Geospatial context of social and environmental factors associated with health risk during temperature extremes: Review and discussion

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Abstract

This study reviews forty-six publications between 2008 and 2017 dealing with socio-environmental impacts on adverse health effects of temperature extremes, in a geospatial context. The review showed that most studies focus on extremely hot weather but lack analysis of how spatial heterogeneity across a region can influence cold mortality/morbidity. There are limitations regarding the use of temperature datasets for spatial analyses. Only a few studies have applied air temperature datasets with high spatial resolution to health studies, but none of these studies have used anthropogenic heat as a factor for analysis of health risk. In addition, the elderly is generally recognized as a vulnerable group in most studies, but the interaction between old age and temperature risk varies by location. Other socio-demographic factors such as low income, low education and accessibility to community shelters may also need to be considered in the future. There are only a few studies which investigate the interaction between temperature and air pollution in a geospatial context, despite the fact that this is a known interaction that can influence health risk under extreme weather. In conclusions, although investigation of temperature effects on health risk is already at the "mature stage", studies of socio-environmental influences on human health under extreme weather in a geospatial context is still being investigated. A comprehensive assessment is required to analyse how the spatial aspects of the geophysical and social environments can influence human health under extreme weather, in order to develop a better community plan and health protocols for disaster preparedness.

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Introduction

Climate change leading to increasingly extreme weather events is considered the most prominent risk faced by the international community (*e.g.* World Meteorological Organization) because of its significant impact on society. Extremely high or low temperature will lead to increasing mortality and morbidity (Hondula *et al.*, 2013; Onozuka and Hagihara, 2017a). In large parts of Europe, summer temperature records have increased substantially in recent decades (Rey *et al.*, 2009; Schuster *et al.*, 2014; Urban *et al.*, 2016). The heat wave in 2003 affecting most of the Western Europe led to approximately 30,000 deaths (Laaidi *et al.*, 2012). In the United States, the heat wave in Chicago led to over 700 deaths in a week in 1995 (Johnson and Wilson, 2009). In early 2012, at least 590 people died during a cold snap in Europe with temperature falling below -35ºC in some regions. Climate change predictions indicate that severe heat waves will increase in frequency, which would probably increase heat related impacts to the region (Benmarhnia *et al.*, 2017). It is imperative for governments to develop measures to mitigate health damage caused by extreme temperatures and undertake the implementation of extreme weather warning systems (Hondula *et al*., 2012).

Studies have been conducted to examine the geospatial impact of extreme weather on morbidity and mortality (Lee *et al.*, 2016). In general, these studies suggested that there is an association between temperature and health risk. Some studies suggested that the elderly may be affected by extreme temperature owing partly to poorer physical health in general (Chien *et al.*, 2016). In addition, socio-economic factors including income, education and occupation are also considered to be common factors affecting the spatial distribution of health risk during temperature extremes (Hondula *et al.*, 2015). These studies observed that there are spatial variations in health risks but some focus on larger regional studies while others focus on intra urban differences. While a regional study may not necessarily take into account local characteristics and fails to identify major factors affecting the vulnerability of the community (Onozuka and Hagihara, 2017b), studies based on local administrative units may also be limited by the number of samples available and the resulting data bias. Moreover, different methodologies have been deployed with reference to the quality of the variables available. The spatial models developed thus need to be observed with reference to the limitation in data and methodology used.

The current study aims to conduct a review to better understand the spatial variability of health risk under temperature extremes. We examined the factors affecting regional vulnerability to extreme temperature and the statistical modelling techniques used. Our results and discussion can help public health officials to better understand the factors to be considered at the macro-scale, as well as to identify the spatial heterogeneity at the local level, which should provide a useful reference when developing health warning measures in relation to extreme temperature (Chau *et al.*, 2009; Ho *et al.*, 2017a).

Summary of publications

Using PubMed and Google Scholar, we accessed multiple literature databases between 2008 and 2017 with the following search terms: "heat", "cold", "mortality", "morbidity", "health" and "spatial". A preliminary check based on the titles of the articles was carried out to screen out the unrelated papers. We then further searched on the abstracts and those with relevant content were read in further detail before inclusion in the current study. In general, these articles aim at evaluating the health risk across a region, with a view to improve risk assessments relating to spatial impacts of extreme weather. To enable a more comprehensive review, we also added the papers that, as far as we are aware, provide useful research data on the topic under review in the current study.

After excluding all irrelevant papers, a total of 46 publications between 2008 and 2017 were identified for the current study (Table 1A, given in Appendix). Most, within these 10 years focused on impacts of high temperature and heat waves, with about 11 papers having collected data on cold or both cold and heat. Geographically, they covered areas located mainly in the temperate and tropical zones, with 37% having subtropical/tropical climate; 22% oceanic climate; 18% continental climate; and 9% temperate climate. Over half the studies focused on urban regions. Only one study in southern Ontario focused on heat distress in rural areas within a small community (Bishop-Williams *et al.*, 2015). Over 70% of the papers used mortality cases as the study sample, while others used emergency calls and hospital admission data (Table 1). The scale of the

Table 1. Summary of overall risk during heat events in various regions.

Heat Wave No	Region	Case	Sample size	Relative risk (95%CI)
1	Nanjing, China	Stroke mortality	n.a	1.34 (1.22-1.47)
2	China	Non-accidental mortality	n.a.	1.63 (0.98-2.89)
3	Hong Kong	Mortality, all-natural causes	n.a.	2.11 (-0.11-4.33)
		Cardiovascular cause		4.31 (0.12-8.50)
		Respiratory cause		3.91 (-0.97-8.78)
4	Taiwan	Cardiovascular mortality	13 events	0.57 (0.29-0.51)
5	Japan	Cardiac arrest outside hospital	166,496	1.21 (1.12-1.31)
6	Japan	Emergency transport, all causes Cardiovascular disease Respiratory disease	5,289,660	1.292 (1.251-1.333) 1.039 (0.989-1.091) 1.287 (1.210-1.368)
7	Brisbane, Australia	Hospital admission	n.a.	0.72 (0.47-0.98)
8	Australia	Suicide death	45,293	2.27 (0.73-3.82)
9	Paris, France	Deaths aged ≥65	241	2.17 (1.14-4.16)
10	Southern Ontario, Canada	Emergency room visit	n.a.	1.11 (1.07-1.15)
11	Georgia, North Carolina, and South Carolina, USA	Non accidental mortality	n.a.	2.05 (0.87-3.24)
12	Phoenix, USA	Heat distress call	n.a.	1.17 (1.09-1.25)
13	94 MSAs in USA	Hyperthermia ED visit	11,031	NW: 1.14 (1.08-1.20) W: 1.12 (1.10-1.15) WNCen: 1.17(1.07-1.26) SW: 1.07 (1.07-1.15) S: 1.12 (1.10-1.14) ENCen: 1.18 (1.15-1.21) Cen: 1.17 (1.15-1.18) SE: 1.15 (1.13-1.17) NE: 1.15 (1.13-1.17)

MSA: metropolitan statistical areas; ED: emergency department.

study varies from counties to local administrative units. Regression analysis is commonly used to quantify the temperature-mortality relationship and to determine the socio-economic and environment variables associated with region's variability of risk. Types of regression models used include Poisson regression (20%), logistic regression (13%) and linear regression (11%). A further 6 of the papers used Generalised Additive Models (GAM). Amongst the papers using mortality cases as the study sample, more than half used daily all-cause death data collected from health authorities and census departments, with 3 studies focussing on age 65 and over and one focusing on age 35 and over. Another 28% of papers measured data on heat-related death or death during a heat wave event, with two of them also focused on age ≥65 and age ≥55. Five papers measured cause-specific deaths including stoke, respiratory and cardiovascular diseases during their specific studied period. For the papers that used emergency calls or hospital admission data as samples, most of them measured health outcome's information on cardiovascular and respiratory diseases. One paper used hyperthermia related emergency visit, while another used heat related illness as defined in the 911 codes (Bassil *et al.*, 2009). About 76% of the studies used temporal data on apparent temperature, or mixed data of temperature, rainfall and wind speed, mainly obtained from meteorological stations as the primary data. Another 20% used land surface temperature as spatial measure, which retrieved from satellite and remote sensing sources. The studies showed that increasing mortality or morbidity is positively related to extreme temperature. For instance, in Hong Kong, a 1ºC change in Physiological Equivalent Temperature (PET) was associated with excess risk (%) of 2.99 (95%CI: 0.50-5.48) for all natural-cause mortality. In Japan, the emergency transport reported during the summer months from 2007 to 2010 were acquired and the overall cumulative relative risk was 1.292 (95%CI: 1.251-1.333) for all causes. Three papers analysed whether heat and/or air pollution are associated with increase in mortality (Benmarhnia *et al.*, 2014; Pascal *et al.*, 2014; Willers *et al.*, 2016). The air pollutants studied included particular matter 10 micrometers or less in diameter (PM_{10}); particular matter 2.5 micrometers or less in diameter ($PM_{2.5}$); $PM_{10\text{-}2.5}$; nitrogen dioxide (NO_2) and ozone (O_3). The results indicated that high temperature and air pollution affect mortality, particularly among the aged and the socially deprived. Overall, there are no conclusions as to whether risks are greater in urban or rural areas (Table 2A, given in Appendix). In China, rural areas seem to have higher mortality when exposed to high heat. For example, in Nanjing, the heat wave significantly increased the overall stroke mortality at a relative risk (RR)=1.34, 95% CI: 1.21-1.47) in 2010. Meanwhile, in rural areas, the RR was 1.89 (95% CI: 1.63-2.17), which indicated higher risk of stoke mortality in rural area. However, an analysis of excess mortality in France associated with the heat wave in August 2003 (Rey *et al.*, 2009) indicated that the average heat wave mortality ratio, which is defined as the ratio of number of deaths during the heat wave period (3-15, August 2003), to the expected number of deaths during the reference period (July and August 2000-2002), were higher in urban units (1.78) than rural units (1.62). The heat wave mortality ratio in Paris-and-suburbs was 3.34 in the same study.

The shape and magnitude of the urban heat island are affected by the actual urban landscape, including the density of constructed features and vegetation cover (Burkart *et al.*, 2016). The study in Lisbon, Portugal, showed that the association between mortality and a 1ºC increase in Universal Thermal Climate Index (UTCI) above 24.8ºC was stronger for areas with lower vegetation cover (Burkart *et al.*, 2016).

Socioeconomic deprivation and temperature risk

Over half of the papers use social and economic data as a variable in their analysis of the spatial variation of heat-related health impacts. The socially deprived including those with lower education attainment, old age, unemployed and racial minority groups are considered to be more vulnerable to extreme temperature (Rosenthal *et al.*, 2014). About 28% of the papers used age as a variable, excluding those which only included data from those aged ≥65 as study sample. Old people are considered more vulnerable because of their depreciating physical condition and lower mobility (Hattis *et al.*, 2012). In Rotterdam, the Netherlands, the increased risk of natural-cause mortality on smoggy summer days can reach 10% (95% CI: 9-11) for those ≥85, the highest among all age groups (Willers *et al.*, 2016). The differences, however, are not so apparent for studies in Japan and South Korea (Heo *et al.*, 2016). In Paris, France, it was observed that living in an old age neighbourhood may be an advantage as the homogeneity of the population means more social adhesiveness, and they also received more attention from the health care authority (Benmarhnia *et al.*, 2017). Some papers highlight the impact of severe temperature on ethnic minority or aboriginal groups. In North Carolina, South Carolina and Georgia, USA, the risk of deaths from natural cause for Blacks is 4.4% (95% CI: 2.22-6.53) compared to 0.6% (95% CI: -0.84-2.07) for Caucasians (Lee *et al.*, 2016). A study in Australia (Qi *et al.*, 2014) found that the proportion of aboriginal people of the Torres Strait Islands, Queensland is positively associated with suicide, with RR=1.0107, 95%CI: 1.0062-1.0151 for the period 1996-2000, and RR=1.0126, 95%CI: 1.0076-1.0176 for the period 2001-2005. This study concluded that sociodemographic factors played more important roles than meteorological factors in the spatial pattern of suicide incidence.

Representativeness of temperature datasets

We noted in this review that in most cases, extreme temperature is related to increase in deaths and hospital admission. For instance, the study in Brisbane estimated that a 10ºC temperature increase during the summer would increase hospital admission by 7.2% on the following day (Hondula *et al.*, 2014). In Nanjing, stroke mortality was also higher during the heat wave in 2010 compared with the same period in the previous and following years (Chen *et al.*, 2015). However, based on the general observation of all papers, there is spatial heterogeneity in the risk involved, which can be attributed to a number of underlying factors. These studies have also shown that a population's adaptation to extreme temperature may be affected by their physical built-up; socio-economic status; access to medical and health services; and the environment surrounding their residence. To measure the heat exposure, apparent temperature which takes into account temperature and humidity obtained from weather stations or national meteorological centres are most commonly used *e.g.* Ho *et al.* (2017b). In some cases, precipitation and wind speed are also included. While it is easier to obtain the data required, it should be noted that in some cases, spatial interpolation of temperature measures is not possible when we examine the temperature at a community level, *e.g.* Vaneckova *et al.* (2010). In some cases, air temperature measurements obtained from stations located near an airport may be different from those at the city centre (Willers *et al.*, 2016). Even though it may be possible to use meteorological data from the nearest station, the characteristics of the immediate surroundings are more significant heat exposure variables reflecting the local condition. Some studies used remote sensing data with series of thermal infrared images. This is considered a more effective way to measure the land surface temperature and can take into account night and day temperature differences, which can also be used as an input for estimating human thermal comfort. Additionally, the surface albedo, cloudiness and relative amount of vegetation can also be computed from the satellite images, thus they can provide more information about the local environment. The remotely sensed processes used are, however, likely to introduce some uncertainties, as in a highly urbanized area, many different land cover types are present. The results are therefore dependent on the spatial resolution of the imaging system. For instance, the satellite image thermal data include rooftop temperatures, which may not be representative of the surface conditions experienced by an individual spending time outdoors. The image acquisition time may not correspond with the hottest time of day, or a time when the urban heat island is developed enough to discern temperature differences between warmer and cooler areas. The land surface temperature of the image may not effectively represent air temperature which, affects human comfort (Tsin *et al.*, 2016), although some studies combined data from a ground station weather network and satellite images to model apparent temperature and air temperature for heat mortality estimation (Ho *et al*., 2017b). More importantly, none of these studies has applied anthropogenic heat datasets for health prediction, although anthropogenic heat is a major source of heat affecting the daily life of urban populations.

Representativeness of health datasets

Data in papers on mortality obtained from national health authorities or census departments were commonly used to measure health impacts of extreme temperatures. Some studies used all deaths on extremely hot or cold days in their samples, while others used age of the people dying to stratify their samples. Some papers focused on specific causes of mortality, *e.g.*, stroke or cardiovascular disease (Chen *et al.*, 2015; Urban *et al.*, 2016). Search of an individual's medical history and health condition is always a challenge; thus, it depends highly on the medical surveillance system to identify the cause of death. These may cause bias as there is no clear definition of heat-related deaths, thus the mortality may either be over- or under-reported. For the papers that measured morbidity using emergency calls or heat distress calls, there were more variations and uncertainties in the data collected. For instance, a study in Japan used the number of emergency transport calls to measure the risk of low temperature, but people did not rely only on ambulance transport to go to an emergency department (Onozuka and Hagihara, 2016). The sample used may therefore be limited to a specific group of the population which tended to rely on ambulance transport. In addition, during a heat wave period, people will easily associate their sickness with the high temperature and the reported number of heat distress cases may be subjective and overstated. In addition, neither mortality studies nor morbidity research focused on the relationship between temperature and personal health status or medical history. For example, a study of the association of meteorological and socio-demographic factors with suicide in Australia suggested that the study was limited by the lack of personal information of each suicide case, such as mental disorders and use of medication (Qi *et al.*, 2014). Furthermore, since suicide is an external cause (Ibrahim *et al.*, 2015; Rebholz *et al.,* 2011), it is different from the internal causes of adverse mental conditions, such as depression and dementia. There were also more studies finding that genitourinary-related issues can be associated with extreme temperature (Kim *et al.*, 2018; Ross *et al.*, 2018). Therefore, future studies may have to examine the associations between more types of diseases/causes of death and extreme temperature in a geospatial context.

Representativeness of socioeconomic indicators

Older age was considered a widely recognized socio-economic variable that could influence health risk during an extreme weather event, though it can vary by location (Chan *et al.*, 2012; Eisenman *et al.*, 2016). Older age is particularly relevant because it may partially reflect the effectiveness of the local health care system. Of the other types of socio-economic deprivation examined, not all were associated with temperature-related health risks (Vaneckova *et al.*, 2010). However, there were several key socioeconomic factors such as lower education and unemployment that may influence health risk in developing countries or slums. As there were only a few studies describing such factors, future studies may investigate these socioeconomic issues.

Importantly, socio-economic variables change over time (Ho *et al.*, 2018), but some studies, derived data from a fixed point in time (Hondula *et al.*, 2012), which introduced some uncertainty in the results. For finer scale or intra-urban studies, the data available may not be identical with local district boundaries. For example, a study in New York City noted that the administrative boundaries of Community Districts and the United Hospital Fund, where mortality data were obtained, define different areas (Rosenthal *et al.*, 2014). The issue of local district boundaries has also been highlighted in other health studies (Ho *et al.*, 2015; Schuurman *et al.*, 2007; Thach *et al.*, 2015), as a scaling or zoning issue of the Modifiable Areal Unit Problem (MAUP), or a problem of ecological fallacy. These problems may affect the correlation between individual variables and consequent implications for community health planning. Some potentially confounding factors which were not measured do need to be considered by the health care authorities, such as the fact that individual behaviour and adaptation to extreme temperature vary by time and location. Also, access to and use of air conditioning may help to alleviate an individual's discomfort caused by high temperature, and thus lower the rate of heat related complications, though it may not necessarily be a solution for adaptation to rising urban temperature (Harlan *et al.*, 2013). Assistance at the neighbourhood level is also important. The study in Paris showed that homogeneity at the neighbourhood level will enhance social adhesiveness, and enable the local authority to focus on the health care measures needed (Benmarhnia *et al.*, 2017).

Missing linkages between temperature and air pollution

The effect of air pollution was not included in most studies. For example, tropospheric ozone is a hazardous photochemical pollutant formed from precursor emissions and is accelerated on hot and sunny days. However, the relationships between temperature and ozone and health were seldom examined in a geospatial context. Moreover, there is lack of available data to allow for a reliable spatial interpolation of daily air pollution in some locations (Vaneckova *et al.*, 2010). In some local communities, especially in rural areas, there is inadequate environmental monitoring infrastructure to measure air pollutants (Wang *et al.*, 2017). Nonetheless, where some studies showed that air pollutants were potential confounders to the temperature-mortality relationship, others reported no significant confounding effect (Heo *et al.*, 2016). Further studies may be required when more precise data on air pollution are available at the local level. While we tried to review the health risks related to extreme temperature, there appear to be more articles on the impact of heat rather than cold. The few studies considering the impact of low temperature (Bayentin *et al.*, 2010; Carmona *et al.*, 2016; Onozuka and Hagihara *et al.*, 2017) suggested that cold exposure would increase the risk of mortality and hospital admission for cardiovascular and respiratory diseases. In Spain, low temperature had higher impact on mortality than the effect of heat. Studies in Taiwan and China had similar findings. This may be partly due to the fact that both Spain and Taiwan have a less severe winter climate, and people are less adapted to cold exposure. In China, the effect of temperature varied in different climate zones due to the complicated geography and socio-economic differences at the regional level. Generally speaking, people living in regions with a higher socio-economic status are less vulnerable to extreme temperature, and are more protected with a higher standard of medical and health care. Further studies on the impact of cold temperature would therefore be needed to better understand the impact and spatial implications.

Conclusion

Based on our analysis, we observed that extreme temperature remains a concern for public health authorities. It is generally agreed that social, economic and environmental factors affect the spatial variations of health impacts caused by extreme temperature. In general, old age, the socially deprived and ethnic minority/aboriginals constitute the most vulnerable groups. In addition, it is also noted from other studies that urban vegetation would be effective in alleviating the risk of heat. Local health authorities should, therefore, make reference to these factors in developing an effective heat warning system.

While our analysis focused only on literature available from PubMed and Google Scholar, there may be other accessible information available. From a global point of view, the studies available in this review tend to focus on developed regions in the North America, Europe, Australia and Asia. Though national factors may not have significant impacts on population mortality and morbidity, local conditions in some geographical regions, especially the less developed regions, are unique from a spatial and cultural perspective. More studies focusing on these regions should be explored as they are considered to be more vulnerable to natural hazards.

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