hypothermia are direct impacts of flood (Du et al. 2010)		In Beijing some severe haze events were studied (Gao et al. 2015; Yin et al. 2015).
	Increased heart disease mortality in China is linked with extreme temperatures (Guo et al. 2012)	People with limited physical capacity or limited mobility are at particularly high risk (Galea et al. 2005; Jonkman and Kelman 2005)		Respiratory and cardiovascular hospitalization are associated with the dust events after adjusting 319 the effect of sulphur dioxide and/or nitrogen dioxide (Pan and Liu 2011; Wang et al. 2004)
	Cold spells lead to increases in patients with fractures due to icy ground(Yao-Dong et al. 2013)	China's coastal region (East China) is physically vulnerable to coastal flooding (Wang et al. 2011; Ahern et al. 2005; Fang et al. 2017; Zhang et al. 2002; Lilai et al. 2016; Wang et al. 2012a)		