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Health impacts of heat in a changing climate: how can emerging science inform urban adaptation planning?

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Abstract

Extreme heat is one of the most important global causes of weather-related mortality, and climate change is leading to more frequent and intense heat waves. Recent epidemiologic findings on heat-related health impacts have reinforced our understanding of mortality impacts of extreme heat and have shown a range of impacts on morbidity outcomes including cardiovascular, respiratory and mental health responses. Evidence is also emerging on temporal trends towards decreasing exposure-response, probably reflecting autonomous population adaptation. Many cities are actively engaged in the development of heat adaptation plans to reduce future health impacts. Epidemiologic research into the evolution of local heat-health responses over time can greatly aid adaptation planning for heat, prevention of adverse health outcomes among vulnerable populations, as well as evaluation of new interventions. Such research will be facilitated by the formation of research partnerships involving epidemiologists, climate scientists, and local stakeholders.

Keywords

heat; extreme temperature; climate; health; mortality; morbidity; vulnerable populations; adaptation strategy

1. Introduction

Heat is responsible for more fatalities per year on average than any other weather-related hazard in the United States, according to the National Weather Service [1]. Furthermore, heat-related mortality and morbidity are the most well understood, measureable, and potentially important impacts of climate change on human health [2]. Global mean temperatures have been rising at a rate of about 0.2 °C for the past few decades and are

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expected to rise even more rapidly for the next few decades regardless of the stringency of future greenhouse gas emission reduction policies [3].

Urban areas are thought to be particularly vulnerable to the impacts of heat, since they concentrate large numbers of vulnerable people (e.g., elderly, infirm) in settings where ambient temperatures are often higher than suburban and rural areas. Many cities contain relatively high proportions of older housing stock that may be less well adapted to hot weather. In addition, populations are aging and the prevalence of obesity in adults has been increasing. Being elderly, obese, and/or diabetic are risk factors for heat-related mortality [4–6].

In the face of these challenges, many cities are developing strategies to build greater resilience against heat-related health impacts, often in the context of overall climate adaptation plans. Climate adaptation planning efforts usually involve an assessment of infrastructure and population vulnerabilities to climate extremes and the development of plans to reduce adverse impacts. The overall goal of the present paper is to review the recent epidemiologic literature on heat-related health impacts, and to evaluate the utility of the emerging knowledge base for use in adaptation planning related to heat and health.

2. Health impacts of heat

2.1. Findings from prior reviews

A number of prior literature reviews have examined the impacts of heat on morbidity and mortality. For example, Basu and Samet reviewed studies published since 1970 and found consistent evidence of increased mortality during heat waves, as well positive associations between ambient exposures to heat in general and increased mortality, particularly among the elderly [5]. Individuals with preexisting medical conditions, particularly cardiovascular and respiratory, as well as those of low socioeconomic status, were reported to be at increased risk. In a follow-up study, based on evidence from the epidemiologic studies published since the previous review, Basu confirmed these findings and also concluded that the mortality effects of heat have been observed in response to not only heat waves, but also daily excursions of temperature [4]. While fewer original studies have focused on morbidity, a recent review of the literature has found significant effects of ambient temperature on both total and cause-specific morbidity, including cardiovascular and respiratory hospital visits [7].

Some recent reviews have focused on temperature impacts among the elderly population, due to the elevated mortality and morbidity risks in this age group. Åström and colleagues reported strong and globally consistent relationships between heat exposure and mortality among the elderly [8]. Yu et al. carried out a meta-analysis of recent mortality studies, finding a 2–5% increase in all-cause mortality for 1°C increase during heat exposures [9]. Xu and colleagues reviewed evidence of the impact of ambient temperature on children's health, finding increased sensitivity to ambient temperatures compared to adults and a high risk of heat-related mortality in children under one year of age [10]. Occupational heat exposures have also received increasing attention in the literature and a recent review article has found that workplace heat exposure may pose manual workers at risk of heat stress [11].

Assessment of future temperature-related morbidity and mortality is of particular relevance in light of the projected rise in global average temperatures under a changing climate [3]. A review summarizing the findings from studies assessing future mortality impacts concluded that climate change is likely to result in increased heat-related mortality [12]. However, projecting future heat-related health impacts has been hampered by lack of data on how exposure-response functions will change in the future, due to autonomous and/or planned adaptation.

2.2. Review of Recent Mortality Literature

While a range of exposure metrics have been used to quantify the effects of temperature on mortality, recent evidence suggests that choice of metric has little influence on epidemiologic findings. Most studies have used daily mean, minimum or maximum temperature or composite indices of temperature and humidity such as the Heat Index or apparent temperature and the Humidex. Other exposure metrics such as the Temporal Synoptic Index and Spatial Synoptic Indexbased are based on the Synoptic Climatological Classification [13] and include measures of wind speed, barometric pressure, cloud cover and others. In a study of various exposure metrics, including mean, minimum and maximum temperature, as well as apparent temperature and the Humidex, Barnett and colleagues concluded that all of the metrics were highly correlated and none of them had a better predictive ability [14]. In an analysis of heat-related mortality in New York City, various exposure metrics were also found to perform similarly as predictors of heat-related mortality [15]. Therefore, there is an argument for converging to the consistent use of a small number of simple metrics.

It is important to note, however, that estimates of heat-related mortality do depend on the underlying definition of heat-related deaths. Government reports on heat-related deaths often are based on counting deaths that have been listed on death certificates as heat-related (heat-stroke or hyperthermia). This approach has the advantage of enabling rapid surveillance. However, since heat-related deaths are often underreported, enumeration of deaths directly attributable to heat is likely to significantly underestimate the actual effect size and is rarely utilized in epidemiology studies. The magnitude of this underestimate has not yet been well quantified. Most epidemiologic studies follow a more comprehensive approach that estimates the total burden of heat-related mortality based on a statistical analysis deaths for large cause categories or all causes in relation to observed temperatures.

The impacts of heat on mortality can be assessed in the context of specific heat wave episodes or by analyzing the relationship between elevated temperatures and mortality over long periods of time. Studies utilizing the first approach assess the impacts of temperature on mortality during specific heat waves [16, 17] and compare those data to periods of normal temperatures. Data from such studies can be helpful for improving extreme heat preparedness in communities. The second approach involves regression analysis of long records of daily deaths vs. temperature in a city, while controlling for temporal confounders such as trends, seasonal cycles, day of week patterns, and sometimes air pollution. The derived exposure-response functions can be used to quantify the excess mortality that occurs above arbitrarily chosen threshold temperatures. This approach provides a comprehensive assessment of the heat-mortality relationship at a particular location and can be used to characterize changing effects over time. In addition, the location-specific heat-mortality response functions can be used to estimate potential future impacts of heat under different climate change scenarios.

Mortality displacement or harvesting refers to the phenomenon of deaths occurring as a result of environmental exposure among physically susceptible individuals who would have died several days later if the environmental exposure in question has not occurred [4]. The evidence of harvesting in the heat-health domain has been inconclusive to-date. One study found patterns of mortality displacement to be dependent on population characteristics with London having the highest mortality displacement followed by Sao Paolo and Delhi [18]. Short-term mortality displacement resulting from the 2003 European heat wave was relatively small [17]. A recent study in California did not find evidence of mortality displacement [19].

Recent studies have added to our understanding of characteristics that confer increased risks in response to elevated temperatures (i.e., effect modifiers). Studies suggest increased risks for women [20–22], for individuals with no education or living in low socioeconomic districts [21, 22] and for older age [20, 21, 23, 24]. Recent evidence has also highlighted cardiovascular and respiratory deaths as being especially responsive to heat extremes [22, 25].

Though we focus on heat in the present review, it is important to note that in the context of climate change, it is useful to also consider how cold-related health effects may change in a warming climate. Evaluating cold effects is of value to public health and climate adaptation planning. The epidemiologic analysis of cold impacts has been hampered to-date by problems of confounding by seasonal effects. This is especially problematic when multi-week distributed lags of cold temperatures are used as the temperature exposure metric, since such exposure definitions are strongly counfounded by season. Elevated mortality in winter is driven largely by respiratory infections and associated cardivascular sequelae. Using a two-day lag of cold temperatures, Li and colleagues projected substantial increases of net annual temperature-related mortality in New York City across a wide range of climate models and scenarios [26]. A few other studies that have quantified both heat- and cold-related mortality found that the increases in heat-related mortality may be offset by decreases in cold-related mortality in some cities [27–29].

Numerous studies have investigated the relationship between high ambient temperature and mortality in recent years. While previous literature focused on heat impacts mainly in North American and Western European populations, a growing number of studies have recently been reported in other parts of the world, particularly Asia [21, 22, 30–32] and Australia [23, 33]. Much of the recent heat-mortality literature has focused on identifying and quantifying a “heat wave” effect above and beyond impacts of single-day temperature excursions.

Two multi-city studies have quantified the impact of heat waves (after accounting for single-day temperature risks) in the United States. Anderson and Bell analyzed the impacts of heat waves defined as two or more days with temperature above the 95th percentile in 43 communities in the United States [34]. The study found that mortality increased 3.74% during heat waves vs. non-heat wave days nationally, and that mortality risk was higher for longer, more intense and early season heat waves. Barnett and colleagues examined the mortality impacts of heat waves lasting two or more days in 99 United States cities and using various temperature thresholds between the 95th and 99th city-specific percentile [35]. Heat waves were found to generally increase mortality risk, particularly for the highest heat threshold. Increases in deaths associated with cold waves were also investigated but were found to be smaller and not statistically significant.

The EuroHEAT project in nine European cities (Athens, Barcelona, Budapest, London, Milan, Munich, Paris, Rome, Valencia) concluded that, not considering the 2003 heat wave, mortality during heat wave days increased between 7.6% in Munich and 33.6% in Milan among people over 65 years [20]. Other studies reported increased mortality during heat waves in Berlin, Gemany [24], the Castile La Mancha region of Spain [36], Moldova [37] and Croatia [38]. A study in Catalonia, Spain reported a 19% increase in mortality after three consecutive hot days [25]. Son and colleagues examined the effect of heat waves on mortality in seven Korean cities and found an overall increase in mortality of 4.1% on heat waves vs. non-heat wave days, with the highest 8.4% increase reported in Seoul [21].

Several studies reported mortality associated with specific heat wave episodes: an 13% increase in mortality during a 2011 heat wave in Sydney [23], 41 % increase during a 2010 heat wave in in Harbin, China [32] and 75 excess deaths during a 2004 heat wave in Brisbane, Australia [33].

In a study of England and Wales, Armstrong and colleagues found a consistent increase in mortality on the hottest days with region-specific temperature thresholds of around the 93rd percentile and overall mortality increase of 2.1% per each °C [39]. Rocklov at al. found that persistent exposure to extremely high temperatures in Stockholm County, Sweden was associated with additional mortality, with the risk increasing significantly per every day of additional exposure [40].

Sung et al. 2013 reported that daily mean heat indices above the 95th percentile were associated with increased morality risk ratios in six Taiwanese cities. In Chiang Mai, Thailand, the relative risk of non-external mortality at the 99th relative vs. the 75th percentile of temperature was 1.11[41]. In Hong Kong, 1.8% increase in mortality was observed per 1°C increase in temperature [22]. In Tianjin, China, a 2%, 3%, 2.8% and 3.4% increase in non-accidental, cardiopulmonary, cardiovascular and respiratory deaths, respectively, was observed per 1°C increase in mean temperature above the hot thresholds. Across five Chinese cities, ischemic heart disease mortality increased by 18% at the 99th percentile of temperature compared to the 90th [30].

New evidence on population-level adaptation to heat has also emerged from various locations. One study found temperature-related mortality, especially during late summer, to be decreasing in Seoul [42]. Another study attributed the observed reduction in heat impact on mortality in Italy to variations in the summer temperature distributions, as well as the adaptation measures introduced after the 2003 European heat wave [43]. In analyses encompassing over 100 years of temperature and mortality data, Ekamper and colleagues and Åström and colleagues reported declining trends in heat-related mortality in the Netherlands [44] and Sweden [45], respectively. It is not yet clear to what extent these decreasing trends in heat effects reflect unplanned, autonomous adaptation factors and to what extent they may reflect planned adaptation strategies. This is an important area for future research.

2.3. Review of Recent Morbidity Literature

In comparison to studies on heat-related mortality, studies on heat-related morbidity are less abundant for several reasons. This related in part to the more ready availability of death counts in many cities around the world. It may also reflect to some extent the epidemiology of extreme heat, which often involves impacts on homebound elderly persons who may not be able to seek medical care before succumbing to heat stroke. Still, there has been a recent increase in heat-related morbidity studies in the literature, based on outcomes including hospital admissions, emergency room visits, ambulance dispatches and others. Several studies reported increases in emergency department visits and or ambulance calls for heat-related illnesses during or after increases in ambient temperature in Australia [23, 46, 47], Canada [48, 49], and in parts of the U.S. [50, 51].

Studies are increasingly assessing cause-specific hospital admissions or emergency department visits. The following section highlights several of the common outcomes associated with heat exposure. Understanding the level of heat exposure, the consequent health impacts, and vulnerable subpopulations is critical in preparing for future extreme heat events and adaptation planning.

Heat can aggravate chronic respiratory diseases such as asthma and chronic obstructive pulmonary diseases. In Brisbane, Australia, a 9.5 °C increase in temperature above 29 °C significantly increased ambulance attendances for respiratory effects for all ages, and those over 75 years had a much greater risk [52]. In New York City, increases in temperature and apparent temperature exceeded 28.9 degrees and 31.7 degrees, respectively, respiratory hospital admissions increased by 2.1–2.7% on the same day [53] More broadly in the U.S., high outdoor heat was associated with respiratory hospitalizations among Medicare beneficiaries [54].

Pre-existing cardiovascular diseases can be exacerbated by exposure to heat. In California, apparent temperature increased emergency room visits for ischemic heart disease and stroke [55]. In Quebec, Canada, men and women between ages 45–65 years were surprisingly reported to be at greater risk for hospitalization due to ischemic heart disease compared to those 65 years and older during the summer. However, a greater total number of hospitalizations were recorded for those 65 and over early in the summertime [56]. In Melbourne, Australia, hospitalizations for acute myocardial infarctions for those between ages 55–64 increased significantly on days exceeding 30 °C [57]. During the 2009 heat wave in Adelaide, Australia, hospital admissions and emergency department visits for ischemic heart disease increased significantly for those between ages 15–64 years [58, 59].

While the elderly are clearly an important vulnerable population group, recent literature indicates the fetus is also at risk of heat impacts from maternal heat exposure during pregnancies. In California, a 5.6 °C increase in weekly average apparent temperature was associated with a significant increase in preterm deliveries [60]. In Brisbane, Australia, infants aged 0–4 years were at greater risk for emergency department admissions for intestinal infectious diseases, respiratory, endocrine, nutritional, and metabolic diseases [61], as well as for asthma [62].

Other less studied, but critical, health outcomes of heat exposure include mental health effects. Having a mental disorder itself could put the individual at risk for heat-related morbidities, such as through thermoregulatory dysfunctions commonly associated with schizophrenia. Further, heat causes undesirable side effects of psychiatric medications [63]. In Toronto, Canada, higher daily mean temperature was associated with an increase in emergency department visits for schizophrenia, mood disorders (depression, mania, and bipolar disorder), and neurotic disorders (anxiety, panic, and stress disorders) [64]. There is also some evidence for renal morbidities as well from a study on the 2009 heat wave in Adelaide, Australia [58, 59], and in California [55].

Heat exposure at workplaces concerns both outdoor and indoor workers. Health impacts include acute heat-related illnesses such as dehydration, heat stroke, fatigue, nausea, and loss of coordination, as well as chronic effects such as cardiovascular and respiratory diseases and mental health problems [11]. In Thailand, nearly 20% of a large national cohort of full-time workers, of which 19 and 81% were physical and office jobs, respectively, experienced heat stress. Heat stress was significantly associated with poor overall health as well as psychological distress, and was more common among laborers and male workers [65]. Specific types of workers at risk include those in agriculture, construction, mining, military, and in manufacturing industries who work around heat-generating machines [11].

3. Implications for Adaptation Planning

Public health adaptation to climate change encompasses strategies aimed at reducing adverse health impacts or enhancing resilience in response to observed or anticipated changes [66]. Although the mechanisms of public health adaptation to heat are yet to be well understood, several studies have demonstrated that population mortality responses to high temperatures have tended to decline over time [44, 45, 67, 68]. Heat adaptation is a complex process that may involve physiological, behavioral, and technological components over various time scales. While the reasons for these trends remain uncertain, social advances such as improved means of communication and increased prevalence of air conditioning are likely to play some role.

A wide range of adaptation strategies, both short-and long-term, can facilitate the heat adaptation process. Adaptation can be defined as autonomous or planned, as well as reactive or anticipatory actions [69]. Autonomous or spontaneous adaptation occurs without coordinated planning in individuals or communities and is usually reactive by nature. Planned adaptation, on the other hand, usually involves deliberate policy actions that are based on anticipated climate risks. For instance, increased use of air conditioning during a heat wave episode is an example of an autonomous adaptation. The implementation of a heat warning system is, however, an example of planned adaptation. Since autonomous adaptation may not be able to adequately address the health challenges posed by a changing climate, the need for planned adaptation is being increasingly recognized globally.

Increased awareness of heat impacts on mortality and morbidity has led to the introduction of heat adaptation interventions in many urban areas around the world. Most of these interventions are focused on heat preparedness and response during heat wave episodes and include heat warning systems, AC programs, ‘heat lines,’ cooling centers and educational programs targeted at vulnerable subgroups. Due to the many interconnections between climate change, the built environment [70] and public health, initiatives aimed at improving urban land use, city planning and building design may be included as a long-term strategy. Many countries have implemented heat-health adaptation plans as a component of broader climate action plans [71]. Yet, despite the rapid adoptions of such interventions, there is insufficient evidence of their effectiveness [43, 72, 73]. More comprehensive methodologies need to be developed for the assessment of the effectiveness of heat interventions [74, 75].

Epidemiology can play a key role in building the knowledge base to develop, implement, and evaluate effective adaptation interventions aimed at reducing heat impacts on public health. In Table 1, we list several ways in which epidemiologic methods will be critical in this process, and where new knowledge can play an especially significant role in future adaptation planning.

Since the impacts of heat are location-specific, and appear to change over time, locally-derived heat-health response functions estimated from recent data are essential for assessing temperature-mortality and morbidity impacts and utilizing these assessments in urban adaptation planning. Identifying accurate locally-relevant temperature thresholds above which adverse impacts are observed is particularly important for issuing heat warnings and timely communication with vulnerable populations.

Recent developments in syndromic surveillance systems have demonstrated capacity for rapid detection of heat-related emergency department visits and ambulance calls and ultimately preventing heat-related adverse outcomes [23, 76–81]. Systematic collection of health indicators during heat events is important for both evaluating their impacts and monitoring heat adaptation over time. Long records of syndromic surveillance data can also greatly facilitate the development and improvement of interventions targeted at reducing heat-related mortality and morbidity among vulnerable subgroups.

Vulnerability mapping is another emerging area of research that can provide valuable information for use in preventing heat-related morbidity and mortality in vulnerable populations. Characterizing neighborhood-level heat vulnerability brings together evidence from epidemiological studies on individual level susceptibility factors and information on neighborhood characteristics [82–84] thus enabling more informed preventive actions.

Finally, multidisciplinary and interdisciplinary research and collaboration across sectors is necessary to better assess the health benefits of alternative adaptation investments in heat warning and response systems, education and health communications, and long term

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architecture and urban planning. However, the information necessary for making informed adaptation decisions remains limited. Filling this data gap will require the development and ongoing support of research partnerships involving epidemiologists, climate scientists, and local stakeholders such as health department professionals.

4. Conclusions

Recent epidemiologic findings on heat-related health impacts have reinforced our understanding of mortality impacts of extreme heat and have shown a range of impacts on morbidity outcomes including cardiovascular, respiratory, and mental health responses. Evidence on temporal trends towards decreasing exposure-response is documenting population adaptation. In the meantime, cities are actively engaged in the development of heat adaptation plans to reduce future health impacts. Epidemiologic research on local heat-health responses can play a central role in adaptation planning for heat, to reduce adverse health outcomes among vulnerable populations, and to evaluate the effectiveness of interventions. Such research will be most impactful if it arises from partnerships involving epidemiologists, climate scientists, and local stakeholders.

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Table 1

Epidemiologic research needs in support of adaptation planning.

Research Need	Description
Documenting adaptation trends	Assessing trends in heat-health response over time, based on local data, can provide valuable insight into heat adaptation trends
Evaluating the effectiveness of planned interventions	Consistent methods are needed for evaluating the effectiveness of heat-health interventions
Syndromic surveillance	Real-time surveillance of heat-related health syndromes can provide data of use in resource mobilization during heat events
Targeting interventions to those most vulnerable	Heat vulnerability maps need to be developed that take into account local, fine-scaled health outcome data
Projecting future health impacts	Exposure response functions and adaptation assumptions are needed for assessing impacts of future climate scenarios
Health relevance of spatial patterns of exposure	Recent evidence suggests that outdoor temperatures can vary substantially within urban areas depending on local land use. Understanding implications for health will be important.
Assessment of personal exposures	Virtually no data are yet available assessing actual exposures of vulnerable populations during heat events.
Quantifying the impacts of power failures	Epidemiology is needed for quantifying the health impacts of heat events that coincide with power failures