10-27-2017

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Citation Information

Li, Ying; Odamne, Emmanuel A.; Silver, Ken; and Zheng, Shimin. 2017. Comparing Urban and Rural Vulnerability to Heat-Related Mortality: A Systematic Review and Meta-Analysis. *Journal of Global Epidemiology and Environmental Health*. https://doi.org/10.29199/GEEH.101016 ISSN: 2637-7144

NorCal Open Access Publications
Journal of Global Epidemiology and Environmental Health
Volume 1; Issue 1
Li Y et al.

Review Article

Comparing Urban and Rural Vulnerability to Heat-Related Mortality: A Systematic Review and Meta-analysis

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Received Date: 06 September, 2017; **Accepted Date:** 12 October, 2017; **Published Date:** 27 October, 2017

Abstract

Studies of the adverse impacts of high temperature on human health have primarily focused on urban areas, due in part to urban centers generally having higher population density and often being warmer than surrounding rural areas (the "urban heat island" effect). As a result, urban areas are often considered to be more vulnerable to summer heat. However, heat vulnerability may not only be determined by heat exposure, but also by other population characteristics such as age, education, income, baseline health status, and social isolation. These factors are likely to increase vulnerability among rural populations compared to urban populations. In this exploratory study, we compare the vulnerability to heat-related mortality between rural and urban communities through a systematic review and meta-analysis of existing epidemiological studies, based on the idea that urbanicity can be considered as a "combined" indicator of climate variables and socioeconomic variables. We searched studies that examined the association between high ambient temperature and mortality in both rural and urban settings published between 2000 and 2017. A random-effects meta-analysis of Ratios of Relative Risks (RRR) of heat-related mortality in rural compared to urban areas (RR_{rural}/RR_{urban}) was performed. The pooled RRR was 1.033 (95% CI = 0.969, 1.103), which indicates that the rural relative risk is about 3.3% larger than the urban relative risk. Heterogeneity measures show considerable heterogeneity across studies. Our findings suggest that vulnerability to heat-related mortality in rural areas is likely to be similar to or even greater than urban areas. More studies, particularly studies in developing nations, are needed to understand rural vulnerability to heat hazards as a basis for providing better guidance for heat action plans.

Keywords

Heat Vulnerability; Meta-Analysis; Mortality; Rural; Urban

Introduction

Climate change is anticipated to raise overall temperatures in the 21st century and is likely to be the biggest global health threat of the century [1]. Exposure to higher and more extreme temperatures in the warm season has been associated with both increased mortality and morbidity [2-5]. Although numerous epidemiological studies of the association between high temperature and mortality have been performed globally, most of these studies focused on urban areas and few have been done in rural areas, mainly based on the assumption that urban areas are most vulnerable to heat because of high concentrations of susceptible people and greater exposure to heat associated with the "urban heat island" effect [6-10].

However, being an urban resident does not necessarily make one more vulnerable to heat. Heat vulnerability may also be determined by sensitivity and adaptive capacity [11,12]. Rural residence is more likely to be associated with higher sensitivity (e.g., worse baseline health status, higher poverty rates) and lower adaptive capacity (e.g., a lack of access to health care and air conditioning) compared to residing in urban areas. This difference tends to be more prominent in less developed nations, placing the rural areas in these nations at greater risk of mortality or morbidity due to heat exposure. In addition, occupational exposure is a factor that may make rural populations particularly susceptible to extreme heat [13].

A few recent studies, conducted both in developed and developing countries, have reported greater or similar vulnerability of rural populations to elevated summer temperature compared to their urban counterparts [12,14-21], whereas some others have reported opposite results [3,11,22]. Given the conflicting findings as to whether the magnitude of heat risk is the same or not in urban and rural areas, a systematic review and assessment of the urban and rural difference in heat vulnerability would provide valuable information to governments at all levels in the development of heat action plans. No study to date has done such a review.

This study aims to conduct a systematic review and assessment of the peer-reviewed, international epidemiologic literature concerning the effects of urbanicity (urban versus non-urban) on heat mortality vulnerability. The aim of the review is to compare vulnerability to heat-related mortality in urban communities with the surrounding rural communities. We perform a meta-analysis of the ratio of the rural effect estimate to the urban estimate to obtain a quantitative comparison of the heat mortality risk between urban and rural populations.

The remainder of the paper is organized as follows. Section 2 describes the methods used to conduct the review and meta-analysis, including the search strategy, the selection of studies, data extraction and the meta-analysis of the ratio of the rural effect estimate to the urban estimate. Section 3 presents the search, selection and meta-analysis results. Section 3 also discusses the uncertainty and limitations of our estimates. Section 4 summarizes the major conclusions of this study and issues to be further investigated in future work.

Methods

Search strategy

We searched peer-reviewed epidemiological studies of the associations between high ambient temperature and mortality published in English between January 2000 and June 2017. The literature search was first carried out in July 2016 and then updated in July 2017, using search engines PubMed, Google Scholar, and Web of Science. The keywords used for this search were: (Rural OR non-urban OR population density) AND (Heat OR temperature OR climate change OR hazards) AND (Vulnerability OR deaths OR mortality OR risk OR health effect). In addition, we also reviewed the references of the articles initially found, paying particular attention to published reviews or meta-analyses, to identify studies that may have been overlooked in the initial keyword search. There was no restriction on the locations of studies.

Selection of studies

We manually screened the studies identified through the literature search and excluded studies based on the following criteria:

- Studies not performed on human populations;
- Studies that investigated morbidity instead of mortality;
- Studies that focused on climate variables other than temperature;
- Studies that investigated the effects of heat waves on mortality, due to non-comparable definitions of heat waves used in different studies (we only included and conducted a meta-analysis of high ambient temperature studies, but excluded heat-wave studies; our method is consistent with the review study by Benmarhnia [23]);
- Studies that did not report estimates of the association between high temperature and mortality;
- Commentaries, editorials, or review articles.

Then we further screened studies based on the following criteria:

- Including studies that investigated associations between high ambient temperature and mortality in both urban and surrounding rural areas, while excluding studies that considered only urban or rural settings with no comparison to the other.
- If more than one study had been conducted using the same population, the most recent one was included, regardless of whether the research groups were the same (listed as "Duplicated studies" in figure 1).

The systematic screening steps are summarized in figure 1.

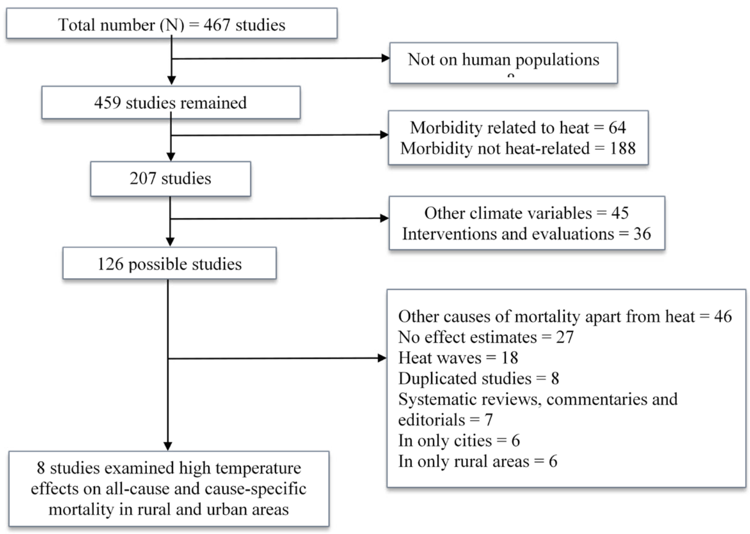

Figure 1: Systematic screening process for literature review.

Note: Eight studies were selected, and ten sets of estimates from these eight studies were included in the meta-analysis.

Data extraction

From the selected studies, we extracted estimates of the association between high temperature and mortality (i.e., relative risk, RR) for both urban communities and their surrounding rural communities. The estimates were obtained from text descriptions, tables, figures (when it was possible to determine the estimates from the published figures), or supplemental materials. The Bai et al., [19] study reported effect estimates for different time lags up to 14 days in their main analysis. We used estimates for the shortest lag period (0 day) because the effect of elevated temperature on mortality has generally been found to be immediate [4]. In addition to relative risk estimates, we also documented study locations, time periods, temperature metric utilized to represent exposure to heat, range of temperature examined, air pollution confounders included in the statistical models, and how rural and urban populations were classified in the original studies (table 1 in the results section).

Meta-analysis

To compare the effect estimates of urban and rural subpopulations within a study, we used the natural logarithm of the ratio of RR values (RRR; or analogous estimates of association) for the two subgroups, i.e., RR_{rural}/RR_{urban}, a method given by Benmarhnia et al. [23]. The formula used to calculate the standard errors of the ratios is as follows (adopted from [23]):

$$SD\ (ratio) = ratio \times \sqrt{\left(\frac{SD\ RR_{rural}{}^{2}}{RR_{rural}}\right) + \left(\frac{SD\ RR_{urban}{}^{2}}{RR_{urban}}\right)}$$

Where SD is Standard Deviation. The random-effects model was used to account for heterogeneity between studies. The model takes into account the uncertainty associated with the between-studies variance estimate when calculating an overall effect. A Cochran Q test was conducted to assess heterogeneity across studies.

Results and Discussion

Selection of studies

The initial literature search identified 467 studies. Using the exclusion criteria discussed in section 2.2, eight studies were identified and included in the meta-analysis (Table 1). All eight studies were published over the last ten years between 2007 and 2017, with two studies being conducted in North America (United States), two in Europe (United Kingdom and Czech Republic), and four in Asia (China and Bangladesh). Two of the eight studies [12,19] reported relative risk for both all-cause and cause-specific mortality. We included both sets of relative risk in the meta-analysis, since the analysis focused on the ratio of the RR values for the rural and urban subgroups instead of the RR values themselves. Altogether, ten sets of RR from eight studies were included in the meta-analysis.

Reference	Study location and period	Temperature metric	Range of temperature (°C)	Mortality health outcome	Effects of air pollution included	Rural and urban classification	RR-Rural (95% CI)	RR-Urban (95% CI)
Chen et al. [12]	Jiangsu Province, China, 2009-2013	Daily mean	24.13-32.27	All-cause	Monthly $PM_{2.5}$	Percentage of urban population below or above median percentage (57.11%)	1.43 (1.36-1.5*)	1.26 (1.23-1.3*)
				Cardiorespiratory (CRD)			1.69 (1.58-1.8*)	1.43 (1.36-1.5*)
Madrigano et al. [11]	New York, New Jersey, Connecticut, US, 1988-1999	Daily maximum	21.2-32.2	All-cause	Daily mean 8-hour ozone	Below or above 1,000 persons/mile^2	1.08 (1.06-1.1*)	1.09 (1.07-1.1*)
Hajat [24]	England and Wales, UK, 1993-2003	Daily mean	17.7-22	All-cause	Daily PM_{10} and ozone	Population below or above 10,000	1.02 (1.01-1.03)	1.03 (1.02-1.04)
Bai et al. [19]	Tibet, China, 2008-2012	Daily mean	15.5-21.7	All-cause	None	Not specified	1.23 (0.89-1.7)	1.09 (0.87-1.38)
				Cardiovascular (CVD)			1.31 (0.82-2.1)	1.06 (0.73-1.54)
Burkart et al. [25]	Bangladesh, 2008	Universal Thermal Climate Index (UTCI)	26.6-35.5	All-cause	None	Not specified	1.26 (1.22-1.36)	1.46 (1.39-1.61)
Lee et al. [16]	North Carolina, South Carolina, Georgia, US, 2007-2011	Daily mean	28-33.2	All-cause	Daily $PM_{2.5}$	US Census Bureau definition of metropolitan or micropolitan areas	1.021 (0.995, 1.047)	1.015 (1.002, 1.029)

Urban and Kyselý [22]	Czech Republic, 1994-2009	Daily mean	22-28	Cardiovascular	None	OECD's international definition: Above or below 37.5% of inhabitants living in municipalities with population density less than 150 inhabitants per km^2	1.09 (1.05, 1.14)	1.12 (1.08, 1.17)
Zhang et al. [14]	Hubei Province China, 2009-2012	Daily mean	27.7-32.4	All-cause	None	Not specified	1.14 (1.02, 1.26)	1.095 (1.00, 1.19)

Table 1: Description of high temperature studies and Relative Risk (RR) for rural and urban included in the meta-analysis.

Note: * indicates 95% Posterior Intervals (PI) were reported instead of 95% confidence intervals.

Meta-analysis results

We conducted the meta-analysis of the ln (RRR) for rural and urban populations (i.e., RR_{rural}/RR_{urban}) on the ten sets of relative risk estimates from the eight selected studies. The pooled RRR was 1.033 (95% CI = 0.969, 1.103; figure 2 and table 2), which indicates the rural relative risk is about 3.3% larger than the urban relative risk, although the overall effect is not statistically significant at an alpha level of 0.05. Considerable heterogeneity was found across studies, with the Cochrane Q statistic being 146.58 ($p<0.001$).

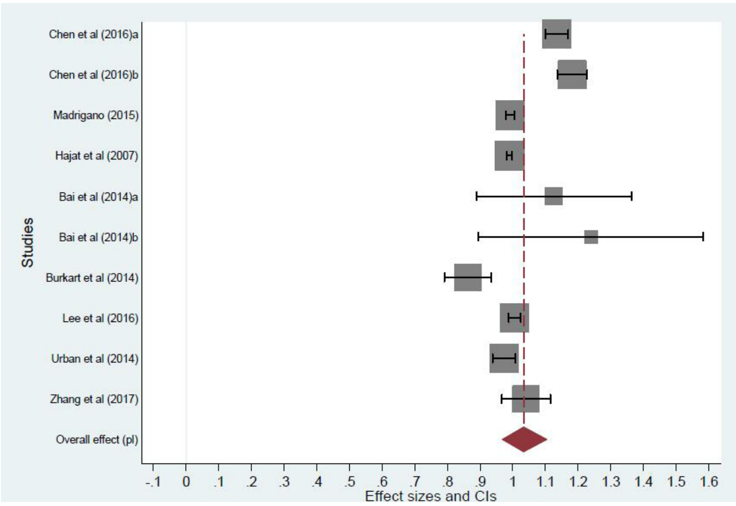

Figure 2: Meta-analysis of the ratio of the Relative Risks (RRs) according to urbanicity (comparing the RR for rural populations with the RR for urban populations, RR_{rural}/RR_{urban}); n = 10 studies.

Studies	Country	Effect Size (95% CI)	% Weight*
Chen 2016 (All-cause)	China	1.14 (1.10, 1.17)	11.9
Chen 2016 (CRD)		1.18 (1.14, 1.23)	11.6
Madrigano 2015	United States	0.99 (0.98, 1.01)	12.4
Hajat 2007	United Kingdom	0.99 (0.98, 1.00)	12.4
Bai 2014 (all-cause)	China	1.13 (0.89, 1.36)	4.2
Bai 2014 (CVD)		1.24 (0.90, 1.58)	2.4
Burkart 2014	Bangladesh	0.86 (0.79, 0.93)	10.5
Lee 2016	United States	1.01 (0.99, 1.02)	12.3
Urban 2014	Czech Republic	0.97 (0.94, 1.01)	11.9
Zhang 2017	China	1.04 (0.97, 1.12)	10.4
Overall effect		**1.03 (0.97, 1.10)**	**100.00**

Table 2: RR_{rural}/RR_{urban} effect estimates (95% CI) and the weights assigned to each study.

Note: * Weights are from random effects analysis.

Discussion

Most epidemiologic studies of heat-related mortality over the past decade have focused on urban areas, mainly based on the assumption that urban residents are generally at higher risk for heat exposure. The disparity in number of research studies for urban and rural areas is also related to data availability and population size, which are less problematic for studies focusing on urban populations [11]. Until now there have been quantitative challenges in using statistical methods to estimate mortality impacts of temperatures in rural areas. These include lower population density and more dispersed weather stations [13]. As a result, many monitoring and climate change adaptation efforts have been concentrated in major metropolitan areas throughout the world [9,21]. Little is known about the vulnerability to heat exposure in rural areas, which may be characterized by lower socioeconomic status, greater proportions of elderly people, lack of access to air conditioning and health care - all factors that have been linked to greater vulnerability to heat-related mortality [23]. There is also evidence that rural communities are not well represented in climate and health research [26]. If the health impacts of temperature on mortality are not limited to the “urban heat island”, public health preparedness efforts should be oriented to nonurban areas in addition to cities.

Urbanicity can be considered as a combined indicator of climate variables related to heat exposure, and socioeconomic variables, such as income, education levels, living conditions (including access to air conditioning), and access to health care. Although rural residents may be far removed from the “urban heat island”, they may live with disadvantages in terms of socioeconomic status and health care. Based on this “combined indicator” idea, we conducted a systematic review and meta-analysis of international epidemiologic studies published between 2000 and 2017 to explore the impact of urbanicity on population vulnerability to heat-related mortality. We found evidence of slightly greater vulnerability to heat-related mortality for populations residing in rural areas compared to their urban counterparts based on limited studies of both urban and surrounding rural areas that are currently available. We also found considerable heterogeneity of the RR_{rural}/RR_{urban} ratio of the studies we analyzed, which complicates the interpretation of a single summary estimate [23]. Possible explanations include the study designs, rural-urban definitions, and confounders and effect modifiers. We briefly discuss some of these issues below.

A third issue of concern is that urban-rural differences, including economic inequality might be considerably different between developed and developing countries, making it difficult to compare the rural-urban risk ratio across studies conducted at different locations. We further explored the differences in RR_{rural}/RR_{urban} ratios between developed versus developing nations. According to the United Nation’s country classification scheme based on per capita gross national income[1], four of the eight selected studies were conducted in developed countries (US, two studies, UK and Czech Republic) and the remaining four were conducted in developing countries (China, three studies, and Bangladesh). Three of four studies in developed countries reported lower RRs in rural than in urban areas, with the RR_{rural}/RR_{urban} ratio being smaller than 1 [11,22,24] (Table 1). By contrast, three of the four studies in developing countries reported greater RRs in rural than in urban areas, with the RR_{rural}/RR_{urban} ratio being greater than 1 [12,14,19] (Table 1). Our findings reveal some evidence that high vulnerability to heat is likely to be pronounced in less developed economies, although the sample size is still too small to draw any firm conclusions.

Exposure to ambient air pollution, mainly Particulate Matter (PM) and ozone, have also been linked to premature mortality [27], and thus may have a confounding effect on the temperature-mortality association [4,28]. Ozone is a summer pollutant and climate change is projected to detrimentally affect ozone air quality and consequently increase mortality [29]. Regarding PM, although the observed correlations of PM concentrations with temperature are weaker than for ozone [30], PM has been found to peak in the summer in certain regions, such as the East Coast of the US [4]. Therefore, PM also may be a confounder for the association between temperature and mortality in these regions [4]. As shown in table 1, four of the eight selected studies controlled for PM or ozone, or both in their statistical analyses. In general, the confounding effect of air pollution is small and there is an independent effect of temperature on mortality [4].

Limitations of the meta-analysis

Our meta-analysis has some limitations. First, a main limitation of this study is that there was limited number of studies (n=10) that met the inclusion criteria and thus were included in the meta-analysis, which partially explains why the overall estimate was not statistically significant. Our comprehensive literature review indicates that globally epidemiological studies on heat-related mortality and morbidity studies of rural populations are rare. Including more studies in future work, if they become available, is likely to increase the statistical power of analysis and provide stronger evidence. Also the fact that rural communities are not well represented in climate and health research is likely to lead to selection bias in this study. This bias may be reduced if more heat-related studies of rural populations are conducted in the future. Second, a challenge of the present study is that we combined the rural-urban ratio of relative risk from different studies conducted all over the world whereas rural-urban classification varies significantly from a nation to another, and even among regions within a country. For instance in the US, the population density cutoffs used to classify urban and rural may range from 300 persons per square mile in the state of Tennessee [31] to 1,000 persons per square mile in the nation’s most densely populated northeast region [11]. As shown in table 1, the eight included studies generally followed the rural-urban classification used by a nation or region’s census; thus these classifications reflect the nation’s unique social and economic characteristics, but it is still likely that the disparity in rural-urban classification increases the heterogeneity across studies. Finally, different modeling approaches were conducted by the eight selected studies, leading to future heterogeneity in the estimates. For example, two [11,12] studies used Bayesian analysis and thus reported Posterior Intervals (PI) whereas the remaining six studies reported Confidence Intervals (CI). This issue is also likely to contribute to the high heterogeneity

[1] Refer to:
http://www.un.org/en/development/desa/policy/wesp/wesp_current/2014wesp_country_classification.pdf,
accessed September 4, 2017.

across the eight selected studies.

Conclusion

While earlier studies have documented the impacts of individual factors (such as age and sex) and socioeconomic factors (such as education, ethnicity and income) on the vulnerability to heat-related mortality, the impacts of the "combined" urbanicity indicator remains unexplored. In particular, there is a knowledge gap in understanding rural vulnerability to heat exposure. This exploratory study aimed to compare the vulnerability to heat-related mortality in urban communities with their surrounding rural communities through a systematic review and assessment of international epidemiologic literature.

Our literature search identified eight studies conducted in five countries in three continents. Ten sets of relative risk estimates from these studies were used to perform a random-effects meta-analysis of the ratio of the rural effect estimate to the urban estimate. Our findings show a slightly (3.3%) greater vulnerability to heat-related mortality for rural populations compared to urban populations. Considerable heterogeneity was found across studies. The overall effect is not statistically significant at an alpha level of 0.05, likely a result of the small number of studies that met the criteria for inclusion in this meta-analysis. Studies are needed to further clarify the vulnerability to heat-related mortality for rural populations. However, our findings provide evidence that challenges the widely accepted assumption that urban areas are more vulnerable to heat, in particular in less developed nations. Our findings also reveal some evidence that high vulnerability to heat is likely to be pronounced in less developed economies, and thus further research is particularly warranted in developing countries. Overall, knowledge about rural vulnerability to heat hazard remains incomplete. There is a need for more studies to examine population vulnerability to heat hazards in nonurban settings, both in developed and developing countries.

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