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Assessing urban population vulnerability and environmental risks across an urban area during heatwaves – Implications for health protection

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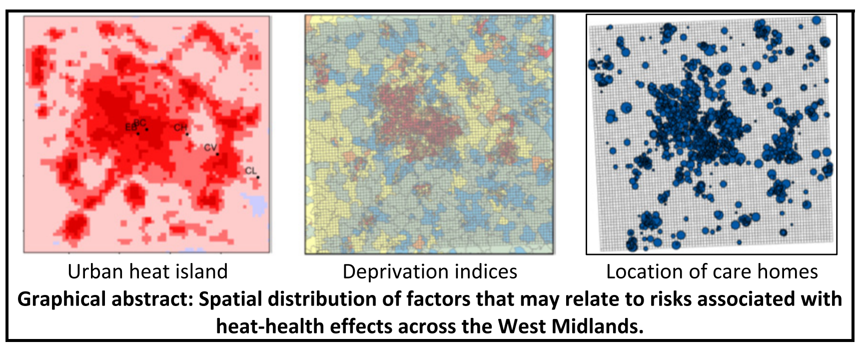
HIGHLIGHTS

- Multiple factors are associated with health effects of heat exposure.
- Cities in the West Midlands have a pronounced UHI.
- Care homes and hospitals are exposed to higher ambient temperatures than average.
- Housing types more likely to overheat are located in the warmest parts of the city.

GRAPHICAL ABSTRACT



Spatial distribution of factors that may relate to risks associated with heat-health effects across the West Midlands.

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ABSTRACT

Heatwaves can lead to a range of adverse impacts including increased risk of illness and mortality; the heatwave in August 2003 has been associated with ~70,000 deaths across Europe. Due to climate change, heatwaves are likely to become more intense, more frequent and last longer in the future. A number of factors may influence risks associated with heat exposure, such as population age, housing type, and location within the Urban Heat Island, and such factors may not be evenly distributed spatially across a region. We simulated and analysed two major heatwaves in the UK, in August 2003 and July 2006, to assess spatial vulnerability to heat exposure across the West Midlands, an area containing ~5 million people, and how ambient temperature varies in relation to factors that influence heat-related health effects, through weighting of ambient temperatures according to distributions of these factors across an urban area. Additionally we present quantification of how particular centres such as hospitals are exposed to the UHI, by comparing temperatures at these locations with average temperatures across the region, and presenting these results for both day and night times. We find that UHI intensity was substantial during both heatwaves, reaching a maximum of +9.6 °C in Birmingham in July 2006. Previous work has shown some housing types, such as flats and terraced houses, are associated with increased risk of overheating, and our results show that these housing types are generally located within the warmest parts of the city. Older age groups are more susceptible to the effects of heat. Our analysis of distribution of population based on age group showed there is only small spatial variation in ambient temperature that different age groups are exposed

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to. Analysis of relative deprivation across the region indicates more deprived populations are located in the warmest parts of the city.

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1. Introduction

1.1. Heat exposure and health

Heatwaves, or extended periods of hot weather, are associated with various risks to health including heat exhaustion, heatstroke, emergency hospitalisations, and death. A severe heatwave in August 2003 has been associated with up to 70,000 excess deaths across Europe (Robine et al., 2008), with over 2000 excess deaths estimated in England (Johnson et al., 2005), and a record breaking maximum temperature of 38.5 °C reached in south east England. High temperatures were also recorded throughout much of the UK during the summer of 2006. In the West Midlands, the two heatwave events of 2003 and 2006 were comparable in terms of estimated excess mortality, being around 10% higher than baseline rates at this time of year in both cases (Health Statistics Quarterly, 2006; Johnson et al., 2005). In the future, heatwaves are projected to become more frequent, more intense, and last longer, due to climate change (Kirtman et al., 2013), which will likely lead to increases in heat-related mortality (Hajat et al., 2014; Mitchell et al., 2016; Vardoulakis et al., 2014). Some evidence suggests there is an upper limit to which humans can adapt to temperature (Arbuthnott et al., 2016; Sherwood and Huber, 2010).

In the UK, the risk of temperature-related mortality is projected to increase steeply in the UK over the 21st century under climate change and demographic change scenarios, reaching 260% by 2050, and 540% by 2080 (compared with the 2000s heat-related mortality baseline of around 2000 premature deaths), with the elderly being most at risk (Hajat et al., 2014; HPA, 2012).

Future climate projections are often produced at relatively coarse spatial resolution, due to the cost of computing power required. Factors relevant for the study of heat-exposure and human health, including population age, socioeconomic factors, and the built environment such as dwelling type and the Urban Heat Island, are at a much finer spatial scale. Our study aims to simulate ambient temperature across an urban area during a heatwave period, and subsequently quantify the variation in ambient temperature with other factors that relate to and influence heat-related health effects. This includes population-weighting of ambient temperatures, as well as calculating the ambient temperature weighted according to distributions of different housing types, population age, and deprivation score, all factors that influence heat-health relationships. Using environmental modelling techniques in this way to look at human health in relation to heat exposure during heatwaves (which will become increasingly important in the future with climate change) is a novel way of analysing spatial distribution of risks across a large urbanised region. While we have used a detailed case study here, the technique and metrics are applicable to any scenario, which we feel is useful for a wider scientific community.

1.2. The Urban Heat Island (UHI)

Populations may be particularly at risk from heat due to the Urban Heat Island (UHI) effect (Heaviside et al., 2017), whereby ambient temperatures are often observed to be higher than those in surrounding less-urbanised areas, particularly at night. The main cause of the UHI is the modification of land surfaces, for example, replacing natural surfaces (e.g. vegetation which provide natural shading and cooling via evaporation) by paving or construction of buildings. Urban construction materials (such as concrete, tarmac and asphalt) generally absorb, retain and re-radiate heat more than natural surfaces. Buildings also provide multiple surfaces to reflect and absorb sunlight, increasing urban heating, and impeding air circulation. Heat from human activities (such as air conditioning, vehicles, and industrial processes) can also add to the UHI effect. The UHI effect is often most extreme during anticyclonic summer weather conditions, which are associated with heatwaves. In England and Wales, 82% of the population reside in urban areas (ONS, 2011), leaving them vulnerable to the impacts of heat exposure due to the UHI effect. The West Midlands is a highly urbanised area of the UK, which includes the city of Birmingham with a population of 1.1 million, and has a notable UHI (Bassett et al., 2016; Heaviside et al., 2015; Tomlinson et al., 2012). A health impact assessment for the heatwave of 2003 based on high resolution meteorological modelling suggested that in the West Midlands, around half of the heat-related mortality during the heatwave could be attributed to the UHI (Heaviside et al., 2016). The UHI intensity is often defined as the difference in temperature between urban and rural areas, and can be quantified by comparing ambient air temperature observations at a location in the centre of an urban area, and at a location in surrounding rural areas (Bassett et al., 2016; Hatchett et al., 2016; Ketterer and Matzarakis, 2015; Kim and Baik, 2002; Oke, 1973, 1982), or from satellite measurements (Azevedo et al., 2016; Benz et al., 2017; Du et al., 2016). However, observation stations are limited in number, are often not sited within urban centres, and may only cover certain time periods, while satellite measurements record land surface temperature (rather than air temperature), and are often temporally limited and may have missing data if it is cloudy. The use of meteorological computer simulations makes it possible to investigate spatial variations in temperature across urban areas, and to quantify the UHI intensity, by comparing temperatures simulated both with and without urban surfaces such as buildings and roads.

1.3. Mapping spatial variation in heat-exposure and risk

Heat exposure for urban populations will vary across urbanised areas, due to spatial variations in physical infrastructure that influences the UHI. Susceptibility to health risks associated with heat exposure is also influenced by other factors, including population age, housing type, socioeconomic factors, pre-existing health conditions, and location within the UHI (Taylor et al., 2015; Wolf and McGregor, 2013). It is therefore important in terms of health protection to understand the pattern of risk across a region, which may help target resources to reduce heat risk in the most vulnerable areas, since it is possible that environmental risks and vulnerable population groups are co-located within urban areas.

A number of studies have investigated heat risk across the Greater London area. Wolf and McGregor (2013) developed a Heat Vulnerability Index (HVI) for London based on principal component analysis of socio-demographic factors relating to heat vulnerability, combined with land surface temperatures (derived from a satellite measurement), finding clustering of high vulnerability in the east and central areas of the city. Heat risk has also been mapped across London using a building physics model and monitored weather data, together with information on modelled UHI, housing type and population age, finding that building type and UHI have a significant influence on the distribution of risk across the city for summer 2006 (Taylor et al., 2015). Building fabric types and characteristics, and thus thermal properties, will depend on the age of the building, and may be an important modifier for thermal comfort and energy efficiency, in addition to behavioural aspects of building occupancy that can also modify heat exposure risk (Vardoulakis et al., 2015). An existing spatial heat risk assessment of Birmingham combined

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