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ORIGINAL ARTICLE

Heat wave–related mortality in Sweden: A case-crossover study investigating effect modification by neighbourhood deprivation

DANIEL OUDIN ÅSTRÖM[1], CHRISTOFER ÅSTRÖM[2], BERTIL FORSBERG[2], ANA M. VICEDO-CABRERA[3], ANTONIO GASPARRINI[3], ANNA OUDIN[2,4] & KRISTINA SUNDQUIST[1]

[1]*Center for Primary Health Care Research, Department of Clinical Sciences, Malmö, Lund University, Lund,* [2]*Deptartment of Public Health and Clinical Medicine, Occupational and Environmental Medicine, Umeå University, Sweden,* [3]*Department of Public Health, Environments and Society, London School of Hygiene & Tropical Medicine, UK, and* [4]*Occupational and Environmental Medicine, Lund University, Sweden*

Abstract

Aims: The present study aimed to investigate if set thresholds in the Swedish heat-wave warning system are valid for all parts of Sweden and if the heat-wave warning system captures a potential increase in all-cause mortality and coronary heart disease (CHD) mortality. An additional aim was to investigate whether neighbourhood deprivation modifies the relationship between heat waves and mortality. *Methods*: From 1990 until 2014, in 14 municipalities in Sweden, we collected data on daily maximum temperatures and mortality for the five warmest months. Heat waves were defined according to the categories used in the current Swedish heat-wave warning system. Using a case-crossover approach, we investigated the association between heat waves and mortality in Sweden, as well as a modifying effect of neighbourhood deprivation. *Results*: On a national as well as a regional level, heat waves significantly increased both all-cause mortality and CHD mortality by approximately 10% and 15%, respectively. While neighbourhood deprivation did not seem to modify heat wave–related all-cause mortality, CHD mortality did seem to modify the risk. ***Conclusions*: It may not be appropriate to assume that heat waves in Sweden will have the same impact in a northern setting as in a southern, or that the impact of heat waves will be the same in affluent and deprived neighbourhoods. When designing and implementing heat-wave warning systems, neighbourhood, regional and national information should be incorporated.**

Keywords: *Heat wave, mortality, neighbourhood deprivation, heat-wave warning system*

Introduction

There is an extensive body of evidence concerning the impact of high ambient temperatures and heat waves on mortality [1–4]. The effect of heat on mortality usually corresponds with increases in mortality the same day or one or two days after an increase in temperatures [1]. Even in a colder climate, such as in Sweden, heat-related mortality has been observed [2,5,6]. Risks due to high and low temperatures tend to be higher in colder and warmer regions, respectively, which suggests partial adaptation of populations to their own climate [1,4].

Heat-wave warning systems have been implemented in some countries in order to help relieve some of the negative burdens on public health associated with heat waves [7]. For instance, due to a new heat-wave warning system, it was estimated that approximately 4400 premature deaths were avoided in France during the 2006 heat wave [8]. In 2013, in Sweden, the Swedish Meteorological and Hydrological Institute (SMHI) initiated a heat-wave warning system. The system was designed based on epidemiological data from Stockholm and was set to issue warnings when temperatures on three consecutive

Correspondence: Daniel Oudin Åström, Department of Clinical Sciences, Center for Primary Health Care Research, Malmö, Lund University, Lund, 221 00, Sweden. E-mail: danielastrom@hotmail.com

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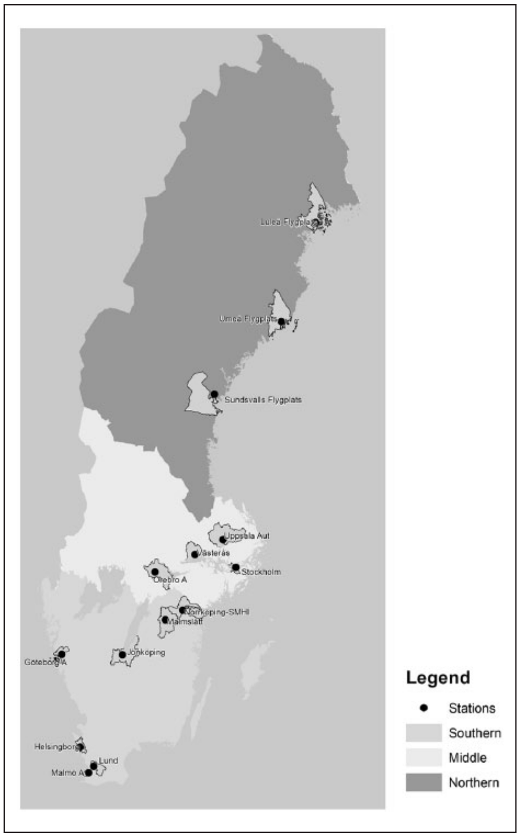

Figure 1. The study setting.

days were expected to exceed certain thresholds [9]. The thresholds were set to be the same in all parts of the country.

However, a recent study showed that the relationship between temperature and health, as well as the thresholds at which temperatures become hazardous, varies around the globe and by region [4]. In addition, it has been shown in several studies that neighbourhood characteristics, such as neighbourhood deprivation, are strongly associated with increased all-cause mortality [10] and increased mortality due to coronary heart disease (CHD) [11].

To assume that the impact on mortality is the same in all parts of a country might therefore not be appropriate. To date, most studies investigating the impact of heat waves on mortality in Sweden have been only been conducted in the Swedish capital of Stockholm [2,5,12,13] and have not investigated mortality due to CHD. The aim of the present study was to investigate if set thresholds in the Swedish heat-wave warning system are valid for all parts of Sweden and if the heat-wave warning system captures the increase in mortality due to CHD. Furthermore, another aim was to investigate whether neighbourhood deprivation modifies the relationship between heat waves and mortality.

Material and Methods

Data

Temperature data. We collected data from SMHI for the five warmest months (May, June, July, August and September) from 1990 until 2014. Data on daily maximum temperature for 14 municipalities in Sweden were collected from Malmö, located in the most southern part of Sweden, to Luleå, located in the most northern part of Sweden (Figure 1) [9]. Meteorological data were complete for the municipalities of Lund, Jönköping, Linköping, Norrköping, Stockholm, Sundsvall and Luleå. For Örebro, Norrköping and Helsingborg, the monitoring stations used at the beginning of the study were discontinued during the study. Therefore, we used the replacement station thereafter. As an example, for the municipality of Helsingborg, the measuring station moved from one central location to another location approximately 4 km away from the original one in 1995.

Heat waves. We defined three different heat-wave categories based on the three levels of the Swedish heat-wave warning system. A message of high temperatures is issued when daily maximum temperatures are expected to be at least 26°C for three consecutive days. However, this threshold is one degree lower than that used in the epidemiological model on which the warning system is built due to a ‘cold bias’ present in the temperature forecasts. In this study, we used 27°C as the threshold for the first warning level. A class 1 warning for very high temperatures is issued when daily maximum temperatures are expected to be at least 30°C for three consecutive days, and a class 2 warning is issued when daily maximum temperatures are expected to be at least 30°C for five consecutive days and/or daily maximum temperatures are expected to be at least 33°C for three consecutive days [9]. We refer to these three heat wave categories as HW_1, HW_2 and HW_3.

Mortality data. Mortality data were extracted for the 14 municipalities from the Cause of Death Register provided by The National Board of Health and Welfare. Daily counts of all-cause mortality, as well as CHD mortality (ICD-9: 410–414; IDC-10: I20–I25), were collected for the municipalities.

Neighbourhood level of deprivation. Based on previously described methods [11], we calculated the neighbourhood deprivation index (NDI) for each neighbourhood of residence (all residential addresses in Sweden have been geocoded into units with an average population of 1000–2000 inhabitants) within the selected municipalities. NDI is a summary measure based on four variables that indicate deprivation: proportion of inhabitants with low educational status, low income, unemployment and social welfare recipients [11]. These four variables were selected after a principal component analysis of several deprivation indicators used by previous studies to characterise neighbourhood deprivation. The index was categorised into three groups: <1 standard deviation (*SD*) from the mean=low deprivation, >1 *SD* from the mean=high deprivation and within 1 *SD* of the mean=moderate deprivation. Lower scores indicate more affluent neighbourhoods, whereas higher scores indicate more deprived neighbourhoods. Within each neighbourhood in each municipality, we then collected the daily counts of all-cause and CHD mortality occurring in each of the three categories of neighbourhood deprivation. The number of neighbourhoods included in the study was 2720.

Statistical methods

To investigate the hypothesised association between heat waves and mortality, we used a case-crossover design, where each individual serves as its own control. The case-crossover design thus adjusts for individual time-invariant confounders [14]. Control days were selected within the month and year of the date of death and matched on day of the week. This selection of control days controls for both seasonality and trends over time as well as potential effects of the day of the week on the mortality patterns in the municipalities [15]. We ran a conditional Poisson regression model with a stratum variable, which yields identical results to those generated from a conditional logistic regression when there is a common exposure across individuals, as is the case in our study where all individuals within the same municipality are assumed to have identical temperature exposure [16]. We used an indicator variable for heat wave and additionally controlled for Swedish public holidays (yes/no).

We then pooled the municipality specific relative risks (RR) using inverse variance meta-analysis to obtain national-level estimates. In addition, we pooled the RRs for the southern, middle and northern parts of Sweden to explore heat wave–related mortality in these three regions. Sweden is often divided into three regions (it has been done for centuries), and SMHI uses these regions when issuing warnings.

For each municipality, we further stratified the analyses on NDI, where we again pooled the estimates to a regional and a national level. To investigate if neighbourhood deprivation modifies the relationship between heat waves and mortality, we calculated the relative effect modification (REM) and corresponding 95% confidence intervals (CIs) using the most deprived neighbourhoods as reference [17].

All results are presented as RRs for HW_1 and HW_2, along with their corresponding 95% CIs. We did not investigate mortality associated with HW_3 due to the low number of such events.

R v3.2.3 was used for statistical modelling, and for the meta analyses we used the package Meta [18].

Results

Table I shows the daily maximum temperatures during the warmest months in Sweden. The percentiles of the local temperature distribution, for a HW_1, ranged from the 92nd percentile in Stockholm and Uppsala to the 98th percentile in Luleå. The number of such heat-wave days occurring during our study period ranged from four in Luleå to 128 in Stockholm. HW_2 occurred consistently at the 98th and 99th percentiles of the local temperature distribution, and all but two municipalities experienced such heat waves during the study period. HW_3 only occurred in Lund (10–12 July 2010) and in Stockholm (28–30 July 1994), when these cities experienced three consecutive days with temperatures >33°C, and in Västerås (4–10 July 2001) and Uppsala (4–9 July 2001), when these cities experienced five consecutive days with temperatures in >30°C. Descriptive statistics on the number of daily deaths occurring in each of the municipalities is presented in Supplementary Table S1.

Figure 2 shows the pooled RRs (with 95% CIs) of mortality associated with HW_1 and HW_2 for the three regions as well as on a national level. The national pooled RRs for HW_1 was 1.08 (95% CI 1.05–1.11) for all-cause mortality and 1.11 (95% CI 1.04–1.17) for CHD (Figure 2 and Supplementary Table S2). To investigate the impact of heat waves on mortality further in the three regions of Sweden, we pooled the heat-wave data accordingly. For the two southernmost regions, the pooled RRs were, as expected, similar to the RR on a national level. In the three northernmost cities (i.e. Sundsvall, Umeå and Luleå), the pooled estimate was 1.32 (95% CI 0.98–1.77), which is higher than in the south, although not to a statistically significant extent.

On the municipality level, Malmö, Norrköping and Stockholm experienced significantly increased all-cause mortality during such heat waves, whereas an increased CHD-related mortality was only statistically significant in Malmö and Stockholm (Supplementary Table S2).

During HW_2, only Stockholm had a statistically significantly increased all-cause mortality. However,

Table I. Descriptive statistics of meteorological data for the investigated municipalities during the study period 1990–2014.

Municipality (region)	Latitude	Daily maximum temperature					Percentile[a]		*n* heat wave days[b]		
	°N	*M*	*SD*	Min	Max	Missing (*n*/%)	27°C	30°C	HW_1	HW_2	HW_3
Malmö (S)	55.4	19.9	4.1	6.8	33.5	58/0.6	94	99	65	1	0
Lund (S)	55.4	20.2	4.3	7.0	34.3	0/0	93	98	101	7	1
Helsingborg (S)	56.2	19.3	4.1	6.8	31.0	78/0.85	95	99	54	0	0
Göteborg (S)	57.4	19.6	4.3	5.2	33.8	434/4.7	93	98	94	6	0
Jönköping (S)	57.5	18.4	4.6	3.3	33.4	0/0	96	99	29	3	0
Linköping (S)	58.2	19.3	4.5	3.9	34.6	0/0	94	99	71	7	0
Norrköping (S)	58.4	19.7	4.5	4.4	33.9	0/0	94	99	76	5	0
Örebro (M)	59.2	19.7	4.5	3.9	33.7	249/2.7	94	99	93	9	0
Stockholm (M)	59.2	19.7	4.9	4.8	34.2	0/0	92	99	128	18	1
Västerås (M)	59.4	19.4	4.6	1.0	33.0	993/10.8	95	99	76	10	2
Uppsala (M)	59.5	19.8	4.8	4.6	33.3	54/0.6	92	99	111	13	1
Sundsvall (N)	62.2	17.6	4.6	2.7	33.0	0/0	98	98	11	1	0
Umeå (N)	63.5	17.0	4.7	1.6	32.2	29/0.3	98	98	8	2	0
Luleå (N)	65.3	16.2	4.9	2.1	32.1	0/0	99	99	4	0	0

[a]The percentile of the municipality level temperature distribution during the warmest months corresponding to each of the first two levels of heat-wave warnings.
[b]Number of heat waves according to the three levels of heat waves in the heat-wave warning system.
HW_1: three consecutive days with daily maximum temperatures >27°C; HW_2: three consecutive days with daily maximum temperatures >30°C; HW_3: three consecutive days with daily maximum temperatures >33°C or five consecutive days with daily maximum temperatures >30°C; S: southern region; M: middle region; N: northern region.

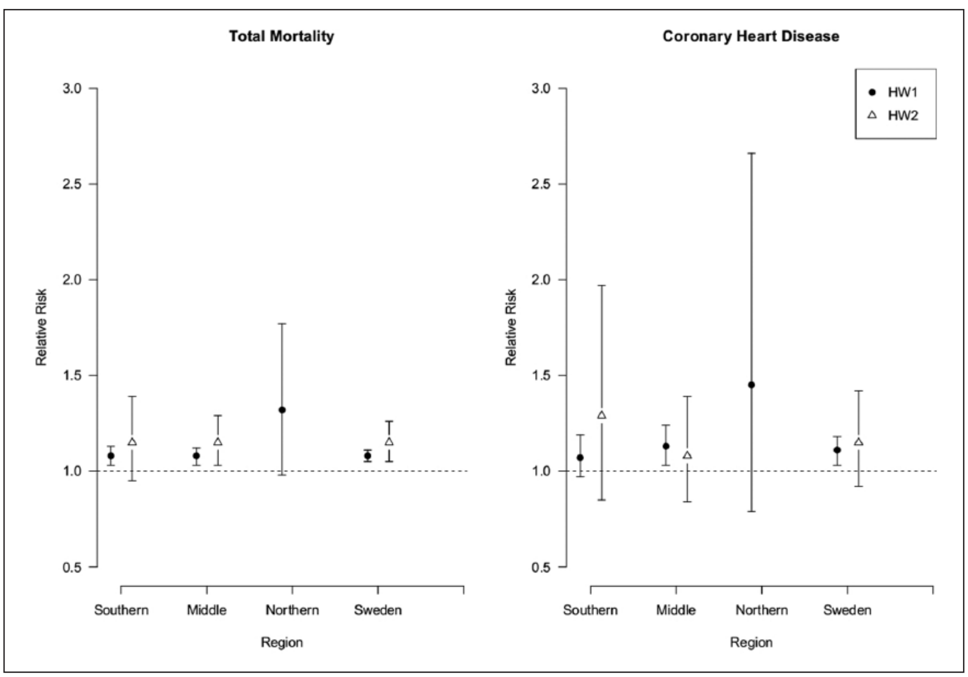

Figure 2. Relative risks and 95% confidence intervals associated with heat waves for the three regions and on a national level during the study period 1990–2014.

in the majority of the cities, the estimated coefficient was positive, and the pooled estimate for all-cause mortality was statistically significant on a national level, as well as for the middle region of Sweden. The RRs associated with these heat waves were 1.13 (95% CI 1.00–1.28) for Stockholm, and the pooled RR was 1.15 (95% CI 1.05–1.26). The northern region only experienced three category 2 heat waves. Thus, no pooled results are presented (Figure 2 and Supplementary Table S2).

In addition, we explored if neighbourhood deprivation modified the effect of heat waves. Due to the

Table II. Pooled relative risks with 95% confidence intervals associated with heat waves for the three regions and on a national level during the study period 1990–2014.

Region		HW_1			HW_2		
	Mortality	NDI 1	NDI2	NDI 3	NDI 1	NDI2	NDI 3
Southern	All-cause	1.04 (0.94–1.16)	1.07 (1.00–1.14)	1.13 (1.06–1.22)	1.35 (0.89–2.05)	1.12 (0.87–1.43)	1.21 (0.81–1.82)
	CHD	0.81 (0.66–0.99)	1.09 (0.96–1.24)	1.21 (1.04–1.42)	1.77 (0.86–3.65)	1.15 (0.67–1.97)	1.48 (0.54–4.04)
Middle	All-cause	1.08 (1.00–1.15)	1.07 (1.01–1.13)	1.10 (0.99–1.22)	1.03 (0.87–1.23)	1.22 (1.05–1.44)	1.27 (0.95–1.69)
	CHD	1.15 (1.00–1.33)	1.10 (0.97–1.24)	1.49 (1.22–1.80)	0.87 (0.57–1.33)	1.29 (0.93–1.80)	1.07 (0.57–2.02)
Northern	All-cause	1.75 (1.12–2.75)	1.12 (0.73–1.72)	1.61 (0.73–3.56)	NA		
	CHD	0.20 (0.13–0.31)	1.63 (0.79–3.38)	1.15 (0.28–4.65)	NA		
Sweden	All-cause	1.07 (1.01–1.14)	1.07 (1.03–1.12)	1.12 (1.05–1.20)	1.07 (0.91–1.26)	1.19 (1.04–1.36)	1.25 (1.00–1.59)
	CHD	1.02 (0.91–1.15)[a]	1.10 (1.01–1.20)[a]	1.31 (1.17–1.48)	1.04 (0.72–1.50)	1.27 (0.97–1.68)	1.17 (0.69–2.01)

*Significant REM. REM index when comparing the most deprived neighbourhoods to the most affluent: 1.29 (95% CI1.09–1.52). REM index when comparing the most deprived neighbourhoods to the medium deprived: 1.19 (95% CI 1.03–1.41).
NDI: neighbourhood deprivation index, where 1=‘most affluent neighbourhoods’ and 3=‘most deprived neighbourhoods’; CHD: coronary heart disease; REM: relative effect modification; CI: confidence interval.

low number of deaths occurring in each category of neighbourhood deprivation during the heat waves, we only calculated the pooled estimates on a regional and national level rather than on a municipality level.

Table II shows the RRs for each level of neighbourhood deprivation associated with the first two categories of heat waves. We found no evidence of a modifying effect on a regional or national level for all-cause mortality. This was the case for both categories of heat waves. However, for CHD and on a national level, we found significantly higher RRs for the most deprived neighbourhoods compared to the more affluent ones during HW_1. The REM index was 1.19 (95% CI 1.03-1.41) and 1.29 (95% CI 1.09-1.52) when comparing the most deprived neighbourhoods to the medium deprived and most affluent neighbourhoods, respectively.

Discussion

The present study investigated heat wave-related mortality in 14 different municipalities located from north to south in Sweden, since most previous studies on heat wave–related mortality have only been performed in the Swedish capital of Stockholm. Three consecutive days of temperatures >27°C, which occurred in all municipalities, increased mortality on a national level by approximately 8% compared to normal day temperatures during the warmest months. The magnitude of this estimate is similar to what has previously been reported for the county of Stockholm only. Using the same metric as in our present study, Rocklöv et al. reported an increased mortality during heat waves of approximately 8–11% [19]. Åström et al. (2014) investigated the health impact of temperatures between 27°C and 30°C and found an estimated increase in mortality rates of between 4.3% and 10% [20]. More recently, Åström et al. reported an increase in mortality rates of approximately 3–5% on days during a heat wave [2,5], and among the population >50 years of age in Stockholm county, the increase in mortality rates was found to be approximately 8% on days during a heat wave [6].

All but two municipalities, Luleå and Helsingborg, experienced HW_2 during the study period. In this study, we identified 82 such days over a 25-year period. Statistically significantly increased all-cause mortality was found in Stockholm only. We found a non-significant increase in all-cause and CHD mortality in 9/14 municipalities. On a national level, however, the 15% increase in all-cause mortality was significant, whereas the point estimate for CHD mortality was the same but not significant. On a municipal level, this uncertainty may be due to the relatively low number of heat waves occurring in each municipality. Our results should thus, on a municipality level, be interpreted with caution.

Our data shows that neighbourhood deprivation may modify the risk of mortality due to CHD during HW_1 in Sweden, as the pooled RR on a national level was significantly higher for the most deprived neighbourhoods compared to relatively more affluent neighbourhoods. To the best of our knowledge, this is the first study reporting an effect modification by neighbourhood deprivation on CHD mortality during heat waves on a national level. Interestingly, for the Czech Republic, Urban et al. reported no modifying effect of socio-economic status on a national level. However, when comparing districts with high and low socio-economic status, socio-economic conditions seemed to have an influence on excess mortality [21]. Our finding of no modifying neighbourhood effect for all-cause mortality is in line with a number of

European studies, as well as one previous study from Stockholm. Studies from the UK and Italy have reported limited evidence of a modifying effect of neighbourhoods on mortality [22,23]. In addition, Rocklöv et al. categorised municipal wealth in Sweden based on average wealth per person and found no difference between wealthy and deprived municipalities [24]. However, this was performed for Stockholm only, whereas our study is based on national data and a more complex index of neighbourhood deprivation. Rey et al. reported that the residents in the most deprived cantons of Paris had twice as high mortality rates than those residing in the least deprived cantons during the heat wave of 2003 and suggested that the results of their study indicated that the most deprived populations were more vulnerable to heat waves than the least deprived populations [25]. Our results are partially in agreement with Rey et al., as we found that neighbourhood deprivation modifies the effect of HW_1 on CHD mortality but not on all-cause mortality. One possible explanation behind our finding of a modifying effect on CHD mortality but not on all-cause mortality is that individuals with increased susceptibility to heat may, to a greater extent, reside in deprived neighbourhoods than other individuals do. Heat exposure may also differ between affluent and deprived neighbourhoods, which may partially explain the observed differences in effects. Furthermore, the modifying effect of neighbourhood deprivation on mortality was only found during HW_1 and not during the more extreme heat waves. This may be due to smaller sizes of the susceptible population, as many individuals with heightened susceptibility may have already succumbed to the effects of heat.

The present study makes several novel contributions to the field, as some of the municipalities investigated are the northernmost regions, which may have worldwide implications. In Luleå (latitude 65.3°N), Umeå (latitude 63.5°N) and Sundsvall (latitude 62.2°N), the mortality on warm days increased by approximately 30% compared to other days during the warmest months, albeit only borderline significantly so (pooled RR 1.32 (95% CI 0.98–1.77)). These cities are relatively small and had the least number of days above the thresholds in the Swedish heat-wave warning system. The relatively low power in the estimates makes it difficult to draw any clear conclusions from our findings, although our findings seem to be in line with those of Revish and Shaposhnikov who investigated the impact of heat waves on mortality in four cities in northern Russia (Archangelsk, latitude 64.3°N; Murmansk, latitude 68.6°N; Yakutsk, latitude 62.0°N; and Magadan, latitude 59.3°N) and reported a pooled RR of 1.44 (95% CI 1.27–1.57) [26]. Heat waves may thus have an additional detrimental effect on health amongst populations less accustomed to such events, as is the case on these northern latitudes. This suggests that ongoing acclimatisation and adaptation processes may differ within countries and that it would be suitable to develop regional guidelines as a complement to the national heat-wave warning system.

To date, only a few regions in Sweden have developed preventive work plans in anticipation of and during heat waves. Currently, the Swedish heat-wave warning system is set on alert when temperatures are expected to exceed 26°C for more than three consecutive days. During the study period, this happened in all municipalities. However, this warning level is aimed mainly towards care facilities and hospitals and does not trigger a warning to the public. The Swedish heat-wave warning system was developed using data from the Stockholm region only. As this study indicates, the statistical power needed to detect any increases in mortality is only present in Stockholm. However, three cities (Stockholm, Malmö and Norrköping) were found to have positive effect estimates and significant increases in mortality. In addition, the pooled estimates on a regional level suggest an increased mortality from the southern to the northern regions.

With ongoing climate change and an increasingly elderly and more frail population, the need for relevant preventive action is clear. The events found to be rare or non-existent in parts of Sweden are likely to increase in the relatively near future. The changing climate is expected to double the exposure to hazardous temperatures by the middle of the 21st century [27]. The changing climate is one component of the future health burden from high temperatures. Along with the increase in temperatures and a more elderly population, studies from Sweden have indicated that the resilience to heat in Sweden might have decreased over the last two decades [5,6]. As the Swedish heat-wave warning system was only implemented in 2013, we are not currently able to evaluate any possible effects on mortality following its introduction. The effectiveness of heat-wave warning systems has been evaluated in other settings, however, and a majority of studies do report lower mortality due to heat after the implementation of such warning systems [8,28]. However, methodological challenges often restrict the value of published evaluations, and what conclusions that can be drawn are disputed [28].

Strengths and limitations

One of the main strengths of the current study is the long and well defined time series of daily temperature and mortality data for 14 municipalities from north to south in Sweden covering 25 years from 1990 to 2014. The number of missing observations were, for most stations, few. Another strength is that we investigated both all-cause mortality and CHD mortality. The validity of the Swedish death registers can be considered high, and thus misclassification of deaths due to CHD should be limited [29].

A limitation of the study may be that a single monitoring station in each municipality was used to describe temperature exposure for the residents. This is, however, a standard procedure in previous studies on temperature and health, but the exposure measure is clearly prone to misclassification. Not only can the temperature vary within a municipality, housing conditions and time spent indoors naturally affect people's actual exposure. If exposure misclassification is related to the outcome, the bias could cause false-positive results [30], for example if people with worse health, who have a higher probability of dying, would be less likely to leave their homes than people with better health. Furthermore, if their disease was exacerbated by high temperatures, the worsening in health could cause them either not to go out, thus avoiding exposure, or to seek emergency care. It is thus very difficult to speculate on the size or direction of bias caused by such exposure misclassification, but we cannot rule out that exposure misclassification has biased our effect estimates. Furthermore, bias caused by exposure misclassification could potentially differ between municipalities, as many of the measuring stations were located in more urban settings, whereas a number of other stations were located in other settings, such as at the local airport, thereby making direct comparisons between municipalities more difficult.

Another limitation that must be mentioned is the small sample size of daily mortality in a number of municipalities, resulting in imprecise estimates on a municipal level. This was further an issue due to the fact that in some, especially northern, municipalities, heat waves were less frequent.

Conclusions

This study investigated the impact of heat waves on mortality in 14 municipalities located from south to north in Sweden. Our data suggests strong evidence of an effect of heat waves on all-cause mortality as well as CHD mortality, regionally and nationally, even in a country located as far north as Sweden. Our results suggest that it may not be appropriate to assume that heat waves in Sweden will have the same impact on mortality throughout the country, as the effect of heat may occur at lower temperatures in northern regions compared to southern regions. Furthermore, it may not be appropriate to assume that the impact of heat waves will be the same in affluent and deprived neighbourhoods. When designing and implementing heat-wave warning systems, neighbourhood, regional and national information should be incorporated.

Declaration of conflicting interests

The authors declare that there is no conflict of interest.

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