Environment International 144 (2020) 105966

Contents lists available at ScienceDirect

Environment International

journal homepage: www.elsevier.com/locate/envint

Years of life lost and mortality due to heat and cold in the three largest English cities

Katherine Arbuthnott[a,b,*], Shakoor Hajat[a], Clare Heaviside[c], Sotiris Vardoulakis[d]

[a] Department of Public Health, Environments and Society, London School of Hygiene & Tropical Medicine, London WC1H 9SH, UK
[b] Chemicals and Environmental Effects Department, Centre for Radiation, Chemical and Environmental Hazards, Public Health England, Didcot OX11 0RQ, UK
[c] Institute for Environmental Design and Engineering, University College London, Central House, 14 Woburn Place, London WC1H ONN, UK
[d] National Centre for Epidemiology and Population Health, Research School of Population Health, Australian National University, Canberra, ACT 2601 Australia

ARTICLE INFO

Handling Editor: Hanna Boogaard

Keywords:
Temperature
Mortality
Heat
Cold
Climate change
Years of life lost

ABSTRACT

There is a well-established relationship between temperature and mortality, with older individuals being most at risk in high-income settings. This raises the question of the degree to which lives are being shortened by exposure to heat or cold. Years of life lost (YLL) take into account population life expectancy and age at which mortality occurs. However, YLL are rarely used as an outcome-metric in studies of temperature-related mortality. This represents an important gap in knowledge; to better comprehend potential impacts of temperature in the context of climate change and an ageing population, it is important to understand the relationship between temperature and YLL, and also whether the risks of temperature related mortality and YLL have changed over recent years.

Gridded temperature data derived from observations, and mortality data were provided by the UK Met Office and the Office for National Statistics (ONS), respectively. We derived YLL for each death using sex-specific yearly life expectancy from ONS English-national lifetables. We undertook an ecological time-series regression analysis, using a distributed-lag double-threshold model, to estimate the relationship between daily mean temperature and daily YLL and mortality between 1996 and 2013 in Greater London, the West Midlands including Birmingham, and Greater Manchester. Temperature-thresholds, as determined by model best fit, were set at the 91st (for heat-effects) and 35th (for cold-effects) percentiles of the mean temperature distribution. Secondly, we analysed whether there had been any changes in heat and cold related risk of YLL and mortality over time.

Heat-effects (lag 0–2 days) were greatest in London, where for each 1 °C above the heat-threshold the risk of mortality increased by 3.9% (CI 3.5%, 4.3%) and YLL increased by 3.0% (2.5%, 3.5%). Between 1996 and 2013, the proportion of total deaths and YLL attributable to heat in London were 0.50% and 0.40% respectively. Cold-effects (lag 0–27 days) were greatest in the West Midlands, where for each 1 °C below the cold-threshold, risk of mortality increased by 3.1% (2.4%, 3.7%) and YLL also increased by 3.1% (2.2%, 3.9%). The proportion of deaths and YLL attributable to cold in the West Midlands were 3.3% and 3.2% respectively. We found no evidence of decreasing susceptibility to heat and cold over time.

The addition of life expectancy information into calculations of temperature-related risk and mortality burdens for English cities is novel. We demonstrate that although older individuals are at greatest risk of temperature-related mortality, heat and cold still make a significant contribution to the YLL due to premature death.

1. Introduction

There is a well-established relationship between heat and cold and all-cause daily mortality (Gasparrini et al., 2015; Basu, 2009) which has been demonstrated globally, across varying climates. The relationship typically follows a U, V or J shape with increased mortality above and below location-specific thresholds. In general, the size of effect varies between regions and studies, in part driven by epidemiological modelling choices and differences in climate, but also by differences in local population, such as demographic or socio-economic factors affecting vulnerability to the effects of heat and cold. In the UK (and other locations), older age groups are most at increased risk of temperature related mortality (Hajat et al., 2007), though as temperatures continue to rise, other age-groups may become increasingly vulnerable.

* Corresponding author.
E-mail address: Katherine.arbuthnott@lshtm.ac.uk (K. Arbuthnott).

https://doi.org/10.1016/j.envint.2020.105966
Received 10 March 2020; Received in revised form 3 July 2020; Accepted 8 July 2020
Available online 06 August 2020

However, results are rarely presented using a metric which takes the length of life shortening into account. This is important, both to better understand the current impact of temperature on population health and also to appreciate the potential impacts of climate change in an ageing population, where some degree of mortality displacement may account for a proportion of temperature related mortality.

Potential years of life lost (YLL) is a composite indicator, which summarises information on both mortality and life expectancy, providing information on potential life lost as a result of premature mortality. First used as a concept in the 1940s (Dempsey, 1947), YLL gives greater weight to deaths occurring at younger ages. Taking life expectancy and age of death into account gives a metric which is a more instructive summary statistic, allowing for comparison of how health risks and conditions can shorten life. YLL can therefore be helpful to define policy and research priorities (Romeder and McWhinnie, 1977). In the area of environmental health, YLL are widely used to assess the burden of air pollution (e.g. (Broome et al., 2015; Cohen et al., 2005; Huang et al., 2018) and more generally have been used as an outcome metric to reflect premature mortality in the Global Burden of Disease studies (Lopez et al., 2006; Murray and Lopez, 2013). In England, the National Institute for Health and Care Excellence (NICE) uses a metric for health technology assessment which combines information both about the length and quality of life (the QALY) to make funding decisions (Sassi, 2006).

Despite the large number of studies that have described the association between temperature and mortality, there are relatively few studies that have used YLL as an outcome measure (Baccini et al., 2013; Egondi et al., 2015; Huang et al., 2012a, 2012b; Yang et al., 2015; Sewe et al., 2018; Bunker et al., 2017; Luan et al., 2017; Zhang et al., 2018, 2017; Urban et al., 2020). For high income settings specifically, Huang et al. demonstrated a relationship between YLL due to cardiovascular disease and heat in Brisbane, Australia (Huang et al., 2012), and more recently Sewe et al. (2018) demonstrated a relationship between YLL and temperature across a range of settings including low income countries (Burkina Faso), low-middle income countries (Kenya and India) and high income countries (the US and Sweden). To our knowledge, there have been no studies that have focused on the effect of temperature on YLL in the UK, and this represents a gap in knowledge that may be useful to inform policy decisions. Further, understanding temperature related health risks in cities is important. In England, recent estimates indicate that over 80% of the population live in cities (Office for National Statistics. Rural population, 2014). Cities are likely to be at greater risk from the negative health impacts of increased temperatures under climate change, due to factors such as the Urban Heat Island (UHI) (Heaviside et al., 2016) (the phenomenon whereby temperatures in cities or urban areas are generally higher than those in surrounding rural areas) and much adaptation planning in relation to climate change in the UK is starting at city level (e.g. C40, Greater London, Manchester and Birmingham climate change plans (Mayor of London, 2018; Manchester City Council, 2010; Birmingham City Council, 2012).

A second concept, which has important implications for understanding potential impacts of climate change and policy, is that of changing susceptibility of populations to the effects of heat and cold. It is often assumed that populations will 'adapt' to some extent to the effects of heat and/or cold and therefore be less vulnerable to temperature effects in the future. There is some evidence that in a number of locations, populations have become less vulnerable to the effects of heat due to a potential number of influences – some of which may be planned adaptive measures (such as heat wave plans, air conditioning) and some unrelated to climate such as improved healthcare (leading to decreased susceptibility to heat) (Arbuthnott et al., 2016; Vicedo-Cabrera et al., 2018). However, changes in the mortality risk associated with cold over time are less well studied and effects are less consistent between studies (Arbuthnott et al., 2016). For the UK specifically, reductions in vulnerability to temperature were in evidence throughout the last century (Carson et al., 2006). One recent study found little temporal change in the heat risk in the UK over recent years (Gasparrini et al., 2015), and a second study examining changes in heat and cold attributable fractions (AFs) over recent years at the regional level (with results presented at the aggregated national level) found that AFs for heat and cold related mortality remained stable over time (Vicedo-Cabrera et al., 2018). To our knowledge, however, there has been no study which examines temporal changes in heat and cold related YLL or in the UK at conurbation (rather than regional or national) level. The introduction of heat and cold weather plans in England (operational from 2004 and 2011 respectively), combined with a national level commitment to understanding the risks of and adaptation to climate change (Arbuthnott and Hajat, 2017), mean that understanding recent temporal variation in heat and cold risk and the effect of temperature on premature mortality, are both important to inform policy in the UK.

In this paper, we aim to address the gaps in knowledge around heat and cold related premature mortality and changes in this risk in English conurbations over recent years. Using time series regression, we analyse data from three major English conurbations chosen to represent the north, south and middle of England – Greater London, Greater Manchester and the West Midlands (including Birmingham) to determine the relationship between heat, cold and YLL and changes to this relationship over recent years.

Specifically, this study has three main objectives: (a) to determine the nature of the relationship between YLL and temperature in the studied conurbations, (b) to estimate (and compare) the proportion of total yearly mortality and YLL attributable to heat and cold and (c) to examine whether the risk of mortality and YLL due to heat and cold has changed over the study period.

2. Methods

2.1. Data

We used two main health outcomes: YLL (primary outcome) and all-cause mortality (for comparison). Mortality data were obtained from the Office for National Statistics (ONS). All deaths occurring in England on each day between 1st January 1996 and mid December 2013 were used. YLL for the same period were derived by matching each death to the age specific yearly life expectancy for males and females obtained from period lifetables provided by the ONS (Office for National Statistics, 2017) based on the years in the mid-point of our time-series (2004–2006) and extended up to age 110 years. For example, according to these 2004–2006 tables, a 90-year-old male had a life expectancy (and hence YLL in the event of death) of 3.89 years and a 70-year-old female had a life expectancy of 15.88 years.

Data were aggregated by conurbation, as defined by the ONS Built-up Area codes from the 2011 census (Office for National Statistics., 2011). We created time-series of total daily deaths and potential YLL for Greater London, the West midlands and Greater Manchester by summing the individual deaths and/or numbers of YLL for all male and female deaths on any given day. As life expectancy is sex-specific, the time series were also stratified by sex.

We used daily mean temperature (the average of the daily maximum and minimum temperatures) as our main exposure variable, since this has been shown in previous UK studies to be an effective predictor of temperature related health effects (Hajat et al., 2016). Daily mean temperature was obtained from the UK Met Office UKCP09 gridded observation datasets (UK Met Office, 2017). This dataset was created using input from all available temperature stations within the UK, interpolated using inverse-distance weighting (based on a regression model with information on longitude, latitude, coastal influence, altitude, and urban land use) by the UK Met Office to provide daily temperatures for 5 km^2 gridded areas (Perry, 2009). We took the value represented by the 5 km^2 gridded cell that overlapped with the centre of each conurbation (identified using ArcGIS) to provide the daily mean temperature for each conurbation.

In our analysis, we also included regional data on weekly laboratory confirmed influenza A counts, obtained from Public Health England, as a potential time-varying confounding factor of cold effects. Daily mean PM_{10} and ozone counts for London from the UK-AIR (Air information resource data archive) were also collected as confounding factors (DEFRA, 2018).

2.2. Statistical analysis

We undertook an ecological time series regression analysis to determine the risk of YLL and mortality for each 1 °C temperature rise or fall above or below a given heat or cold threshold.

We assumed a Poisson distribution for the outcomes, corrected for over-dispersion and autocorrelation. It is well established that the effects of heat and cold on health can be delayed (lagged), and we used previously published lag periods of 0–2 days for the heat effect and four weeks for cold. We controlled for the effect of season and secular trends using a cubic spline function with 7 degrees of freedom per year (Bhaskaran et al., 2013) and included a term for day of the week. Relationships were visualised using natural cubic splines of the average temperature function, having controlled for time varying factors and confounders. These indicated the presence of heat and cold thresholds, above or below which the risk of YLL (and mortality) increased. Therefore, in order to quantify the effects of heat and cold, a distributed lag double-threshold model was used. Best model fit was used to select the heat and cold thresholds: the model was run across the three conurbations with the heat and cold thresholds fixed separately at temperatures corresponding to all percentiles of each conurbation's annual mean temperature distribution. The percentiles with the lowest summed model deviance across the three conurbations were selected as the heat and cold thresholds for the primary analysis. This corresponded to the 91st percentile of the annual temperature distribution for heat effects (18.9 °C for London, 17.6 °C for the West Midlands and 16.8 °C for Greater Manchester), and the 35th percentile of the year round temperature distribution for cold effects (9.0 °C for London, 8.0 °C for the West Midlands and 7.9 °C for Greater Manchester). These thresholds are consistent with those seen when the data are represented graphically.

Results are presented as the relative risk (RR) or percentage increase in risk for each 1 °C rise or fall above or below the specified threshold and attributable burdens of heat and cold related YLL and mortality (calculated using previously published methods) (Vardoulakis et al., 2014; Hajat et al., 2014) as a proportion (%) of total YLL and mortality over the time-period studied. We used STATA v 15 for all statistical analyses. To aid interpretation of results, heat and cold related mortality analysis was also undertaken by age categories (0–65 years, 65–74 years and 75 years and over) and is included in the supplementary materials (Table S1).

2.3. Changes in YLL and mortality risk over time

A number of approaches have been used previously to analyse the change in risk of heat and cold related mortality over time, each with advantages and disadvantages (Arbuthnott et al., 2016). In order to assess whether the risk of heat and cold exposure on YLL and mortality had changed over time we divided our data into discrete 4 year bands (summer 1996-winter 1999/00, summer 2000-winter 2003/4, summer 2005-winter 2008/9, summer 2008-winter 2011/2). Within each band we estimated the risk of YLL and mortality above and below the given temperature threshold. Cold and heat thresholds were maintained at 35th and 91st percentiles (see above) of the temperature distribution for each particular 4 year band within each given conurbation, to allow the best model fit with the data and the number of hot and cold days contributing to the analysis to remain consistent between time periods. However, we also undertook a sensitivity analysis using absolute thresholds fixed at the 35th and 91st percentiles of the temperature distribution for the whole time period (rather than allowing thresholds to vary with each time band).

2.4. Sensitivity analysis

We undertook a number of analyses to determine the sensitivity of our main modelling approach to certain methodological choices. In addition to using lifetables from the middle of the time period to calculate YLL, we used lifetables based on years at the beginning and end of the times period to calculate YLL as part of our sensitivity analyses. We also carried out analyses using lifetables adjusted for regional differences in life expectancy. As we did not have air pollution data for all three conurbations (series for Greater Manchester and the West Midlands contained large sections of missing data), we used a model which included PM_{10} and ozone as a sensitivity analysis for London. We also carried out year by year (June-May to include a summer/whole winter season) analysis of heat and cold risk to ensure that the overall trend observed using 4 year bands was not sensitive to the time bands chosen for analysis and a sensitivity analysis using absolute thresholds (see Section 2.3 above).

3. Results

3.1. Descriptive statistics

Table 1 summarises the descriptive statistics for our dataset. Greater London had the highest number of all-cause daily deaths and YLL, followed by Greater Manchester, then the West Midlands. We analysed over a million deaths in Greater London and more than 400,000 deaths in each of the West Midlands and Greater Manchester. This is equivalent to more than 15 million YLL analysed for Greater London and more than 5 million YLL each for the West Midlands and Greater Manchester. The mean temperature over the time series was highest in Greater London and similar in the West Midlands and Greater Manchester. For each conurbation, the number of days above and below the heat and cold thresholds respectively are summarised in Table 1. Of note, there was no consistent increase in temperature over the time period analysed (see Fig. S1), which is consistent with temperature trends over this time period published elsewhere (Brohan et al., 2006). In all the conurbations, the number of daily male YLL is greater than daily female YLL (but daily female all-cause mortality is higher than male all-cause mortality in all conurbations) (Table 1).

3.2. Results from regression models

3.2.1. Risk of heat and cold related YLL and mortality: Pattern across the conurbations and differences in risk by sex

For all conurbations, there was an increased risk in total mortality and YLL for each 1 °C rise or fall in temperature above or below the threshold value (Table 2). The relationship between the RR of YLL and daily mean temperature is shown in Fig. 1. This illustrates that the RR of YLL associated with mean temperature follows a similar pattern to that seen using mortality as an outcome.

The RR of YLL per degree above threshold temperature was higher in London than for the West Midlands or Manchester (Table 2). The RR of heat related mortality also varied between conurbations, and was also higher for London, compared to the West Midlands and Manchester (Table 2). In all conurbations, the RR for total heat-related YLL was lower than for total heat-related mortality (though confidence intervals for YLL and mortality risk estimates overlap). In Greater London and Manchester, the RR of heat related YLL and mortality was higher in females compared to males. This difference was significant for the risk of heat related mortality in Greater London. In the West Midlands, however, the risk of both heat related YLL and mortality were higher in males compared to females (but not substantially) and in males the RR

Table 1
Descriptive data.

	Mean temperature (°C) (min, 25th percentile, 75th percentile, max)	Cold threshold (°C) Days below threshold: total over whole time period and average number per year	Heat threshold (°C) Days above threshold: total over whole time period and average number per year	Average (mean) daily values for daily YLL and all-cause mortality (minimum, 25th percentile, median, 75th percentile, maximum)					
				Daily male YLL	Daily female YLL	Daily total YLL	Daily male all-cause mortality	Daily female all-cause mortality	Daily all -cause mortality
Greater London	11.5 (−3.2 ,7.3, 16.0, 28.2)	9.0 Total: 2276 days Average: 126 days	18.9 Total: 604 days Average: 34 days	1277 (563, 1098, 1263, 1437, 2599)	1139 (541, 966, 1120, 1286 2580)	2416 (1261, 2112, 2391, 2677, 5016)	90 (44, 79, 89, 99, 197)	96 (49, 82, 94, 105, 227)	186 (107, 164, 182, 203, 412)
Greater Manchester	10.2 (-6.5, 6.3, 14.3, 24.3)	7.9 Total: 2288 days Average: 127 days	16.8 Total: 600 days Average: 33 days	461 (132, 372, 451, 540, 1117)	420 (106, 336, 409, 484, 1113)	881 (299, 747, 867, 998, 2055)	32 (13, 27, 32, 36, 85)	35 (13, 29, 34, 40, 94)	67 (33, 58, 66, 74, 169)
West Midlands	10.4 (-7.4, 6.4, 14.8, 25.4)	8.0 Total: 2280 days Average: 127 days	17.6 Total: 591 days Average: 33 days	428 (114, 343, 420, 505 1007)	374 (81, 298, 365, 440, 1055)	802 (285, 678, 792, 910, 1767)	30 (11, 26, 30, 35, 76)	31 (10, 26, 31 36, 101)	61 (30, 54, 61, 68, 154)

of heat related YLL was greater than for heat related mortality.

The RR of cold related YLL and mortality varied across conurbations, though not substantially (Table 2). The RR was highest in the West Midlands where the RR of YLL per degree Celsius below the threshold was 1.031 (1.024, 1.037). The RR for cold-related YLL and mortality was most similar in the West Midlands. In general, the RR of cold-related mortality in females was slightly higher than in males (though confidence intervals overlapped). However, in Greater Manchester for cold-related YLL, the RR was lower in females compared to males.

3.2.2. *Risk of heat and cold related YLL and mortality: Differences in heat and cold related burdens depending on metric (YLL vs mortality) used*

We hypothesised that the proportion of total YLL attributable to heat or cold would be lower than for mortality, due to older people being more vulnerable to the effects of heat and cold. The percentage of year-round YLL attributable to heat was 0.391% for Greater London, 0.309% in the West Midlands and 0.206% in Greater Manchester (Table 2). By comparison, the percentage of year round mortality attributable to heat was 0.498% for Greater London, 0.301% for the West Midlands and 0.262% for Greater Manchester. The results for cold related YLL and mortality are shown in Table 2 and similarly indicate a lower proportion total YLL attributable to cold compared to mortality. In the West Midlands, however, the percentage of total YLL attributable to heat and cold were similar for mortality and YLL. Results for heat and cold related mortality analysed by age category are included in the supplementary materials (Table S1 – some results have lower precision due to the small number of daily deaths in some categories). In contrast to London, where as expected the risk of heat and cold related mortality is significantly higher in the oldest age group compared to the youngest, the risk of cold related mortality appears more consistent across the age categories in the West Midlands. This may in part explain the smaller difference in temperature related risk and burdens between mortality and YLL in this conurbation.

3.2.3. *Changes in temperature related YLL and mortality over time*

We divided the time series into four discrete time periods to investigate whether the effect of cold and heat on YLL and mortality changed between 1996 and 2012. The RR of heat and cold related YLL and mortality for each of these time periods are illustrated in Fig. 2a (heat risk) and Fig. 2b (cold risk) and Table S2 (see supplementary materials). Graphs of the sensitivity analysis performed on time periods obtained by dividing data at yearly intervals are included in the supplementary Figs. (S2a and S2b), but overall patterns observed did not change depending on whether yearly series (less precise estimates) or each of the four year bands were used and there was no difference in patterns observed when thresholds were fixed across the entire time period for analysis (Table S3 supplementary materials).

The RR of heat related YLL and mortality did not show any consistent increase or decrease over time within or between the conurbations, both for results of analysis in 4 yearly time bands (Fig. 2a) or by yearly time bands (see Supplementary materials Fig. S2a). For Greater London, the RR of heat related YLL and mortality followed the same path, with no discernible increase or decrease in heat related risk over time. There was, however, a spike in risk for the years 2000–2003 for both YLL and mortality (where the temperature series includes the 2003 heatwave which had a large impact on mortality over Western Europe and particularly London and the South East in the UK (Johnson et al., 2005; Kovats and Kristie, 2006). This spike in risk is also clearly seen in the yearly series in 2003 but over the entire time period there is no increasing or decreasing risk over time (Fig. S2a, supplementary materials). In Greater Manchester and the West Midlands there is no clear spike in risk for the period containing the 2003 heatwave, likely reflecting both that the 2003 heatwave was less severe outside the south of England and also that the 2006 heatwave had greater health impacts in the West Midlands (National Statistics, 2006).

Table 2
Results from time series regression analysis (with control for time varying factors and confounders).

		Mortality RR (95% CI)	Percentage (%) of total mortality attributable to heat or cold (%)	Years of Life Lost (YLL) RR (95% CI)	Percentage (%) of total YLL attributable to heat or cold (%)
Greater London					
Heat (Threshold 18.9 °C)	Total	1.039 (1.035, 1.043)	0.498	1.030 (1.025,1.035)	0.391
	Male	1.029 (1.024, 1.035)	0.377	1.026 (1.019, 1.032)	0.338
	Female	1.049 (1.043, 1.054)	0.619	1.035 (1.027, 1.042)	0.454
Cold (Threshold 9.0 °C)	Total	1.029 (1.026, 1.033)	3.266	1.025 (1.020, 1.030)	2.675
	Male	1.027 (1.022,1.032)	2.991	1.022 (1.016, 1.029)	2.370
	Female	1.032 (1.027, 1.037)	3.521	1.028 (1.021, 1.035)	3.000
Greater Manchester		Mortality		YLL	
Heat (Threshold 16.8 °C)	Total	1.020 (1.014, 1.027)	0.262	1.015 (1.007,1.024)	0.206
	Male	1.017 (1.008. 1.026)	0.220	1.0140 (1.003, 1.025)	0.188
	Female	1.024 (1.015, 1.032)	0.303	1.017 (1.005, 1.029)	0.228
Cold (Threshold 7.9 °C)	Total	1.026 (1.019, 1.032)	2.685	1.021 (1.012, 1.030)	2.150
	Male	1.026 (1.017, 1.035)	2.658	1.028 (1.016, 1.040)	2.761
	Female	1.026 (1.017, 1.035)	2.703	1.014 (1.004, 1.026)	1.436
West Midlands					
Heat (Threshold 17.6 °C)	Total	1.025 (1.018, 1.031)	0.301	1.024 (1.016, 1.033)	0.309
	Male	1.025 (1.014, 1.037)	0.310	1.030 (1.018, 1.043)	0.387
	Female	1.021 (1.012, 1.031)	0.256	1.017 (1.004, 1.030)	0.218
Cold (Threshold 8.0 °C)	Total	1.031 (1.024, 1.037)	3.298	1.031 (1.022, 1.039)	3.213
	Male	1.028 (1.019, 1.036)	2.921	1.030 (1.019, 1.042)	3.142
	Female	1.034 (1.025, 1.042)	3.706	1.032 (1.019, 1.043)	3.295

The RR of cold related YLL and mortality did not show any consistent increase or decrease over time within or between the conurbations (Fig. S2b). Whilst in the West Midlands, there is a possible increase in risk from the first to the third time-bands for both cold related YLL and mortality, the yearly estimates (Fig. S2b) do not demonstrate a pattern of increasing risk and it is likely that the first time band of the 4 yearly estimates was sensitive to the very low cold risk in the winter of 1998/1999 in this conurbation. Of note, in the yearly estimates (supplementary materials, Fig. S1b), a peak in cold related risk can be seen in 1999/2000 in Greater London and Greater Manchester, which may be related to high flu deaths that year (Hardelid et al., 2013), not adequately controlled for in the model using laboratory influenza A counts. Tables S2 and S3 (supplementary materials) detail the relative risks and burdens of heat and cold related mortality and YLL (as a percentage of mortality or YLL for each time period). The increased percentages of cold related deaths and YLL attributable to cold in later time periods (Tables S2 and S3) are likely due to the colder winters during these times (reflecting the contribution of greater extremes in cold temperatures where the threshold temperature is exceeded by a greater amount, to the attributable mortality for these time periods).

4. Discussion

We investigated the association between heat, cold and YLL and

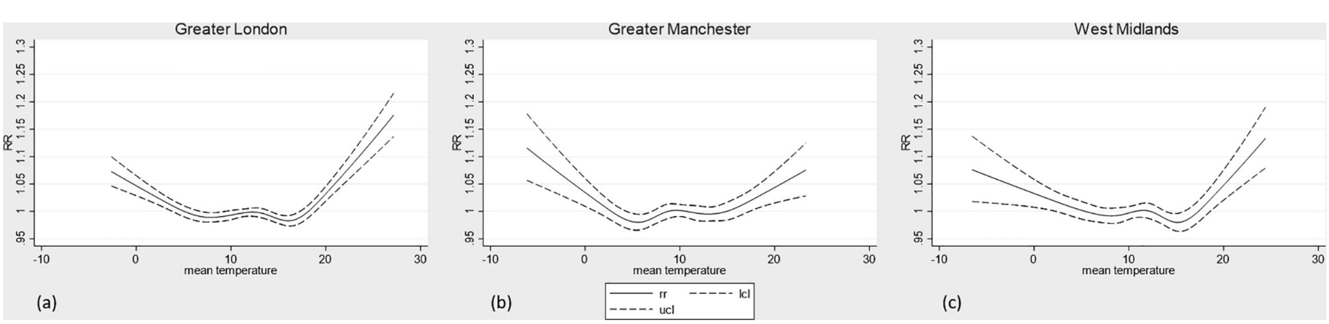

Fig. 1. The RR of temperature related YLL at lag 0–2 days for (a) Greater London, (b) Greater Manchester and (c) the West Midlands (including Birmingham).

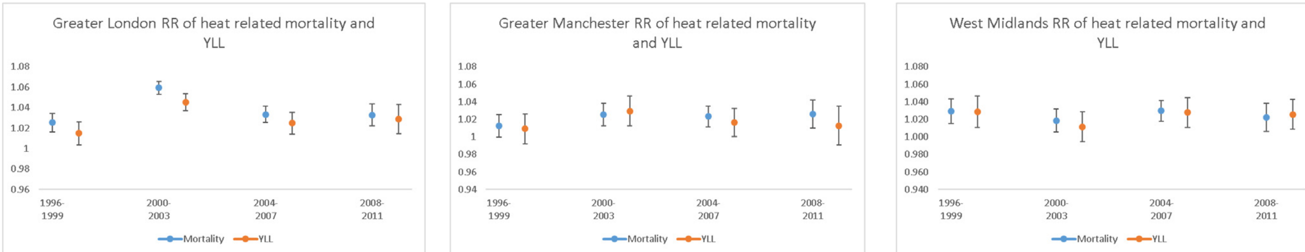

Fig. 2a. Changes in heat related RR of YLL and mortality over time.

mortality and whether these associations have changed in magnitude over recent years. We found an increased risk in YLL for each 1 °C increase or decrease in temperatures above and below identified temperature thresholds in Greater London, the West Midlands and Greater Manchester. We demonstrate that in these conurbations, the nature of this relationship between YLL and temperature is similar to that between mortality and temperature. We found no evidence for a trend of decreasing risk (RR) of heat or cold related mortality or YLL over time in the conurbations, and therefore no evidence of population adaptation to ambient heat or cold over this time period. Heat risks were highest in Greater London, and cold risks were highest in the West Midlands, though variation in risk between conurbations was less pronounced for cold effects. This is broadly consistent with findings from previous studies (Vardoulakis et al., 2014; Hajat et al., 2007; Arbuthnott and Hajat, 2017; Hajat, 2017), though cold effects have not been specifically examined at conurbation level for the UK. This geographical variation in heat and cold effects may be due to social, demographic, built environment and economic factors. For example, the West Midlands has the highest proportion (13.5% of households) of fuel poverty across England (Office for National Statistics, 2017) which may contribute to the increased risk in cold mortality.

Although the effects of temperature on YLL have to date not been specifically studied within England, our results are consistent with those from other high-income settings which have used YLL as an outcome, and have demonstrated an increased risk of YLL with increased temperatures (Huang et al., 2012; Sewe et al., 2018). The percentages of overall YLL attributable to heat and cold related YLL were lower compared to those for mortality in Greater London and Greater Manchester but similar in the West Midlands. However, the overall similarity in RR between temperature related mortality and YLL in all conurbations may imply that the results are mostly dominated by the large number of deaths occurring in older people. This is consistent with existing knowledge that in the UK, older people are at increased risk from temperature related mortality (Arbuthnott and Hajat, 2017; Hajat, 2017).

We found that over the studied time period, there was no consistent decrease in heat or cold related risk across the conurbations based on four yearly and yearly estimates. Importantly, this result remained unchanged when heat and cold related risks were analysed using an absolute threshold value (fixed at the 35th and 91st percentiles of the temperature distribution for the entire time period). This means possible adaptation denoted by an undetected increase in heat thresholds but masked by a lack of increase in the RR, is unlikely for this time period. Across a number of other settings, however, the risk of heat related mortality has been shown to decrease over time, including in studies using data over short (less than 20 years) time periods and in recent years, though this has not been the case in all locations (Sheridan and Allen, 2018). Trends in cold related health outcomes over time are less well studied, and results have been more heterogeneous (Arbuthnott et al., 2016). Some of these studies of changes in heat and cold risks over time have included English data in their analysis. Carson et al. (Carson et al., 2006) found that between 1900 and 1996 there was a decrease in both heat and cold related deaths in London. The time period for this study does not overlap with ours and by contrast includes the period over which England underwent the epidemiological transition, meaning that temperature related deaths may have declined rapidly due to rapid improvements in health and social care. Donaldson et al. (Donaldson et al., 2003) also found a significant reduction in heat related mortality in South East England in an earlier (but similar in length) time period to ours - between 1971 and 1996. However, our results are broadly consistent with more recent UK studies. For example, Gasparrini et al. did not find any attenuation in heat related mortality risk in the UK (Gasparrini et al., 2015). A recent analysis by Vicedo-Cabrera et al. (2018) showed no attenuation in heat and cold related AFs over the time period 1990–2011. However the study did find some attenuation in the relative risk of mortality at a national level when comparing the risk at the 99th or 1st temperature percentile with the minimum mortality temperature, though this may highlight changes in risk of mortality at 'extreme' temperatures (Vicedo-Cabrera et al., 2018). Our study adds to this body of evidence, and contributes information on changes in YLL over time and disaggregated by conurbation.

It is not surprising that vulnerability to heat and cold is context specific and will depend on a number of factors from individual to societal, city and national level influences – the age structure of the population, potentially the rate of recent temperature change, health and social care and also more specific factors which could be adapted to modify the heat or cold risk (e.g. availability of air conditioning, individual behaviour, housing fabric and ventilation and urban design). The similar pattern over time in risk of YLL and mortality would imply that the population age structure over the period is not contributing to an increase in risk. However, in our study, the lack of any decrease in temperature (hot or cold) related risk in these conurbations (compared to other global locations which have seen decreases in risk over similar

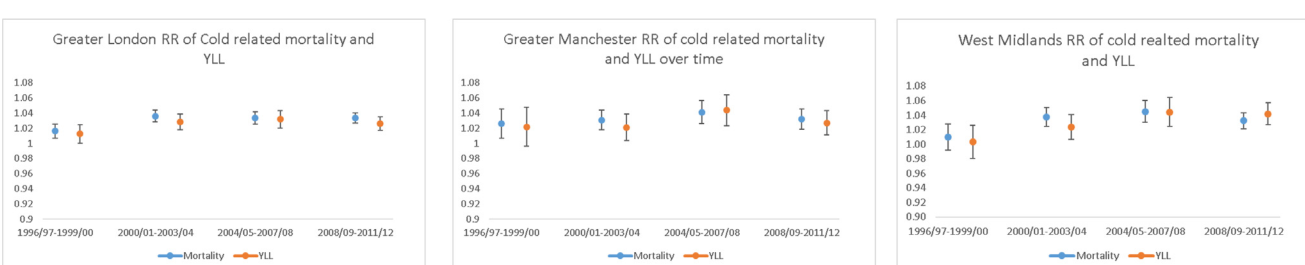

Fig. 2b. Changes in cold related RR of YLL and mortality over time.

time periods) may be due to several factors. For example, regarding specific ‘heat adaptation’, a recent survey (Khare et al., 2015) indicated that the prevalence of air conditioning is still low in the UK (< 3%) and also that populations at high risk, such as the elderly, were less likely to engage in personal and home-related protective behaviours. Regarding specific ‘cold adaptation’, there have also been a number of UK housing improvements made (12.2 million UK homes have undergone some energy efficiency retrofit since 2000 (Hamilton et al., 2016) to reduce energy demand, which may improve indoor air temperatures in the winter and the proportion of energy efficient homes rose from 2% in 1996 to 18% in 2012 (NICE, 2015). Despite this and winter fuel payments, one in-depth survey suggested that in the previous winter those whose income was less than 60% of the national average had trouble paying fuel bills (Anderson et al., 2010). The absence of any decreasing risk of cold related mortality highlights that policies to reduce the effect of cold weather on public health (e.g. Public Health England’s Cold weather plan and the NICE recommendations on cold homes (NICE, 2015)) in the UK remain important, and should not be overlooked in the context of climate change.

England does, however, have heat and cold weather plans (Public Health England, 2020), introduced in 2004 and 2011 respectively. The time period of our analysis would mean that any beneficial effects of the cold weather plan would not be adequately captured, though one recent study suggests that since the introduction of the cold weather plan, cold related mortality has decreased in the under 65s but increased in the over 75s and that geographical variability in cold related mortality has increased since the introduction of the plan (Murage et al., 2018). Importantly, we found no reduction in mortality risk in the time periods after the introduction of the Heatwave Plan (HWP) compared to before its introduction. Whilst the outcomes used in this study may be too narrowly defined to adequately capture all the beneficial effects of the HWP, our findings are broadly consistent with a recent evaluation of the HWP for England. The evaluation found that although mortality during extreme events or heatwave periods has reduced in recent years, there was little evidence since its introduction for a reduction in the risk of annual heat related mortality outside heatwave events (and consequently for those more moderately hot days which contribute to the largest public health burdens) (Williams et al., 2019). It highlighted that in accordance with previous studies, most adults at risk of heat related mortality did not perceive themselves to be at personal risk and that further work around public health messaging (amongst other recommendations) is needed (Williams et al., 2019). Whilst the HWP has motivated the implementation of an alert and response system for high temperatures, many activities could go beyond this acute response (for example into longer term planning such as in levels 0 and 1 of the plan). There are many interventions which may be introduced at the housing or urban/conurbation level to reduce ambient heat exposure, such as those which reduce the effect of the urban heat island effect through reflecting solar radiance or increasing evaporative cooling through increased urban green and blue spaces (Heaviside et al., 2017). For example, a recent modelling study suggested cool roofs could reduce UHI intensity and the associated mortality during heatwave events in the West Midlands (Macintyre and Heaviside, 2019), and well-designed urban greenspaces, have the potential for multiple and varied additional health co-benefits in addition to those from reducing ambient temperatures (though specifics depend on a number of contextual factors) (van den Bosch and Nieuwenhuijsen, 2017; Wheeler et al., 2015; Rojas-Rueda et al., 2019; Twohig-Bennett and Jones, 2018).

To our knowledge, this is the first study to specifically examine the effects of heat and cold on YLL in the UK, and to assess changes in these risks over time at conurbation level. One strength is the assessment of both heat and cold effects: in the context of climate change, many studies have focused on increased temperature effects, while significant cold burdens remain (Almendra et al., 2019). Examining YLL in different English conurbations can reveal differences in risk and trends over time (which may be masked in a larger scale analysis) and contributes to specifically understanding urban temperature risks. Additional strengths include the use of life expectancies specific to each individual year of age (many previous studies have used life expectancy for 5 year age bands), which is especially important for the majority of deaths which occur in older age categories, and the different approaches taken to analysing changes over time. We also made use of gridded temperature data (Perry, 2009), which is more likely to provide an accurate reflection of urban temperatures than previous datasets based on interpolations which have not taken into account urban land use.

However, our study has a number of potential limitations. The method of deriving YLL from the age at death and English life expectancy assumes that those dying from the effects of heat and cold have the same life expectancy as others of their age. Some evidence of mortality displacement in high income settings has previously suggested that a proportion of deaths, due to heat at least, are likely to have been brought forward by only a short amount of time (Hajat et al., 2005; Baccini et al., 2013). More recently, however, methods of quantifying mortality displacement such as those based on displacement ratios from short term Poisson regression analyses have been shown to be unreliable (Armstrong et al., 2014) and a number of more recent studies suggest that deaths are displaced by at least one year (rather than a few weeks as suggested in previous analyses) (Armstrong et al., 2017; Goggins et al., 2015). If this is the case, then the assumptions made when calculating YLL are less likely to have affected our results; the similarity between risk of mortality and YLL would indicate the majority of deaths due to heat and cold occurring in those with close or less than a year’s life expectancy, less than the amount by which deaths have recently been shown to be brought forward. We used England-wide life expectancy rather than city-specific life expectancy, which was not available. However, to account for this, we undertook a sensitivity analysis using YLL corrected for regional differences in life expectancy (produced by ONS), which did not significantly alter results. We also matched deaths to life expectancy values from the mid-point of the time period analysed, meaning that for the years early in the series, life expectancies could be over-estimated, with the opposite being true for the latter part of the study. Consequently, it is possible that upward trends in risk of temperature related YLL may be overlooked. However, we would expect this to be more consequential if changes in susceptibility over time were presented as total attributable burdens or if there was an observed downward trend in risk which may have been exaggerated.

We did not include relative humidity or air pollutants as potential confounders or effect modifiers in our primary analysis (though inclusion of air pollution in our sensitivity analysis for London did not significantly alter the estimates), and note that previous analyses did not find a significant contribution of humidity or air pollution when assessing the relationship between temperature and health within the UK (Hajat et al., 2006). There is also a methodological question as to whether air pollution is indeed a confounder or in fact lies on the causal pathway in the relationship between temperature and health – this has been well considered for ozone (Buckley et al., 2014) and a similar argument could be made for PM being on the causal pathway, for example combustion is likely to be higher on cold days and there may be less dispersion of air pollution on cool still days in the winter. A limitation of our study is that the time-period over which changes in RR of heat or cold related mortality or YLL were examined was relatively short, which has two implications. Firstly, the period may be too short to examine population ‘adaptation’ (and of note, no consistent increase in temperature was seen over the time period), though it does include time-periods over which changes in heat and cold risk have been observed in other settings. Secondly, splitting the time series into 4-year time-bands increases the sensitivity of the analyses to particularly hot or cold winters within each time-band. However, a sensitivity analysis was undertaken splitting the data yearly and results from this have been discussed and presented (supplementary materials Fig. 2a and 2b).

5. Conclusions and implications for policy and research

We have demonstrated a positive association between YLL and temperatures above and below a given threshold, in the three largest conurbations in England – Greater London, Greater Manchester and the West Midlands. The risks of YLL and mortality due to heat and cold were largely similar, though the percentages of total YLL attributable to heat and cold were lower than for mortality in Greater London and Greater Manchester, likely indicating a proportion of deaths are occurring in those with less than one year of life expectancy. Despite this, there remains a significant burden in terms of YLL attributable to heat and cold across all conurbations, indicating that heat and cold remain an important public health concern, warranting attention both now and in the consideration of adaptation to the effects of further climate change. Additional research, using further outcomes relevant to public health and planning, such as those that take into account health losses that are not fatal (for example Disability Adjusted Life Years) would also make an interesting area of study. We did not find evidence of any changes in the risk of heat and cold related mortality or YLL over the course of our study. This is in contrast to studies in other locations and is important, since it has implications for assumptions that are often made (for example in the context of climate change risk assessments) that populations will 'adapt' to heat. We highlight that adaptation is context specific, and will not occur without active policy or structural changes in the UK. There is a growing evidence base of urban adaptation measures that can reduce heat related mortality, for example urban greening, improved architectural and urban design. Whilst the increased use of some interventions such as air conditioning is problematic and can result in anthropogenic warming and increased GHG emissions, many interventions at conurbation level could serve to both reduce heat related mortality and have additional health co-benefits. Further research is needed to better evaluate the specific and contextual adaptive measures to heat and cold which have already been undertaken within UK cities and to better understand how cities can best adapt and mitigate the effects of climate change using measures that will be beneficial to health. Improved integration of research and policy development in this area would be of great benefit.

CRediT authorship contribution statement

Katherine Arbuthnott: Conceptualization, Investigation, Formal analysis, Writing - original draft. **Shakoor Hajat:** Conceptualization, Methodology, Writing - review & editing. **Clare Heaviside:** Conceptualization, Data curation, Writing - review & editing. **Sotiris Vardoulakis:** Conceptualization, Writing - review & editing.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgments

KA was supported by the Public Health England PhD studentship scheme. The research was partly funded by the National Institute for Health Research Health Protection Research Unit (NIHR HPRU) in Environmental Change and Health at the London School of Hygiene and Tropical Medicine in partnership with Public Health England (PHE), and in collaboration with the University of Exeter, University College London, and the Met Office. The views expressed are those of the authors and not necessarily those of the NHS, the NIHR, the Department of Health or Public Health England.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.envint.2020.105966.

References

Almendra, R., Santana, P., Mitsakou, C., Heaviside, C., Samoli, E., Rodopoulou, S., et al., 2019. Cold-related mortality in three European metropolitan areas: Athens, Lisbon and London. Implications for health promotion. Urban Clim. 30.

Anderson, W., White, V., Finney, A., 2010. You Just Have to Get By: Coping with Low Incomes and Cold Homes. Centre for Sustainable Energy.

Arbuthnott, K., Hajat, S., Heaviside, C., Vardoulakis, S., 2016. Changes in population susceptibility to heat and cold over time: assessing adaptation to climate change. Environ. Health 15 (Suppl 1), 33.

Arbuthnott, K.G., Hajat, S., 2017. The health effects of hotter summers and heat waves in the population of the United Kingdom: a review of the evidence. Environ. Health 16 (Suppl 1), 119.

Armstrong, B., Gasparrini, A., Hajat, S., 2014. Estimating mortality displacement during and after heat waves. Am. J. Epidemiol. 179 (12), 1405–1406.

Armstrong, B., Bell, M.L., de Sousa Zanotti Stagliorio Coelho, M., Leon Guo, Y.L., Guo, Y., Goodman, P., et al., 2017. Longer-term impact of high and low temperature on mortality: an international study to clarify length of mortality displacement. Environ. Health Perspect. 125 (10), 107009.

Baccini, M., Kosatsky, T., Biggeri, A., 2013. Impact of summer heat on urban population mortality in Europe during the 1990s: An evaluation of years of life lost Adjusted for Harvesting. PLoS ONE 8 (7).

Baccini, M., Kosatsky, T., Biggeri, A., 2013. Impact of summer heat on urban population mortality in Europe during the 1990s: an evaluation of years of life lost adjusted for harvesting. PLoS ONE 8 (7), e69638.

Basu, R., 2009. High ambient temperature and mortality: a review of epidemiologic studies from 2001 to 2008. Environmental Health 8 (1), 40.

Bhaskaran, K., Gasparrini, A., Hajat, S., Smeeth, L., Armstrong, B., 2013. Time series regression studies in environmental epidemiology. Int. J. Epidemiol. 42 (4), 1187–1195.

Birmingham City Council. Climate Change Adaptation Action Plan 2012. Available from: https://www.birmingham.gov.uk/downloads/file/1888/climate_change_adaptation_action_plan_2012.

Brohan, P., Kennedy, J.J., Harris, I., Tett, S.F.B., Jones, P.D., 2006. Uncertainty estimates in regional and global observed temperature changes: A new data set from 1850. J. Geophys. Res.-Atmos. 111 (D12).

Broome, R.A., Fann, N., Cristina, T.J., Fulcher, C., Duc, H., Morgan, G.G., 2015. The health benefits of reducing air pollution in Sydney, Australia. Environ Res. 143 (Pt A), 19–25.

Buckley, J.P., Samet, J.M., Richardson, D.B., 2014. Commentary: Does air pollution confound studies of temperature? Epidemiology. 25 (2), 242–245.

Bunker, A., Sewe, M.O., Sie, A., Rocklov, J., Sauerborn, R., 2017. Excess burden of non-communicable disease years of life lost from heat in rural Burkina Faso: a time series analysis of the years 2000–2010. BMJ Open. 7 (11), e018068.

Carson, C., Hajat, S., Armstrong, B., Wilkinson, P., 2006. Declining vulnerability to temperature-related mortality in London over the 20th century. Am. J. Epidemiol. 164 (1), 77–84.

Cohen, A.J., Ross Anderson, H., Ostro, B., Pandey, K.D., Krzyzanowski, M., Kunzli, N., et al., 2005. The global burden of disease due to outdoor air pollution. J. Toxicol. Environ. Health A 68 (13–14), 1301–1307.

DEFRA, 2018 Data Selector: DEFRA.; [cited 2018 1st September 2018]. Available from: https://uk-air.defra.gov.uk/data/data_selector.

Dempsey, M., 1947. Decline in tuberculosis; the death rate fails to tell the entire story. Am. Rev. Tuberculos. 56 (2), 157–164.

Donaldson, G.C., Keatinge, W.R., Nayha, S., 2003. Changes in summer temperature and heat-related mortality since 1971 in North Carolina, South Finland, and Southeast England. Environ. Res. 91 (1), 1–7.

Egondi, T., Kyobutungi, C., Rocklov, J., 2015. Temperature variation and heat wave and cold spell impacts on years of life lost among the urban poor population of Nairobi, Kenya. Int. J. Environ. Res. Public Health 12 (3), 2735–2748.

Gasparrini, A., Guo, Y., Hashizume, M., Lavigne, E., Zanobetti, A., Schwartz, J., et al., 2015. Mortality risk attributable to high and low ambient temperature: a multicountry observational study. Lancet 386 (9991), 369–375.

Gasparrini, A., Guo, Y., Hashizume, M., Kinney, P.L., Petkova, E.P., Lavigne, E., et al., 2015. Temporal variation in heat-mortality associations: a multicountry study. Environ. Health Perspect. 123 (11), 1200–1207.

Goggins, W.B., Yang, C., Hokama, T., Law, L.S., Chan, E.Y., 2015. Using annual data to estimate the public health impact of extreme temperatures. Am. J. Epidemiol. 182 (1), 80–87.

Hajat, S., 2017. Health effects of milder winters: a review of evidence from the United Kingdom. Environ Health. 16 (Suppl 1), 109.

Hajat, S., Armstrong, B.G., Gouveia, N., Wilkinson, P., 2005. Mortality displacement of heat-related deaths: a comparison of Delhi, Sao Paulo, and London. Epidemiology 16 (5), 613–620.

Hajat, S., Armstrong, B., Baccini, M., Biggeri, A., Bisanti, L., Russo, A., et al., 2006. Impact of high temperatures on mortality: is there an added heat wave effect? Epidemiology. 17 (6), 632–638.

Hajat, S., Kovats, R.S., Lachowycz, K., 2007. Heat-related and cold-related deaths in England and Wales: who is at risk? Occup. Environ. Med. 64 (2), 93–100.

Hajat, S., Vardoulakis, S., Heaviside, C., Eggen, B., 2014. Climate change effects on human health: projections of temperature-related mortality for the UK during the 2020s, 2050s and 2080s. J. Epidemiol. Community Health 68 (7), 641–648.
Hajat, S., Chalabi, Z., Wilkinson, P., Erens, B., Jones, L., Mays, N., 2016. Public health vulnerability to wintertime weather: time-series regression and episode analyses of national mortality and morbidity databases to inform the Cold Weather Plan for England. Public Health 137, 26–34.
Hamilton, I.G., Summerfield, A.J., Shipworth, D., Steadman, J.P., Oreszczyn, T., Lowe, R.J., 2016. Energy efficiency uptake and energy savings in English houses: A cohort study. Energy Build. 118, 259–276.
Hardelid, P., Pebody, R., Andrews, N., 2013. Mortality caused by influenza and respiratory syncytial virus by age group in England and Wales 1999–2010. Influenza Other Respir. Viruses 7 (1), 35–45.
Heaviside, C., Vardoulakis, S., Cai, X.M., 2016. Attribution of mortality to the urban heat island during heatwaves in the West Midlands, UK. Environ Health. 15 (Suppl 1), 27.
Heaviside, C., Macintyre, H., Vardoulakis, S., 2017. The urban heat island: implications for health in a changing environment. Curr. Environ Health Rep. 4 (3), 296–305.
Huang, C., Barnett, A.G., Wang, X., Tong, S., 2012. Effects of extreme temperatures on years of life lost for cardiovascular deaths: a time series study in Brisbane, Australia. Circ. Cardiovasc. Qual. Outcomes 5 (5), 609–614.
Huang, C.R., Barnett, A.G., Wang, X.M., Tong, S.L., 2012. The impact of temperature on years of life lost in Brisbane, Australia. Nat. Clim. Change 2 (4), 265–270.
Huang, J., Pan, X., Guo, X., Li, G., 2018. Impacts of air pollution wave on years of life lost: A crucial way to communicate the health risks of air pollution to the public. Environ. Int. 113, 42–49.
Johnson, H., Kovats, R.S., McGregor, G., Stedman, J., Gibbs, M., Walton, H., et al., 2005. The impact of the 2003 heat wave on mortality and hospital admissions in England. Health Stat. Q 25, 6–11.
Khare, S., Hajat, S., Kovats, S., Lefevre, C.E., de Bruin, W.B., Dessai, S., et al., 2015. Heat protection behaviour in the UK: results of an online survey after the 2013 heatwave. BMC Public Health 15, 878.
Kovats, R.S., Kristie, L.E., 2006. Heatwaves and public health in Europe. Eur. J. Public Health. 16 (6), 592–599.
Lopez, A.D., Mathers, C.D., Ezzati, M., Jamison, D.T., Murray, C.J.L., 2006. Measuring the global burden of disease and risk factors, 1990–2001. In: Lopez, A.D., Mathers, C.D., Ezzati, M., Jamison, D.T., Murray, C.J.L. (Eds.), Global Burden of Disease and Risk Factors. Washington (DC).
Luan, G., Yin, P., Li, T., Wang, L., Zhou, M., 2017. The years of life lost on cardiovascular disease attributable to ambient temperature in China. Sci. Rep. 7 (1), 13531.
Macintyre, H.L., Heaviside, C., 2019. Potential benefits of cool roofs in reducing heat-related mortality during heatwaves in a European city. Environ. Int. 127, 430–441.
Manchester City Council. Manchester City Council's Climate Change Delivery Plan 2010–2020. Available from: https://secure.manchester.gov.uk/downloads/download/5648/climate_change_delivery_plan.
Mayor of London. Zero carbon London: A 1.5°C compatible plan 2018 [September 2019]. Available from: https://www.london.gov.uk/sites/default/files/1.5_action_plan_amended.pdf.
Murage, P., Hajat, S., Bone, A., 2018. Variation in cold-related mortality in England since the introduction of the cold weather plan: which areas have the greatest unmet needs? Int. J. Environ. Res. Public Health 15 (11).
Murray, C.J., Lopez, A.D., 2013. Measuring the global burden of disease. N. Engl. J. Med. 369 (5), 448–457.
NICE. Preventing excess winter deaths and illness associated with cold homes 2015. Available from: https://www.nice.org.uk/guidance/qs117/chapter/introduction.
National Statistics, 2006. Estimated daily mortality during July 2006 in England and Wales, 2006. Health Stat. Q 32, 107–111.
Odhiambo Sewe, M., Bunker, A., Ingole, V., Egondi, T., Oudin Astrom, D., Hondula, D.M., et al., 2018. Estimated effect of temperature on years of life lost: a retrospective time-series study of low-, middle-, and high-income regions. Environ. Health Perspect. 126 (1), 017004.
Office for National Statistics. Annual Fuel Poverty Statistics Report, 2017 (2015 data) 2017.
Office for National Statistics. Rural population 2014/15 2018 [April 2018]. Available from: https://www.gov.uk/government/publications/rural-population-and-migration/rural-population-201415.
Office for National Statistics. User Requested Data 2017 [March 2017]. Available from: https://www.ons.gov.uk/aboutus/whatwedo/statistics/requestingstatistics/alladhocs.
Office for National Statistics. 2011 Built-up Areas- Methodology and Guidance [cited 2017 12/10/2017]. Available from: http://www.nomisweb.co.uk/articles/ref/builtupareas_userguidance.pdf.
Perry, M.C., 2009. The generation of daily gridded datasets of temperature and rainfall for the UK. National Information Centre. Climate Memorandum No 24. 2009.
Public Health England, 2020. Heatwave plan for England. Available from: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/888668/Heatwave_plan_for_England_2020.pdf.
Rojas-Rueda, D., Nieuwenhuijsen, M.J., Gascon, M., Perez-Leon, D., Mudu, P., 2019. Green spaces and mortality: a systematic review and meta-analysis of cohort studies. Lancet Planet Health 3 (11), e469–e477.
Romeder, J.M., McWhinnie, J.R., 1977. Potential years of life lost between ages 1 and 70: an indicator of premature mortality for health planning. Int. J. Epidemiol. 6 (2), 143–151.
Sassi, F., 2006. Calculating QALYs, comparing QALY and DALY calculations. Health Policy Plan. 21 (5), 402–408.
Sheridan, S.C., Allen, M.J., 2018. Temporal trends in human vulnerability to excessive heat. Environ. Res. Lett. 13 (4), 043001.
Twohig-Bennett, C., Jones, A., 2018. The health benefits of the great outdoors: A systematic review and meta-analysis of greenspace exposure and health outcomes. Environ. Res. 166, 628–637.
UK Met Office. [05/10/2017]. Available from: https://www.metoffice.gov.uk/climatechange/science/monitoring/ukcp09/faq.html#faq1.1.
Urban, A., Kysely, J., Plavcova, E., Hanzlikova, H., Stepanek, P., 2020. Temporal changes in years of life lost associated with heat waves in the Czech Republic. Sci. Total Environ. 716, 137093.
van den Bosch, M., Nieuwenhuijsen, M., 2017. No time to lose – Green the cities now. Environ. Int. 99, 343–350.
Vardoulakis, S., Dear, K., Hajat, S., Heaviside, C., Eggen, B., McMichael, A.J., 2014. Comparative assessment of the effects of climate change on heat- and cold-related mortality in the United Kingdom and Australia. Environ. Health Perspect. 122 (12), 1285–1292.
Vicedo-Cabrera, A.M., Sera, F., Guo, Y., Chung, Y., Arbuthnott, K., Tong, S., et al., 2018. A multi-country analysis on potential adaptive mechanisms to cold and heat in a changing climate. Environ. Int. 111, 239–246.
Wheeler, B.W., Lovell, R., Higgins, S.L., White, M.P., Alcock, I., Osborne, N.J., et al., 2015. Beyond greenspace: an ecological study of population general health and indicators of natural environment type and quality. Int. J. Health Geogr. 14, 17.
Williams, L.E.B., Ettelt, S., Hajat, S., Manacorda, T., Mays N., 2019. Evaluation of the Heatwave Plan for England.
Yang, J., Ou, C.Q., Guo, Y.M., Li, L., Guo, C., Chen, P.Y., et al., 2015.. The burden of ambient temperature on years of life lost in Guangzhou, China. Sci. Rep. 5.
Zhang, Y., Yu, C., Yang, J., Zhang, L., Cui, F., 2017. Diurnal temperature range in relation to daily mortality and years of life lost in Wuhan, China. Int. J. Environ. Res. Public Health 14 (8).
Zhang, Y., Yu, C., Peng, M., Zhang, L., 2018. The burden of ambient temperature on years of life lost: A multi-community analysis in Hubei, China. Sci. Total Environ. 621, 1491–1498.