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

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

Abstract

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

Keywords

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

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11.1 Introduction

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

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

11.2 Defining the Problem

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

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

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

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

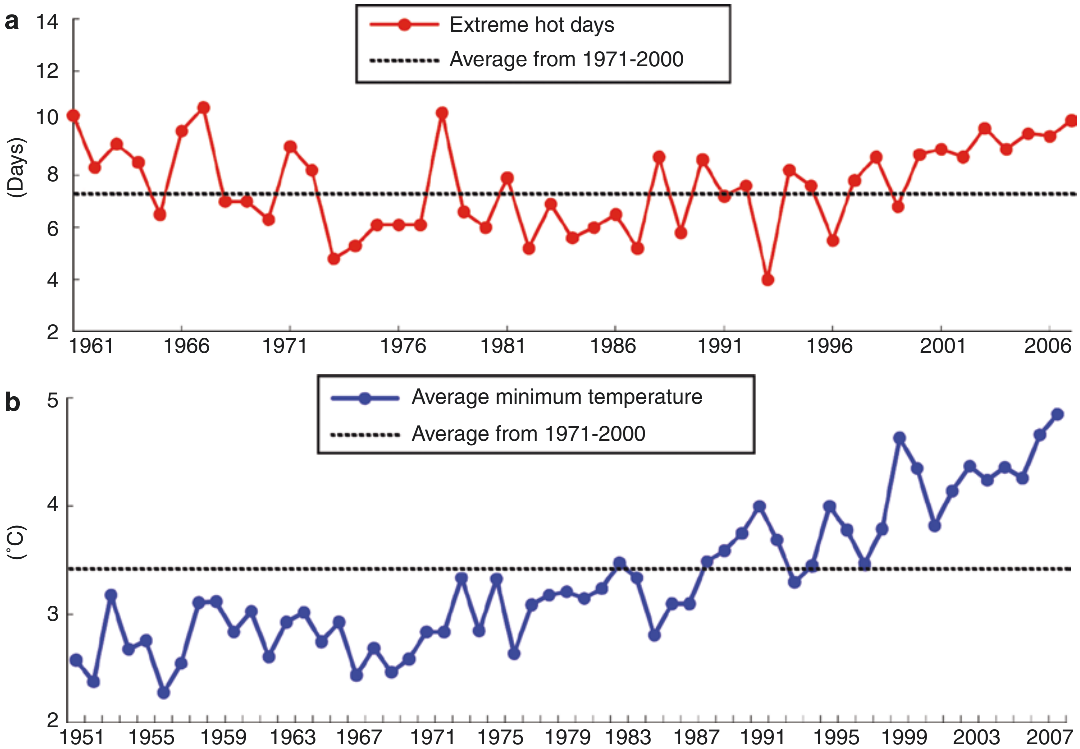

Fig. 11.1 (**a**) Variation of the annual averaged extreme hot days (daily $T_{max} > 35$ °C) during 1951–2007 and (**b**) average annual minimum daily temperature during 1961–2007 in China. Adapted from Luo et al. [6]

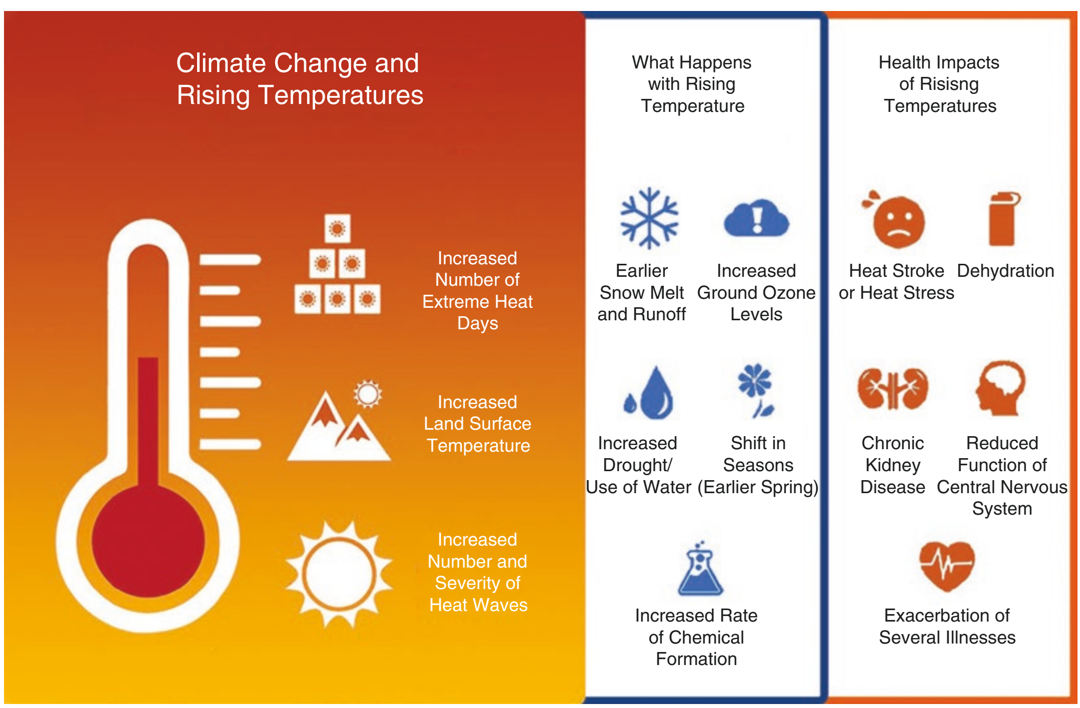

Fig. 11.2 Rising temperature and its health impacts. Adapted from Maggie Bailey et al. [7]

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

11.3 Understanding Susceptibility

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

11.3.1 Outdoor Workers

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

11.3.2 Children and the Elderly

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

11.3.3 Preexisting Diseases

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

11.3.4 Urban Residents

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

11.3.5 Socioeconomic Factors

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

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

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

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

11.4 Future Drivers

11.4.1 Climate Change

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

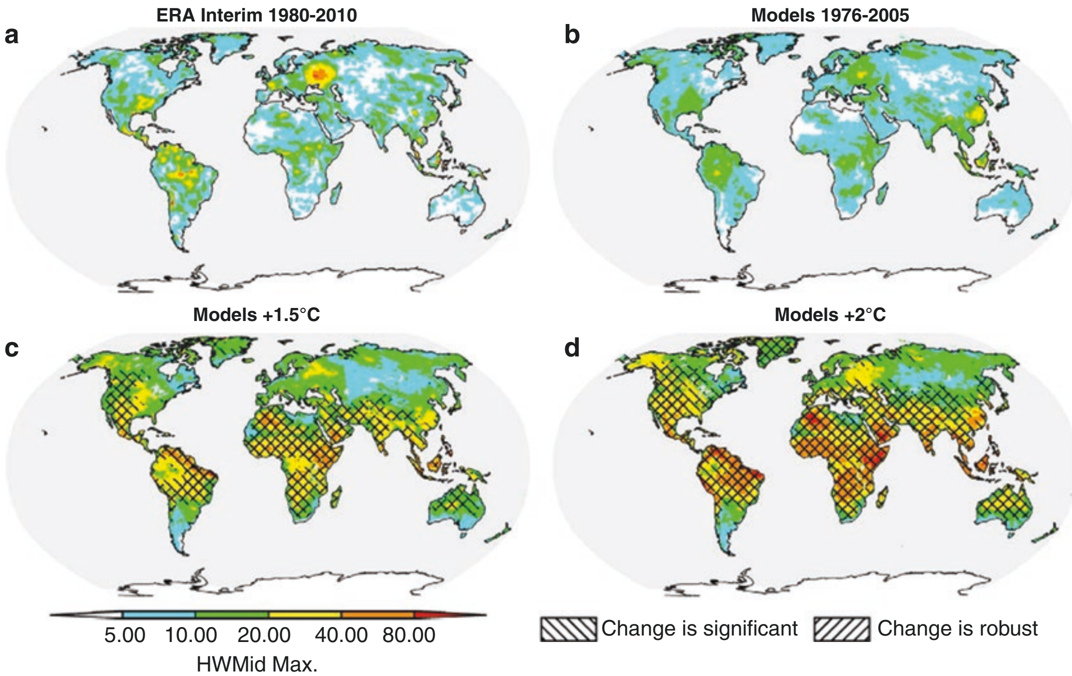

Fig. 11.3 Present and future distribution of heat waves. (**a**) Heat Wave Magnitude Index daily (HWMId) observed during 1980–2010. (**b**) Modeled maximum magnitude during 1976–2005. (**c**) Projected maximum magnitude in a 1.5 °C warming world and (**d**) a 2 °C warming world. Source from an Open Access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

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

11.4.2 Rapid Urbanization

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

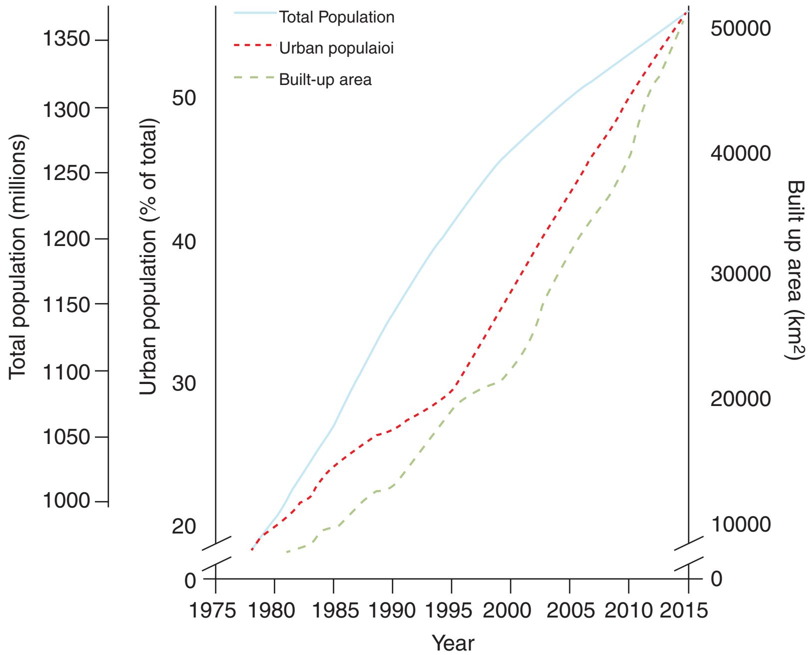

Fig. 11.4 Total population, urban population, and built-up area in China, 1978–2015. Adapted from Yang et al. [53]

11.4.3 Population Aging

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

11.5 Acclimatization Limits

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

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

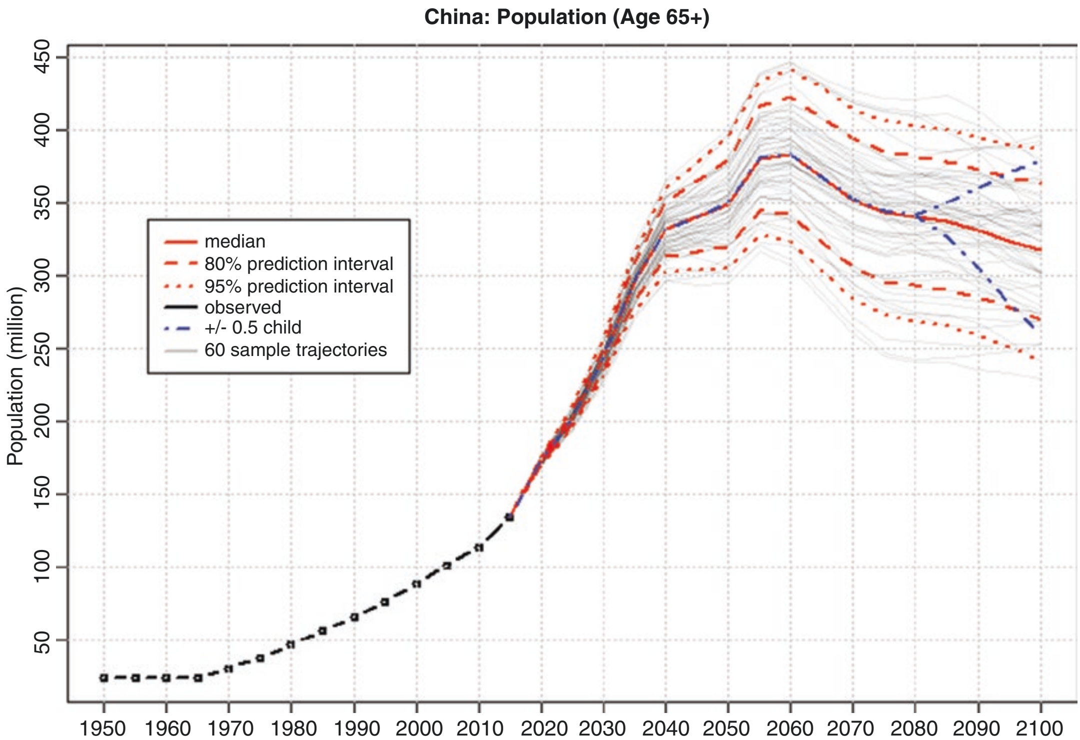

Fig. 11.5 Projections of population aged 65 and over in China. Source from an Open Access article: [54]. (http://esa.un.org/unpd/wpp/)

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

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

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

11.6 Public Health Response and Adaptation Strategies

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

11.6.1 Adaptation Policies

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

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

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

11.6.2 Heat-Health Warning Systems

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

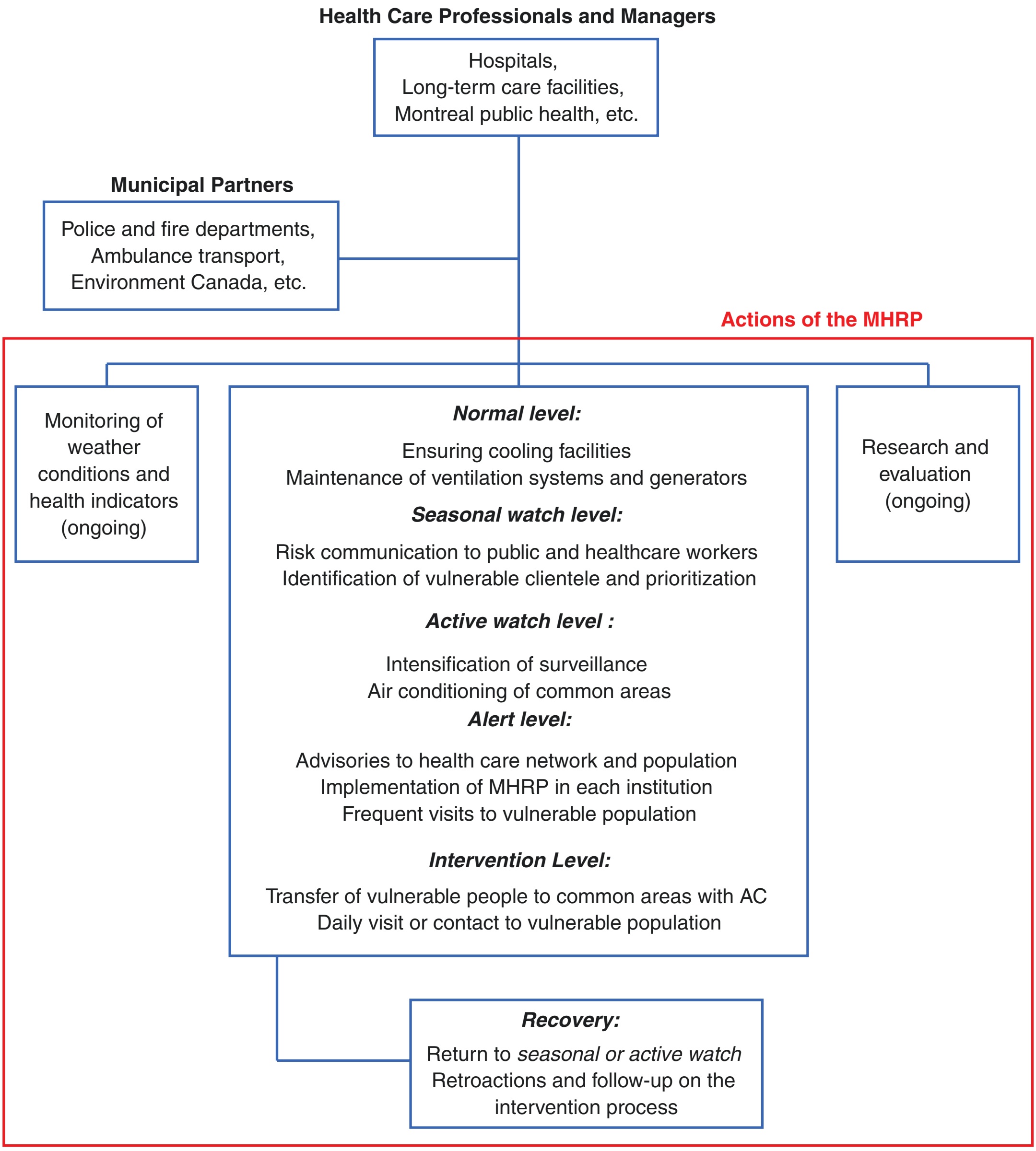

Fig. 11.6 Logic model for the Montreal heat response plan (MHRP). Adapted from Price et al. [69]

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

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

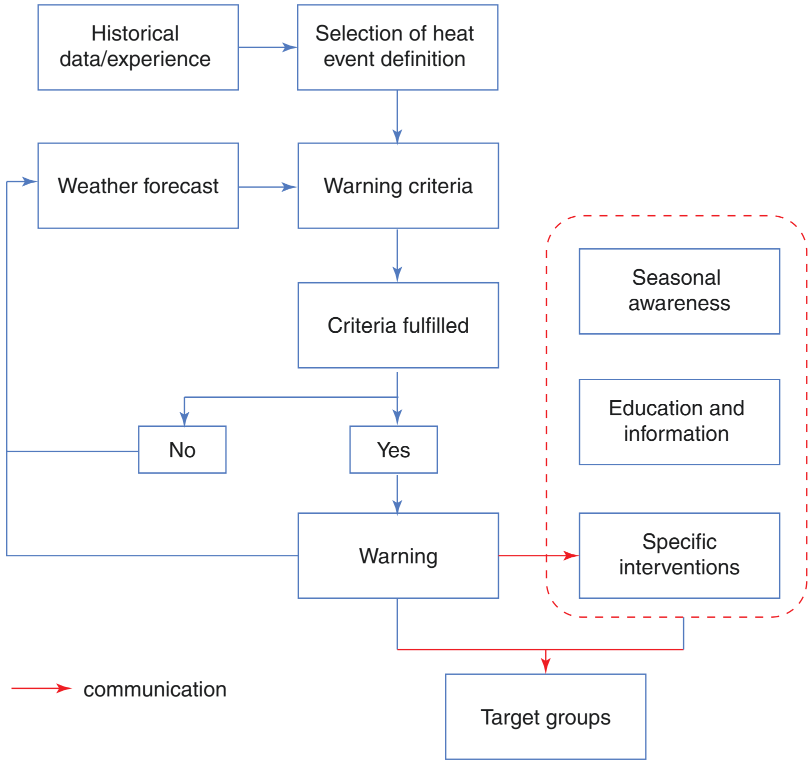

Fig. 11.7 Flow diagram displaying the operation of a typical heat-health warning systems. Adapted from Kalkstein [75]

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

11.6.3 Risk Communication and Behavior Change

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

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

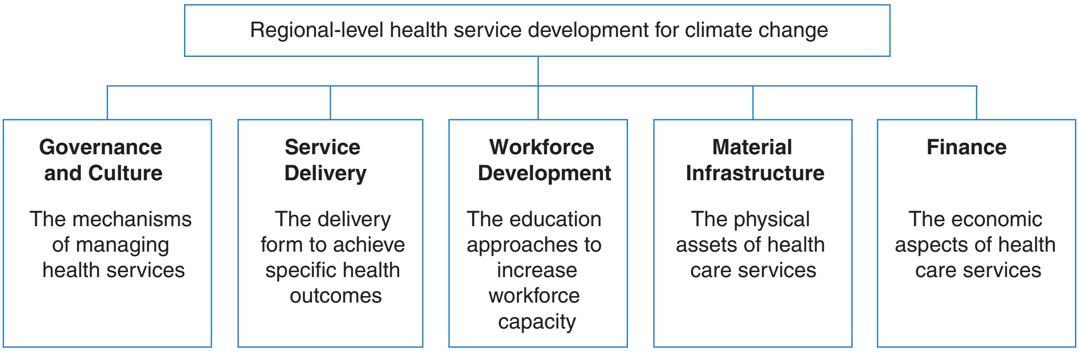

Fig. 11.8 Definition of a whole-of-systems approach to developing health services for climate change. Adapted from Bell [84]

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

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

11.6.4 Provision of Healthcare and Social Services

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

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

11.6.5 Heat Exposure Reduction

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

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

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

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

11.6.6 Urban Planning for Cool City

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

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

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

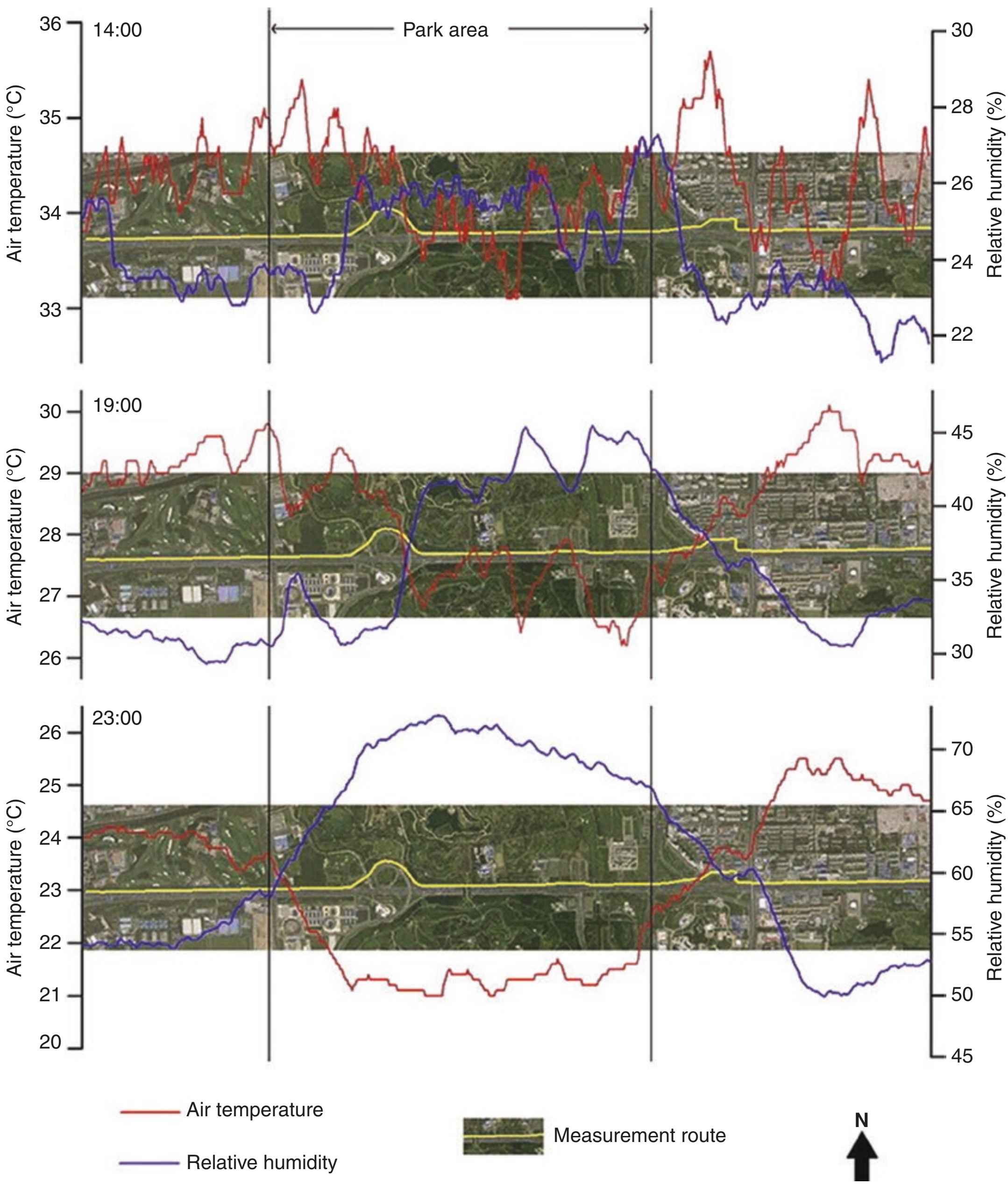

Fig. 11.9 Distribution pattern of temperature and humidity inside and outside the park in Beijing, China (Reproduced with permission from Yan et al. [95] (https://doi.org/10.1016/j.scitotenv.2017.11.327))

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

11.6.7 Vulnerability Mapping

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

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

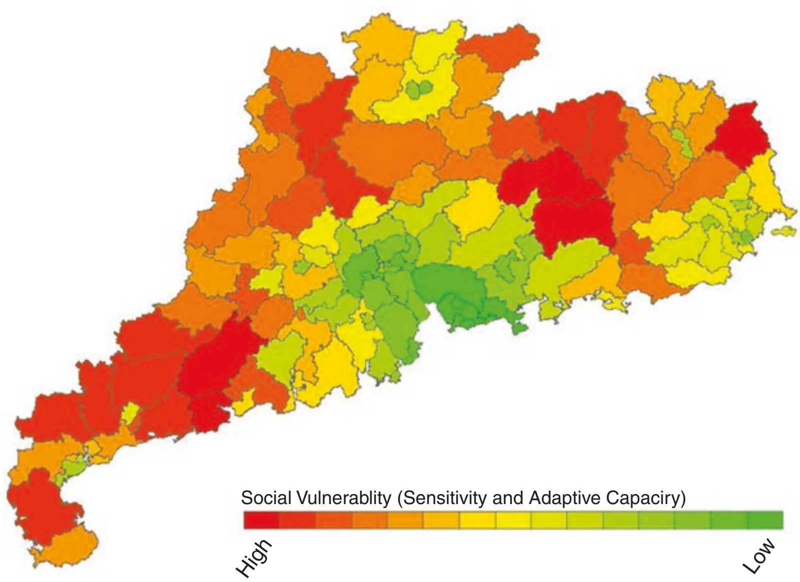

Fig. 11.10 Social vulnerability to heat waves in Guangdong Province, China. Sourced from an Open Access article: [101]. (https://doi.org/10.3402/gha.v7.25051)

11.6.8 Surveillance, Monitoring, and Evaluation

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

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

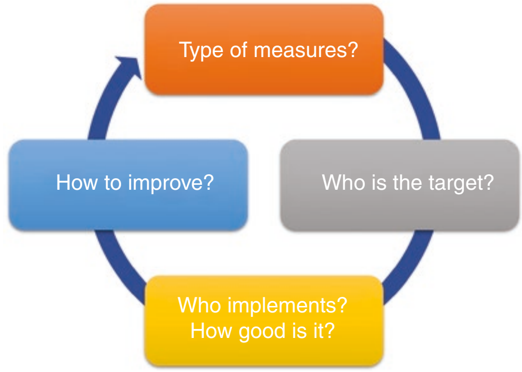

Fig. 11.11 The iterative process for the development and assessment of public health adaptation strategies. Adapted from WHO [74]

11.7 Conclusions

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

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