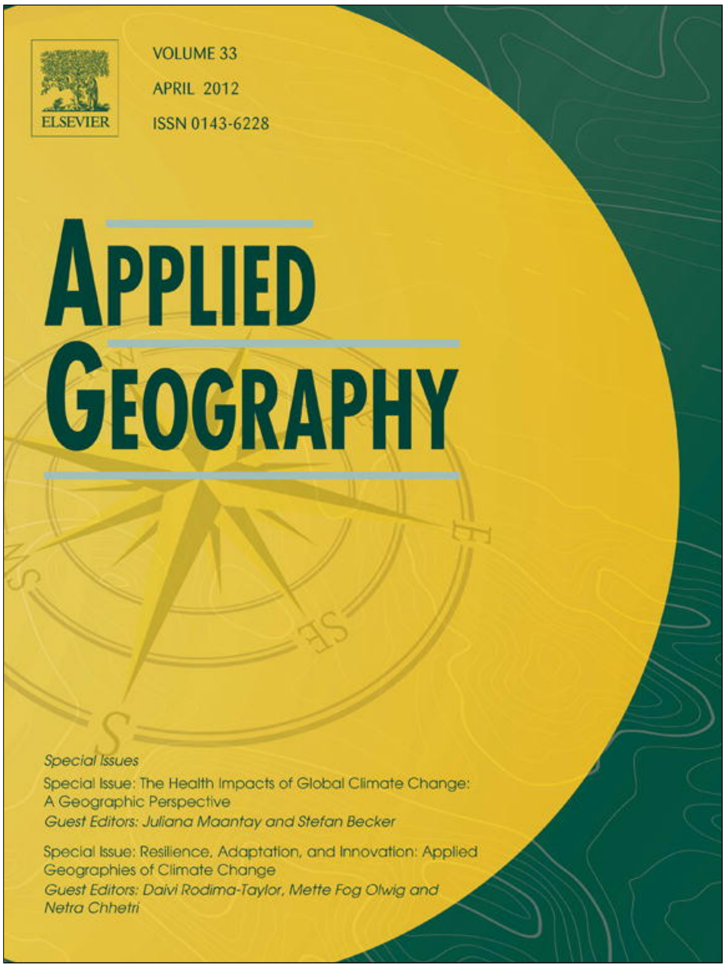
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Climate change and health and social care: Defining future hazard, vulnerability and risk for infrastructure systems supporting older people's health care in England

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A B S T R A C T

Health and social care systems (including the care needs of the population and infrastructures providing health and social care) are likely to be influenced by climate change, in particular by the increasing frequency and severity of weather-related hazards such as floods and heatwaves. Coldwaves will also continue to be challenging in the foreseeable future. Protecting people's health and wellbeing from the impacts of climate change is especially important for older people, as they are particularly vulnerable to climate-related hazards. In addition, the proportion of people aged 65 and over is projected to increase significantly. This paper addresses these issues through a discussion of our work to map variations across England in future hazards, vulnerability and risk. We explain how this mapping has been used to identify areas of the country where the built infrastructure serving the older age group might be most severely impacted by climate-related events over the next 20–30 years and where planning for adaptation and resilience is most urgently required.

Based on a review of research on the links between extreme weather events and their impacts on older people's health and the care services on which they depend, we developed operational definitions of extreme weather-related hazards likely to place particular pressure on health and social care systems that are essential for older people's health and wellbeing. We consider ways to relate these to the latest climate projections for the 2030s from the UK Climate Impacts Programme (UKCP09); river and coastal flooding projections for the 2050s from the 2004 UK Government's Foresight Flood and Coastal Defence Project (Environment Agency, 2004); and demographic projections for 2031 produced by the Office for National Statistics, UK. The research highlights the complexity of undertaking future hazard and vulnerability assessments. Key challenges include: how to define future hazards associated with climate change; how to predict and interpret future socio-demographic conditions contributing to vulnerability; and how geographical variability in hazards and vulnerabilities may combine to produce risks at the local level. In contrast to a number of more local studies which have focused on the vulnerability of urban populations to the impact of climate change (particularly heatwaves), the findings highlight the potential vulnerability of older populations in more rural regions (often in coastal areas) to a range of extreme weather-related hazards in both the North and South of England.

Introduction

In this paper, we explore how to conceptualise future risks to the health and social care system for older people associated with climate change, in ways that allow us to assess the future local

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variation of these risks across England. Based on a review of published research and policy documents, our analysis is based on the conceptual model illustrated in Fig. 1 which we elaborate upon below. The diagram summarises the links between a number of elements of a complex health and social care system and its relationship with climate change. These relationships will vary at the local level across the country.

This paper does not seek to analyse local variations in all aspects of the complex system illustrated in Fig. 1, since we argue below that trying to forecast all these elements for local areas over the national space is not currently feasible and may not be useful. *Risk* is analysed here in terms of some dimensions of weather-related *hazards* and population *vulnerabilities* (referring to more general models of 'risk' proposed by Thywissen (2006) and Cutter et al. (2008)).

The term 'hazard' refers to potentially harmful events (Thywissen, 2006). In this case, we are concerned with weather extremes or anomalies that represent a significant departure from normal weather (Kharin & Zwiers, 2005). Such extreme events include floods, heatwaves, coldwaves and storms. As discussed below, these place stress on older people's health and on the built infrastructure supporting their health and social care. This infrastructure will include a wide array of buildings, such as hospitals, or the services provided to those buildings, such as energy, water and transport, as well as private homes and care homes where much of health and social care is delivered.

Global climate models (GCMs) suggest that, under future climate change scenarios, the UK is likely to experience a change in the probability of weather-related hazards, including an increase in heatwaves, floods and storms. Recent experience and future projections also suggest that extreme cold weather events will still happen, albeit with a lower probability of occurrence, and are likely to continue to cause major disruption. This raises questions about the capability of systems to cope (Auld & MacIver, 2007; Carthey & Chandra, 2007; Carthey, Chandra, & Loosemore, 2008). We discuss below how these hazards for health increase the demand for health and social care support, placing temporary pressure on service infrastructure which may in future be unsustainable unless the capacity of the infrastructure is enhanced. Very extreme weather conditions may also cause direct damage or malfunctioning of the system if they exceed the physical tolerances of a given infrastructure. This can produce undesirable effects that propagate to other infrastructures (Dueñas-Osorio & Vemuru, 2009).

The risk posed by these hazards depends on vulnerability: '*…the pre-event, inherent characteristics or qualities of systems that create the potential for harm or differential ability to recover following an event*' (Cutter et al., 2008: 2). 'Vulnerability' may be determined, for example, by characteristics of demographic, social, economic, environmental, institutional and engineering systems and varies at different scales (individual, household, community, sub-national and national) (Cutter et al., 2008). Weather hazards are expected to challenge the health and social care system especially in view of the anticipated growth of vulnerable groups in the older population, who depend most heavily on continuous support from health and social care services. The Office for National Statistics predicted that the proportion of the population aged 65 and over in England will increase from 15.9% in 2006 (ONS, 2007) to 22.0% in 2031 and 22.6% by 2033 (ONS, 2010a). The population over 85 years is projected to increase particularly quickly from 2.2% in 2008 to 4.2% in 2031 and 4.6% in 2033 (ONS, 2010a), putting more people at risk and increasing pressure on the infrastructure supporting older people's care. In the following analysis we will be concentrating on demographic aspects of vulnerability of the older population, for which future projections are available at the local level.

The geography of future 'risk' can be interpreted by mapping the likely future distribution of hazard and vulnerability. Here we are concerned with predicting future conditions that are likely to place stress on systems of health and social care and support of frail older populations in England. We focus our analysis on available information to anticipate the geography of future trends in hazards and vulnerabilities across the country.

Particular issues arise when attempting to define and map *future* hazard, vulnerability and risk at the local level, across a whole country. While much has been written on the health impacts of extreme weather events, most of this relates to past events and there are fewer attempts to interpolate the findings below the national or broad regional scale, in order to guide future resilience planning at the local level. Also, in order to judge where adaptation to change may be most needed, more work is required to make the connection between future patterns of extreme weather and direct or indirect risks for built infrastructure supporting older people's care. We are developing an approach to this problem involving assessment of: (1) likely future changes in the geographical pattern of weather-related hazards across the country; (2) how these hazards may be distributed with respect to the national geography of vulnerabilities in the population, generating extra demands on health and social care which may strain the capacity of the system; (3) within local areas that are most at risk, a detailed assessment of local organization of infrastructure to ascertain which elements are most important for sustaining older people's care and most vulnerable to extreme climate events. In this paper we focus especially on (1) and (2) in order to identify local areas where a focus on (3) is likely to be most necessary in future.

We first consider the literature that could help us to define extreme weather events (heatwaves, coldwaves and floods) that, in future, might present *hazards* to infrastructure supporting health and social care for older people. Secondly, we discuss demographic dimensions of future vulnerability to such events. We then discuss examples from a national scale mapping exercise, using available projections, to examine how hazard, vulnerability and risk may change over time, and how these trends vary geographically across England. We aimed to identify areas of England where changing environmental conditions and demographic trends are likely

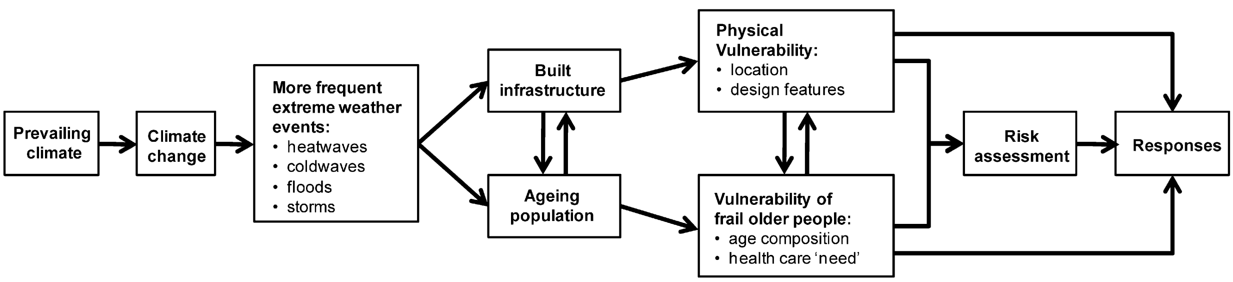

Fig. 1. Conceptual model showing the links between climate change, population ageing and built infrastructure for older people's health care.

to make it particularly urgent to assess the vulnerability of infrastructure and develop adaptation and resilience strategies for older people's care during extreme weather-related events in the future. In the discussion below, we situate our findings in the context of policy and planning for adaptation and resilience in the UK.

Defining future weather extremes relevant to services for older people's care

As discussed below, there is no fixed, universal definition of meteorological conditions likely to place stress on the human body or compromise physical infrastructure (Dessler & Parsons, 2009; Hajat, Kovats, Atkinson, & Haines, 2002). This reflects the acclimatisation of a population to local conditions and the design and specification of existing infrastructure with reference to locally prevailing conditions. The intensity and duration of climatic conditions likely to be a risk for human health vary geographically (and for different population groups) over time. Hazard indicators therefore vary internationally and also within countries. For example, in the UK the critical thresholds for high temperatures, which trigger 'emergency' responses to very hot weather under the recent National Health Service (NHS) *Heatwave Plan*, are defined variably for broad regions of the country, being highest (32 °C) in London, which has relatively high average temperatures, and lowest (28 °C) in the North East of England which on average is cooler (NHS, 2010). The *Heatwave Plan* does not include prospective adjustment to allow for climate changes by the 2030s in England (Armstrong et al., 2010; NHS, 2010), and therefore it may not be adequate for future resilience planning. Definitions of future weather-related hazards should therefore take account of predicted temperature increases associated with climate change and should be defined based on what, in future, will be the locally prevailing average conditions, and the vulnerability of the populations exposed (Dessler & Parsons, 2009). We sought to predict potentially hazardous conditions in relative terms, taking into account predicted climatic conditions. For this reason we have drawn on research in England, but also from areas outside the UK which are experiencing today the kinds of conditions that we may expect for England in future.

Defining and modelling future heatwave hazards

We have drawn on research on past heatwave events with the aim of identifying, relative to future average conditions, the temperature (in terms of level and duration) likely to trigger an increase in morbidity and mortality and, as a result, place pressure on service infrastructure, creating a need for infrastructure redesign and adaptations that are more responsive to heatwave threats. Some research has assessed the risk of adverse health outcomes associated with an *absolute* increase in temperature above the prevailing average minimum and maximum temperatures. For example, Fouillet et al. (2006) considered the health impacts in France in 2003 of extended periods of temperatures exceeding the 30 year average by 5 °C (minimum night time temperature) and 9 °C (maximum day time temperature) respectively. Other research, from England, has identified increased risk of mortality in older age groups when the 3 day moving temperature average is in the extreme *percentile range* of the statistical distribution of prevailing temperatures (variously defined as above the upper 99th/97th/95th/90th percentile value of average temperature) (Hajat et al., 2002). Research using a similar 'relative' measure shows that risks to health and health care systems increase when temperatures reach the upper 93rd percentile of year-round two-day mean temperature distribution (Armstrong et al., 2010).

Temperatures that cause physical changes in built infrastructure tend to be higher than those known to present risks to human health. For example, Hajat et al. (2002) report that heat-related deaths may begin at relatively low temperatures in London (around 19 °C); while the NHS (2010) *Heatwave Plan* explains that excess seasonal deaths have been shown to occur in Britain at temperatures exceeding 25 °C. By comparison, design standards for National Grid electricity transmission components (transformers, circuit breakers, overhead lines, and cables) indicate a maximum ambient temperature of 40 °C (National Grid Electricity Transmission PLC, 2010: 53). However, when the temperature reaches levels that impact on the human body, there will be increased demand for some functions such as equipment and power for air conditioning (Miller, Hayhoe, Jin, & Auffhammer, 2008) or water for drinking/showering (Praskievicz & Chang, 2009). Such demands have the potential to cause unusual surges in peak demand that strain service capacity. Some studies have examined how during heatwaves rates of use of hospital services in urban areas increase (e.g. Knowlton et al. (2009) in the US and Michelozzi et al. (2009) in Europe). Others note that domestic and health service buildings may not be adapted to maintaining temperatures at a comfortable level during heatwaves (Brown & Walker, 2008; Fouillet et al., 2006; Short & Al-Maiyah, 2009; Short, Cook, Cropper, & Al-Maiyah, 2010). Thus, critical criteria for judgements about future heatwave hazards in England relate to human physiological vulnerability to high temperatures, and adaptive human action, including aspects of building design, that are important to mitigate these impacts. These are most likely to be compromised when weather conditions depart significantly from the average.

We therefore define a heatwave as an event where the daily maximum temperature is equal to, or greater than, the locally defined threshold (the 95th percentile value of the prevailing daily maximum temperature distribution) for three or more consecutive days. This definition offers a relative measure of heatwave activity approximately representing future increases in temperature under climate change, older people's likely adaptation to this change, and the spatial variability in heatwave hazard across England. Because the definition is relative to prevailing average temperatures expected in future, it theoretically makes some allowance for future adaption to heat among the older population in terms of physiological habituation, behaviour changes and modification of built infrastructure, which some authors argue will mitigate climate change effects on health (Carson, Hajat, Armstrong, & Wilkinson, 2006). This relative hazard indicator cannot be expressed very meaningfully as a single figure in °C as it would depend on predicted temperatures prevailing at the time. However, our detailed analyses of daily maximum temperature data derived from the UKCP09 Weather Generator (Version 2) suggest that the 95th percentile temperature will, in future, exceed the 25 °C temperature threshold identified in the NHS Heatwave Plan discussed above for a number of areas in central and southern England.

Defining and modelling future coldwave hazards

Coldwave hazards arise partly due to impacts of cold weather on human health, which may result in unsustainable pressure on infrastructure or create a need for infrastructure that is more protective against and resistant to cold. A number of studies have been undertaken to better understand the vulnerability of the older population to winter mortality in Europe and England specifically (Laake & Sverre, 1996; McKee, 1989; Shah & Peacock, 1999; Wilkinson et al., 2004) and to determine the threshold temperatures below which an increase in morbidity and mortality is likely. Findings from a number of multi-country studies including the USA and Europe have demonstrated that cold-related mortality is greater in countries with generally warmer winters such as England (Curriero, Heiner, & Samet, 2002; McKee, 1989; The

Eurowinter Group, 1997). Studies in the UK (e.g. Hajat, Bird, & Haines, 2004; Hajat & Haines, 2002; Maheswaran, Chan, Fryers, McManus, & McCabe, 2004) show that coldwaves do impact on levels of use of health services, although there can often be a delayed effect.

Also relevant for coldwave hazards are temperature thresholds associated with direct damage to built infrastructure. These are better defined for coldwaves than for heatwaves, and are based on a combination of low temperatures and snow/ice loading, and by increased demand during an extreme event and decreased capacity of the service provided. For example, increased use of heating might boost demand for gas or electricity and any interruption of supply would be particularly problematic. National Grid minimum ambient design temperature guidelines for transformers, circuit breakers, overhead lines, and cables are −5 °C (indoor) and −25 °C (outdoor) in winter (National Grid Electricity Transmission PLC, 2010: 53), so temperatures below these values would reduce capacity.

However, the temperatures do not have to be this low to cause disruption to other parts of the infrastructure. For example, ice and snow (occurring at 0 °C and 3 °C respectively) can restrict road and footpath access to buildings for people, such as carers, health and social care professionals, and the provision of supplies, such as medicine and food (Hughes, Bellis, Bird, & Ashton, 2004; Skinner, Yantzi, & Rosenberg, 2009). Measures such as salt/gritting roads may mitigate these problems, depending on local conditions and availability of grit where and when required, but at very low temperatures this becomes ineffective. Other examples include the freezing of external condensate pipes from condensing boilers, as experienced in the UK during the 2010/11 winter (Walker, 2010); and the freezing and bursting of water pipes leading to an interruption to water supply, as recently experienced in Northern Ireland (Glynn, 2010). The latter is dependent on ground frost depth, which can be seen to increase in proportion to the number of days below freezing (0 °C) (Brown, 1964). *We therefore define a coldwave as an event where the daily maximum temperature is 0 °C or below for three or more consecutive days.*

Defining and modelling future flood hazards

The international literature on the potential effects of floods on health have been comprehensively reviewed by Ahern and Colleagues (Ahern & Kovats, 2006; Ahern, Kovats, Wilkinson, Few, & Matthies, 2005) and the health service response required (especially in Europe) was discussed at a WHO meeting in London in 2002 (WHO Regional Office for Europe, 2002). While not on the scale experienced in some other countries (Few & Matthies, 2006), the UK does experience death and injuries due to flooding and contamination spread by flood water which can be damaging to food sources and produce risks of infection (Health Protection Agency, 2010). A more widespread health impact of flooding in countries like England is the longer term effect of displacement from flooded homes and the psychological impacts of floods. UK examples reviewed by Neria, Nandi, and Galea (2008), Norris (2005) and Curtis (2010), and UK studies by Tunstall, Tapsell, Green, Floyd, and George (2006) and Carroll, Morbey, Balogh, and Araoz (2009), indicate that these include post-traumatic stress and depression. For those who rely on regular health and social care and other services provided where they live (such as frail older people in private homes, residential care homes or hospitals) the disruption of services or effects of evacuation can have significant impacts on health and wellbeing (National Flood Emergency Framework for England, 2010).

Generalisable flooding thresholds for built infrastructure are more difficult to assess than heat or coldwave thresholds, though the potential for damage to infrastructure due to flooding is greater than that associated with extreme temperature. The thresholds for flooding of built infrastructure are based mostly on the location of buildings and facilities in relation to flood extents/depths based on return periods (Department of Communities and Local Government, 2010). For this reason, flood hazard is assessed primarily on the microscale location of critical buildings (e.g. hospitals) and services (e.g. new electricity substations or water treatment works must be built 500 mm above the 1 in 100 year flood event depth). Flooding depths at which buildings and infrastructure services could not continue to supply services without interruption can be predicted (e.g. substations must be resilient to flood depths of 300 mm (National Grid Electricity Transmission PLC, 2010: 33)) but, being dependent on many variables, the predictions may be imprecise. As the wellbeing of vulnerable people may depend on uninterrupted supply of services, it is necessary to base resilience planning on the thresholds presenting potential risks for people, and the social and material resources at their disposal at local level (UN-ISDR, 2002) rather than the flood risk threshold of individual critical buildings and infrastructures. *For this reason we are adopting the definition used by the UK Government's Foresight Flood and Coastal Defence Project* (Environment Agency, 2004) *and defining flood events based on the annual probability of inundation in local government areas.*

Defining 'vulnerability' in the older population

Older people, especially those already in poor health, are particularly vulnerable to weather-related hazards (Few & Matthies, 2006; Hajat, Kovats, & Lachowycz, 2007; Haq, Whitelegg, & Kohler, 2007; Kovats, 2008). This vulnerability was seen during the 2003 heatwave in Europe which accounted for over 30,000 deaths in Western Europe including more than 2000 deaths in England and Wales, mainly in older age groups (Hajat et al., 2007); and the 1995 heatwave in England and Wales, where the proportion of excess deaths was 10.3% in the 85 and over age group, compared to 8.4% in the 65-74 age group, and 8.5% in the 75-84 age group (Rooney, McMichael, Kovats, & Coleman, 1998: 484). The 2009/10 coldwave in the UK resulted in an estimated 25,400 excess winter deaths in England and Wales, the majority amongst those aged 75 and over (ONS, 2010b: 1).

Of particular interest for this study were *local authority areas projected to have high concentrations of older people by 2031 (especially in the oldest age groups most likely to need health and social care) and local authority areas projected to experience the greatest increase in the number of older people between 2006 and 2031.*

Mapping future hazards and vulnerability: material and methods

As explained below, we generated maps for England showing predicted heatwave, coldwave and flood hazards, as well as population projections for those aged 65 and over. Exact correspondence of time periods was not possible for the different hazards and vulnerabilities considered here, and they are mapped at different scales, therefore we have not attempted a 'cumulative' risk index that combines area information on each of these dimensions for a given geography.

Maps were produced to illustrate trends in heatwave and coldwave hazards using data derived from the UKCP09 Weather Generator tool (Version 2). We have chosen to present these cartographically in a way that emphasises the relatively 'coarse grained' geographical scale of these projections. Based on the Hadley Centre GCM (HadCM3), the UKCP09 Weather Generator creates a statistically credible representation of what may occur in the future, when combined with the climate signal in the UK Climate Projections, and is based on real observed weather variables for the baseline period (Jones, Kilsby, Harpham, Glenis, & Burton, 2009). Fifty thousand years of daily minimum and maximum temperature data were generated (100 years of data $\times$ 500 runs) for the centre points on a 50 km grid across England for the control (baseline) period and the scenario period (2020–2049), under the medium emissions scenario. The baseline or reference period defines the climatology against which future changes are projected and is defined by UKCP09 as 1961–1990. The large dataset enabled the analysis to capture rare heatwave and coldwave events. The temperature dataset for the baseline and scenario time periods were processed to give the probability of occurrence per year of a heatwave or coldwave event based on the definitions set out above. The percentage change in the annual probability of a heatwave or coldwave hazard between the baseline and the scenario periods was also calculated (Fig. 2).

To assess future flooding hazard, we have used the outputs from the UK Government's Foresight Flood and Coastal Defence Project (Environment Agency, 2004) which analyses present day (2002) and future flood hazard (both fluvial and coastal) at the national scale across England and Wales for various emissions scenarios for the 2080s. Data are also available for the 2050s for the high emissions scenario only. In order to ensure the time periods are as congruous as possible for this study, the outputs for the 2050s have been used. Fig. 2 maps the flood hazard for the baseline period, the scenario period and the *change* in flood hazard between 2002 and 2050s (in this case the change in the annual probability of inundation above 0.0 m) for England. The Foresight mapping is based on the RASP model (*Risk Assessment for flood and coastal defence for Strategic Planning*) which uses information on the location of river channels, the type of floodplain and the standard and condition of flood defences to estimate the annual probability of inundation on grid squares of 10 km $\times$ 10 km (Foresight, 2004).

There are limitations associated with using the *Foresight* projections for this study. The *Foresight* projections are based on the previous generation of climate projections (UKCP02). They focus on longer range predictions to 2050–2080, rather than the 2030s; and the flood projections for the 2050s are available for the high emissions scenario only. Furthermore, *Foresight* focuses on the broad average characteristics of floods at the national scale rather than extreme flood events. Nevertheless, *Foresight* offers a far more comprehensive assessment of present and future flood hazard at the national scale than would otherwise be possible within the scope of this project. Given that climate scientists do not anticipate a significant increase in the amount of precipitation up to the year 2050, it is unlikely that the UKCP09 climate projections would significantly alter the relative spatial pattern of flood hazard at the national scale.

Demographic projections are available for England at the local level up to the early 2030s (ONS, 2007, 2010a). Demographic projections for the older age group (aged 65 and over) were mapped using the most recent population projections available at the time, calculated at the level of Local Authority Districts (LADs) for the period 2006–2031 by the Office for National Statistics (ONS, 2007). These were the latest available at the time the analyses were carried out and have now been superseded by projections for 2008–2033 (ONS, 2010a). For this we used the principle or 'central' projection. We were particularly interested to identify areas where hazards and vulnerability were relatively high and areas where there would be the most rapid *increase* in these factors, since these areas may need to modify and enhance their adaptation strategies and resilience planning the most to cope with future conditions. Maps were produced to the level of 352 LADs in England (two LADs with very small resident populations were excluded).

As demonstrated above, health care needs or vulnerability to the effects of climate are variable among people aged 65 and over. We have therefore weighted the older population using the 'Age-related Needs Element' of the National Health Service Capitation Formula used by the NHS in resource allocation (Department of Health, 2008). The weighting is based on analyses of the population variables that influence varying rates of use of hospital care, across small areas in England, so it is a reflection of the relative demands that people of different ages are likely to make on health services. The older age groups have progressively higher weighting and for this study are considered likely to be more 'vulnerable' to the hazards considered here.

Geographical variation in future hazard, vulnerability and risk in England

Heatwave and coldwave hazards

Fig. 2a and d show (in darker grey) areas of the country where the probability of heatwave activity is greatest for the baseline and scenario periods. For both time periods, the annual probability of heatwave events is greatest in the South West of England. Fig. 2g shows (in darker grey) the areas of the country expected to see the greatest *increase* in heatwave events which exceed the 95th percentile of the prevailing temperature range in the locality. These areas include the East of England, the North West and Yorkshire and Humber. As these areas are expected to experience the greatest increase in heatwave hazard, we suggest they are most likely to have to adjust their resilience strategies to cope with climate change by the 2030s. In the most extreme cases the future probability of events in the 95th percentile will increase by up to 15.5%. The light grey shaded areas may continue to have relatively high average temperatures in some cases (including locations in the South West and South East of England) but the annual probability of heatwave activity may not increase as much as in other parts of England. In these areas, existing strategies for heatwave resilience may be more 'durable' in the face of climate change.

Fig. 2b and e show in darker grey the areas in the northern and central parts of the country most prone to coldwaves at baseline and in the future. Fig. 2h shows the percentage change in annual coldwave activity. All areas in England are projected to see a decrease in the coldwave hazard, the most significant decrease (shown in light grey) occurring in the east of the country, where there is projected to be a relative reduction in the probability of −82.4%. Despite this decrease in the frequency of coldwave activity, LADs must be prepared to respond to coldwaves which will continue to challenge human health and health and social care infrastructure when they occur.

Flood hazards

Outputs from the Foresight project (Environment Agency, 2004) suggest the most significant change in the annual probability of flooding will occur in the South East of England, the East of England and the Yorkshire and Humber region (Fig. 2i). These areas (shown in dark grey) will experience an increase in the annual probability (frequency) of inundation by as much as 4135% and are areas where flood response strategies are most likely to need to be adjusted and enhanced in future. The areas susceptible to the greatest projected increase in flooding are either coastal or located along major estuaries, and are affected by subsidence and sea-level rise, rather than fluvial flooding. This indicator of relative change should be interpreted appropriately. While some areas are projected to experience a significant increase in the annual probability (frequency) of flooding, this does not necessarily imply the occurrence high magnitude events.

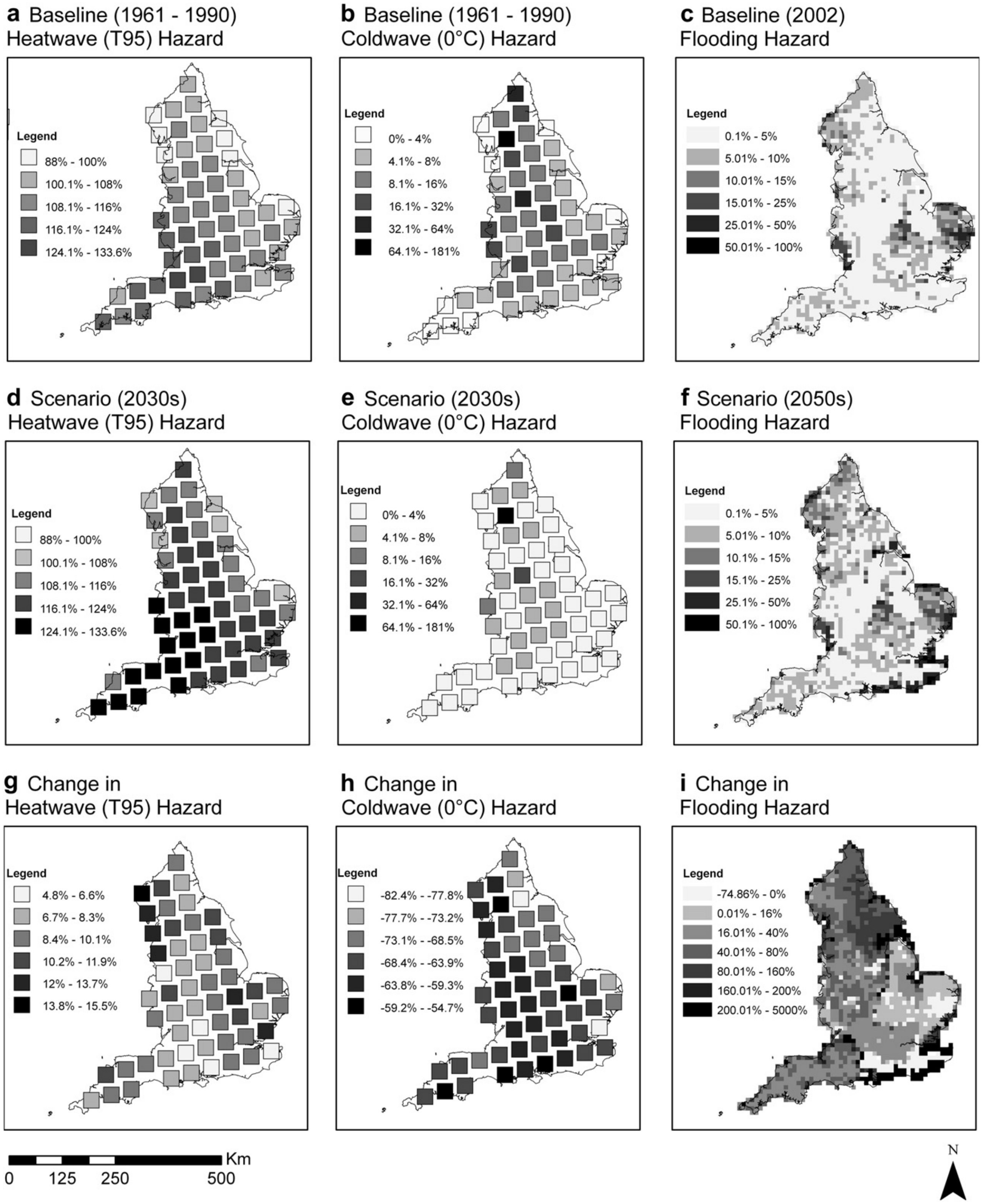

Fig. 2. Hazard maps of England showing the annual probabilities for the baseline (1961–1990), scenario (2030s/2050s) and percentage change in heatwave hazard (a, d and g) coldwave hazard (b, e and h) and flood hazard (c, f and i). Data for the heatwave and coldwave maps were derived from the UKCP09 Weather Generator (Version 2) under the medium emissions scenario. Flood maps c and f, and the data derived for map i, were sourced from the UK Government's Foresight Flood and Coastal Defence Project under the high emissions scenario (Environment Agency, 2004). Note that an annual probability of 100% denotes one event per year.

Vulnerability

Fig. 3a shows the projected weighted proportion of older people in the population by 2031. These areas are predominantly coastal and are located in the South East, South West, East and North East of England. This partly reflects retirement migration towards coastal regions among this age group. Also showing relatively high concentrations are the rural districts in the West Midlands and

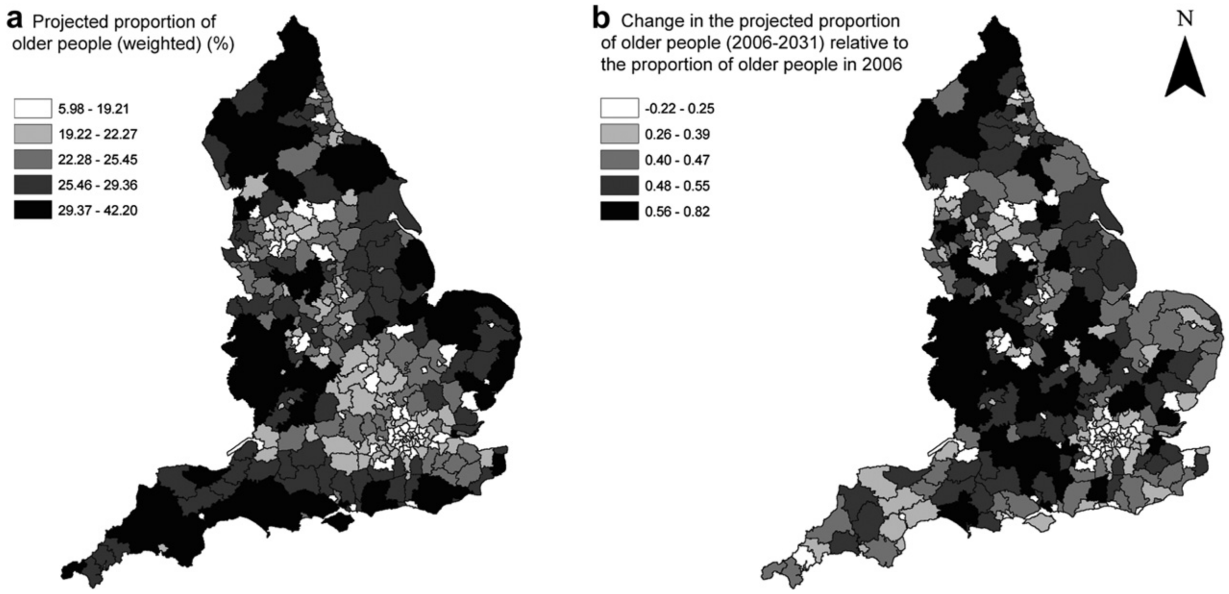

Fig. 3. Maps of local authorities in England showing a) the projected proportion of older people in the population by 2031 and b) the change in the projected proportion of older people (2006–2031) relative to the proportion of older people in 2006. In both examples the older population has been weighted by age-related differences in the likely need to use health care. Analysis based on 2006-sub-national population projections by age group at local authority level (ONS 2007).

North West of England. In some areas, by 2031, over 40% of the population will be aged 65 and over. The weighting used here emphasises that many areas with the largest proportion of older people will also have larger numbers in the oldest age groups, who are most likely to be vulnerable to extreme climate-related events. Fig. 3b shows the relative change in the projected proportion of older people in the population 2006–2031. In some areas the numbers of people aged 65 and over will more than double. These rapid rates of relative change, which in several areas coincide with the strongest concentrations, will require significant adjustments to local provision for older people. Some places, where concentration of older people is less, but numbers are projected to increase very rapidly, may be less prepared than those districts already dealing with a large ageing population.

The areas with greatest future concentrations, and greatest growth in the weighted older population are distributed especially in parts of England outside major cities. Visual inspection of the pattern seen in Fig. 3a indicates that it often coincides with zones of increased risk of flooding and extreme temperature events shown in Fig. 2.

Discussion

This paper set out to address the challenges associated with defining and mapping future hazard, vulnerability and risk at the local level across England. The literature review drew attention to the problems of developing comparative indicators of change in weather-related hazard and age-related vulnerability that might be usefully applied in resilience planning, especially at the local level. The risk of extreme temperature or flood events need to be defined relative to changes in prevailing average conditions and in view of likely population and infrastructure adaptation to climate change. Therefore existing planning criteria defining conditions to trigger emergency responses may not be appropriate in future. Furthermore, the pattern of risk is quite dependent on the definitions of hazard and vulnerability used and a range of local contextual variables intervene to influence the significance of the risks and the responses to them.

Our results illustrate the spatially variable combination of hazard and vulnerability faced in different parts of the country. Several areas can expect more extreme weather events which are very different from the average and will be particularly likely to challenge human health and infrastructure supporting the care of frail older people. The maps shown here suggest that areas experiencing the most rapidly changing hazards may often also be coping with high proportions of older people, especially in the oldest age groups who are most vulnerable, for example, the South East, East of England, Yorkshire and Humber and the North West. Some of these areas are also experiencing rapid growth in the older population. Many of the places showing most rapid changes are rural or semi-rural areas, outside the major urban agglomerations in England, which emphasises the challenges presented by climate change and demographic trends for rural and semi-rural communities.

The analysis reported here is limited by some constraints which are also problematic for strategic planning in this field. We have focused on a relatively limited range of indicators of local hazard and vulnerability, for which long range forecasts were available. These are not all available at the same geographical scale. (In fact it may not be theoretically appropriate to assess all of them at a single geographical scale, since crucial variability may operate at different levels of spatial resolution.) Some aspects of extreme weather (notably storm events associated with extreme wind speed) could be important for infrastructure but accurate projections were not available. Heat island effects in cities are only partially reflected in the baseline data for weather projections and may be imperfectly modelled in future weather scenarios. Socio-economic variables and housing conditions will be important for vulnerability to extreme weather-related events but these are not forecast for the 2030s in the same way as population numbers at local level. In the next stage of the project we are considering socio-economic diversity as an additional factor for risks at the very local level, but we do not map this here, partly because future projections are not available systematically across the country at this scale and partly because data at the very local scale within local authorities were considered a more useful way to assess these aspects of vulnerability. Similarly, the local spatial configuration and characteristics of infrastructure are important for the questions considered here, but these are more usefully modelled at the local scale rather than across the country as a whole.

Conclusion

The analysis presented here aims to identify parts of the country where available climate change and population projections suggest that risks due to extreme weather hazards and vulnerabilities associated with ageing of the population are most likely to change rapidly in the next 20 years. In these areas existing resilience strategies may be most severely tested by the combination of climate change and population ageing, and greatest efforts may be required to successfully adapt to these changes. Our findings therefore suggest that, ideally, risk to built infrastructure supporting older people's care should be assessed in terms of multiple facets of hazard and vulnerability. This will be quite challenging for local agencies with limited resources attempting to create resilient environments and people. Mapping exercises, like the one summarised here, reflect this degree of complexity and may be used as tools for local resilience planning. In the next stages of the project, we will assess this potential to apply geographical mapping as part of the consultation and planning process at local level. Stakeholders in local communities, and at national and international levels, will be consulted with the aim of determining how effectively this kind of information (combined with finer scale maps at the local level) can support resilience planning processes which are being developed in diverse settings (Galaz, 2010; Luther, Cicchetti, & Becker, 2000). Local intelligence will also be used to assess in more detail what are the local aspects of hazard and vulnerability and how these relate to parts of built infrastructure that are significant within particular communities for health and social care of older people.

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