Health Climate Change impacts report card technical paper

8. Flooding and health

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Key messages

- Flooding has a range of possible effects on human health, infectious diseases, injuries, drownings, and mental health. Flood has also been associated with cases of carbon monoxide poisoning in the post-flood clean up phase.
- There is little knowledge about the health effects of flooding in the UK, including quantified impacts on mortality or morbidity and how long symptoms may persist after the flood.
- There is little evidence that flooding is associated with an increase in cases of infectious disease **[L]**
- Floods increase the rates of self-reported depression/anxiety, and post-traumatic stress disorder (PTSD) in affected populations. Flooding will also exacerbate illness in persons with pre-existing depression. **[M]**
- People who have been flooded report a range of health concerns, and that these are often made worse by difficulties that occur after the floods, such as being displaced from the home and problems with insurance claims. **[M]**
- Many affected households are displaced from their homes for months after a flood. **[M]** In Hull, 59% of flooded households were displaced, and more than 10% of remained out of their homes for longer than a year. **[H]**
- The overall increase in flood risk due to climate change will be substantially increased if new development occurs in floodplains (coastal or rivers) at the same rate as elsewhere, based on projected population growth and demand of developing new houses. **[H]**
- Any increase in future flood events will have adverse consequences on human health and wellbeing. **[H]**

1. Introduction and scope

Floods are the most common natural disaster throughout the world in terms of the number of affected people and of economic losses (Centre for Research on the Epidemiology of Disasters (CRED), 2011). Recent flooding in the Southeast Europe (2014), Central Europe (2013), the United States (2005, 2008, 2012), well as the UK (2007, 2013/14) illustrate how vulnerable citizens in cities in high income countries are to flooding. Anthropogenic climate change is projected to increase the frequency and intensity of heavy rainfall events. According to the recent Intergovernmental Panel on Climate Change (IPCC) reports, the frequency of extreme precipitation is likely (with medium confidence) to increase in Northern Europe especially in winter months. Sea level rise and such increases in extreme rainfall are projected to further increase coastal and river flood risk in Europe in future, and hence substantial additional flood damages (with high confidence) (IPCC, 2014). It is therefore clearly essential to summarize current knowledge of flood impacts on population health and to evaluate risk assessments regarding future flood-related mortality and morbidity in the UK. PHE published a comprehensive review on health effects of flooding and adaptation in Stanke et al. (2012a). The current review adds updated knowledge since it has been published and more emphasize on critical review of scientific knowledge of health impact. Although infrastructure of health services in emergency is another critical aspect in considering flood impact on health, it is out of scope for this review (Infrastructure report card will cover instead).

The impacts on health vary between populations affected for reasons relating to type of flood, geographic, socio-economic factors, community infrastructure, as well as baseline vulnerability. This review focuses on the health impacts of flooding on the UK population. The flooding across England in summer 2007, in Cumbria and Aberdeenshire during November 2009 and the Somerset Levels in winter 2013/14 highlighted the various forms of flooding that the UK faces. The three main types (or sources) of flooding are from the sea (coastal or tidal) [also called storm surge flooding], from rivers and streams [riverine flooding], and from surface water (caused by excess rainfall that drainages systems are unable to cope with) [pluvial flooding].

Currently 5.2 million properties in England (about one in six properties) and 357 thousands properties in Wales (about one in six buildings) are at risk of flooding from rivers, the sea and surface water, of which 46% in England and 62% in Wales are susceptible to coastal or riverine flooding (including 19% and 31% with additional risk from pluvial flooding, respectively) (EA, 2009a, EA Wales, 2009). Though less is known about pluvial flooding in Scotland and Northern Ireland, 125 thousands in Scotland (about one in 22 residential properties or one in 13 non-residential/business properties) and 60 thousands properties in Wales are reported to be at risk of coastal or riverine flooding (Rivers Agency, 2008, SEPA, 2011). Overall, approximately six millions of properties in the UK are estimated to be at risk of coastal, riverine and pluvial flooding and these numbers are expected to increase significantly by combined effects of climate change, housing development, and population pressure (particularly in England) in the next few decades (EA, 2009b).

Recently UK government identified coastal flooding as one of the highest priority risks of emergency, taking both likelihood and impact into account (The UK National Risk Register of Civil Emergencies). The Cabinet Office (2013) noted that the likelihood of an event like the severe impacts of the 1953 east coast floods as “low” due to the investment made in coastal flood defences. However, considering the current increased development and the population living and working on the East Coast, the government anticipated the impacts of an overtopping and breaching of flood defences would be potentially more serious than in 1953.

This paper summarises firstly the current understanding of health impacts of flooding events (section 2), followed by evaluation of health burden estimates of observed flood events (section 3) and future events (section 4), and finally discussed avoidable impacts by adaptation measures (section5).

2. Evidence of health impacts of flooding

The health effects of flooding can be categorised broadly as direct or indirect (WHO Europe, 2002, Du et al., 2010, WHO, 2013). The former effects are those resulting from ‘direct’ exposure to the water and the flooded environment such as drowning, injury, hypothermia, whereas the latter includes the impacts from damage done by the water to the natural and built environment, such as infectious diseases, poisoning, malnutrition, and health consequences associated with displaced populations. Du et al. (2010) proposed a conceptual framework that demonstrates the health consequences of floods in terms of time-scale of impacts as well as direct/indirect separation. Generally, time-scale of flood impacts are described as immediate (during the flood), medium (days to weeks), and long-term (months to years) after the flood.

This section discusses both direct and indirect health effects at any time-scale of impacts reported in the UK. Some evidence from Europe, however, is mentioned when appropriate resources exist. For details on international evidence including other developed and developing countries, large epidemiological systematic reviews have been conducted and reported elsewhere (Ahern et al., 2005, Galea et al., 2005, Stanke et al., 2012b, Alderman et al., 2012). Table 1 summarises the epidemiological evidence of health impacts of flooding events in the UK.

Table 1. Epidemiological studies assessing the relationship between flood and health outcomes in the UK

Authors, year	Flood event (area, year)	Study design	Main results
Bennet, 1970	Bristol, 1968	Controlled interrupted time-series study. 12 months pre- and post-flood event. 316 flooded and 454 non-flooded households.	**Deaths**: 50% increase in flooded area, no increase in non-flooded area, dominantly over 65 years old, especially in females over 75 years old. **Medical attentions**: GP attendance 53% increase in flooded area. Hospital admissions ≥200% increase in flooded area. **New psychiatric symptoms (self-reported)**: 18% of the flooded female and 6% of the non-flooded female reported. These rates include symptoms which might have been present before the flood.
Reacher et al, 2004	Lewes, 2000	Retrospective cohort study. 9 months post-flood telephone interviews with 227 cases (house flooded) and 240 controls (non-flooded from same postcode, not matched)	**Earache**: flood associated with earache in all age groups (RR=2.2, 95%CI: 1.1, 4.1). **Gastroenteritis**: association is less marked (RR=1.7, 95%CI: 0.9, 3.0), p for trend by flood depth = 0.04. **Psychological distress**: fourfold higher risk in flooded group (RR = 4.1, 95%CI: 2.6, 6.4)
Milojevic et al. 2011	England and Wales, 1994-2005 (319 flood events)	Controlled interrupted time-series study. 12 months pre- and post-flood event. Non-flooded area defined by <5km from flooded boundaries.	**Deaths**: Post-flood 771 deaths and pre-flood 693 deaths in flooded area. Ratio of change in flooded / non-flooded areas 0.90 (95%CI: 0.82, 1.00). The ratio consistent by subgroups of age, sex, population density or deprivation. Observed/Expected deaths show the similar post-flood `deficit'. Possibly due to population displacement.
Paranjothy et al., 2011	England (South Yorkshire and Worcestershire), 2007 summer	Cross-sectional study by 3-6 months post-flood telephone survey. 2265 individuals in total.	**Mental health**: 2-5 fold higher prevalence of mental health symptoms in those flooded compared to those non-flooded. Highest prevalence was observed where water was above floor level (psychological distress OR 12.8, 95%CI: 9.3, 17.6; anxiety OR 13.9, 95%CI: 9.3, 20.8; depression OR 7.7, 95%CI: 5.2, 11.4; probable PTSD OR 11.9, 95%CI: 6.6, 21.5).
Mason et al., 2010	England, location and year unknown	Cross-sectional study. 6 months post flood, 440 surveys in flood-affected adults.	**Mental health:** prevalent depression 35.1%, PTSD 27.9%, anxiety 24.5%. Females associated with higher risk in these prevalent measure and maladaptive coping styles (emotional and avoidance coping). NB. Response rate is very low (14%).

2.1 Health impacts

Mortality

The UK has experienced a few major flood events in the past: the 1953 East Coast tidal flood resulted in 307 UK fatalities (Baxter, 2005); the Lynmouth flash flood disaster of 1952 resulted in 34 fatalities despite relatively small numbers (approximately 400) of properties affected (Penning-Rowsell et al., 2005). More recently, 3 deaths were attributed to the 2005 Carlisle flood, 13 deaths to the 2007 summer flood in the UK and 1 death to the Cumbria floods in 2009. These immediate fatality effects are heavily driven by the type of flood event and/or warning, the local characteristics of the affected area and also people's behaviour. Generally, the main reason for mortality is death by drowning (Vasconcelos, 2006, Jonkman and Kelman, 2005). Jonkman and Kelman (2005) reviewed 13 flood events in Europe and the US for the causes of 247 reported deaths and found drowning accounts for 70% of the fatalities. These deaths, weather drowning or not, are preventable by education and mitigation measures. This review found generally males who usually attempt and undertake rescue in emergency situations were more vulnerable than females: 70% of deaths were males. The relevant statistics for the UK are not available and hence, little evidence is known about vulnerable groups.

Accurate information on age, gender, and cause-specific mortality attributable to flooding events are limited in the UK due to the lack of systematic disaster (including flood) surveillance. The limited data from the 1953 East Coast flood showed 0.5% mortality (58 deaths in approximately 12000 residents) were *attributed to* the flood event on Canvey Island and 74% of these deaths were aged 60 years and over. Post-mortem examinations showed that 34% died from non-drowning causes such as the exposure-related stressors (e.g. hypothermia: it was at cold night in January), strokes, heart failure, and accidents (Baxter, 2005, Grieve, 1959). However, the quoted number of deaths here may not reflect the *actual* attribution to flood events because the formal disaster statistics usually records only immediate traumatic deaths (namely drowning) without including deaths from injuries, related car accidents during the flood, and carbon monoxide poisoning during the recovery stage. It is therefore not appropriate to apply these reported death rates of 60 years ago to a similar flood event today, given massive improvement of flood protection and emergency responses. In the recent winter storm-surge flooding in 2013/14 which was the highest storm surge since January 1953, eastern and southern England experienced considerably less physical impact than the 1953 event (1,400 vs 24,000 properties and 6,800 vs 65,000 hectares affected in 2013/14 vs 1953) and no directly flood attributable deaths were reported. This is due to a robust warning system, emergency responses and flood defences constructed since 1953.(Met Office and Centre for Ecology and Hydrogy, 2014)

There has been some discussion in the literature about a long term effect of flooding on all cause mortality in the flood population, that is, 6-12 months after the event. A well-controlled study, with double control (i.e. ratio of outcomes after/before the flood event in the flooded area was compared with that of non-flooded area), of the Bristol floods in 1968 suggested a 50% increase in all-cause mortality among the flooded population in the 12 months following to the flood after excluding displaced population, compared to no appreciable change in mortality in the non-flooded area (Bennet, 1970). This is a significant effect on the flooded population. On the other hand, a recent systematic study looking at the 319 flood events from 1994 to 2005 in England and Wales, using a controlled interrupted time-series design, observed an apparent (10%) *reduction* in mortality in flooded areas in the year after flooding (Milojevic et al., 2011). The authors discussed a possible bias in the ascertainment of mortality from the national routine data in relation to population displacement after the floods. A recent descriptive analysis of household displacements after the Hull 2007 summer flood showed very high proportions (59%) of flooded households were displaced and many of them did not start moving until several months after flooding. Over 10% of displaced households remained out of their homes for longer than a year and a further 5% for more than 2 years. These figures supported the discussion in Milojevic et al. (2011) and showed important implications for epidemiological study designs. However, as their original paper discussed, the effects of population displacement is unlikely to turn observed mortality *deficit* into apparent mortality excess, such as that reported by Bennet (1970). This suggests that mortality impacts over the last decades have been much smaller than they were in Bristol in 1968. The response to flooding and the population's resilience to its adverse impacts might have changed appreciably over time. However, the question of unnoticed long-term impacts on mortality, and other outcomes, remains unresolved and deserves further study.

Injuries

Flood-related injuries can occur when individuals attempt to escape from flood waters or during the clean-up process (Jakubicka et al., 2010). However, little information is available on the frequency of nonfatal flood injuries in the UK, partly because a routine reporting system is not in place and it is difficult to identify as flood-related in the existing database of hospital admission or Accidents and Emergencies department visits. The EM-DAT records injuries mostly from massive flood events across large extensive flood plains in the world, which is unlikely to be similar as that in the UK. Also the previous review noted that numbers of injuries reported in the EM-DAT are much less robust than are reports of deaths (Ahern et al.2005).

Incident data for flood-related injuries are not systematically collected in the UK. There are two limited reports on injuries in Europe. A community survey of the 1988 flood in Nimes, France showed 6% of surveyed households reported mild injuries (contusions, cuts, sprains) related to flood (Duclos et al., 1991). A German community survey conducted by telephone after the 2002 flood in Saxony showed the risk of flood-related injuries was increased especially for those whose indoor living area was flooded (OR 1.8, 95%CI 1.1 to 3.3), those exposed to skin contact with floodwater (OR 17.7, 2.4 to 130.5), or those involved in clean-up work (OR 5.1, 1.6 to 16.7) (Schnitzler et al., 2007). Obviously, both community surveys were conducted retrospectively with self-reported information, and hence might to lead over-estimate of these figures, namely recall bias. In this case, exposure information and information on subsequent health outcome were collected at the same time by the same interview survey, thus those flooded (who know already their own exposure status) can lead to information errors that bias the results, for example with more efforts to recall small injuries during or after the flood event than those non-flooded.

Infectious disease

There is potential for increased risk of infectious disease in flood conditions, especially in the areas where there is a lack of access to water for hygiene system. However, generally in high income countries including the UK, the risk of infectious disease appears to be little or very low. A recent retrospective cohort study following a severe river flooding in 2000 in Lewes, East Sussex reported a mild increase in self-reported gastroenteritis, defined as vomiting and/or diarrhoea (3+ loose stools in a 24 hours period): risk ratio in the flooded population against non-flooded population was 1.7 (95%CI: 0.9, 3.0) after adjustment for age and sex (Reacher et al., 2004). The study was conducted about nine months after the flood event by structured telephone interviews with the flooded and non-flooded population sampled by Lewes District Council. Although the higher risk of gastroenteritis in flooded population compared to non-flooded population was not supported by statistical significance, these risk among the flooded population was significantly associated with depth of flooding (p for trend = 0.04). In this study, response rate in flooded population was higher than that in non-flooded population. As the original paper discussed, such difference in response rates would not lead a biased estimation of risk in these subsets of population by itself. However, differences in motivation to this survey may give favour to differences in measuring disease status (prevalence) by retrospective use of self-report (recall bias). Specifically, we cannot rule out the differences in efforts to recall any these symptoms among those flooded and non-flooded, as the interview had included the questions about flood impacts on their house and interviewee who knew their own exposure status at the time of interview could be affected by their own exposure status.

According to the monitoring of the Syndromic surveillance data by Public Health England (PHE), the data collected from GPs (in hours and out of hours), NHS Direct or 111 calls, and local health protection teams, did not show evidence of increased outbreaks of infectious diseases associated with the summer 2007 floods and this is in line with the most recent floods (Public Health England, 2014b, Public Health England, 2014a)

Chemical contamination and CO poisoning

Carbon monoxide (CO) poisoning is the most serious chemical hazards involved in the floods and recovery stage. It occurs when generators or fuel-powered equipment are used indoors or in equivalent enclosed environment without enough ventilation for purpose of drying, pumping out flood water, cooking, or heating. Following the 1988 flooding of Nimes, 12 cases of CO poisoning were reported involving fire fighters, civilians, and members of the military who were pumping water and effluents from basements (Duclos et al., 1991).
In the four major hurricanes hit Florida in 2004, six fatal-cases were reported to be attributed to CO poisoning. A close investigation on 167 non-fatal poisoning cases treated at selected hospitals showed misplacement of portable, gasoline-powered generators was a major source of these CO exposure (CDC, 2005, Van Sickle et al., 2007). Hurricane Rita in the US in 2005 caused five fatalities and 16 non-fatal cases (Cukor and Restuccia, 2007). This is also the case with the 2007 UK floods: 2 deaths due to CO poisoning were reported in Pitt (2008). In the UK, however, there is no official statistics for CO poisoning cases regardless of flood-related or not. A recent review paper describes the different risks of CO poisoning posed by the different phases of a flooding/disaster (pre-disaster, emergency/recovery and post-recovery/delayed phase) and suggests the need of relevant surveillance system (Waite et al., 2014).

Other chemical hazards were summarized in Public Health England (2014b), including car batteries, household chemicals, oil, petrol, enclosed areas, and gas systems. Euripidou and Murray (2004) conducted a literature review of flood-related chemical incidents and health impact. They suggested the improvements in environmental sampling following flooding is necessary, and improving the public knowledge through education and engineering safety is also required to mitigate such risk.

Mental health

Large systematic reviews of epidemiological evidences suggest that flooding has adverse effects on mental health and wellbeing (Ahern et al., 2005, Stanke et al., 2012b). Here, the main epidemiological evidence relates to common mental disorders (CMD, i.e. anxiety and depression) and measurable posttraumatic stress syndrome (PTSD) in the UK.

A well-controlled study by Bennet (1970), referred to in the Mortality section, found a significant increase (flooded 18% v non-flooded 6%, p<0.01) in self-reported psychiatric symptoms (anxiety, depression, irritability, and sleeplessness) among women but no significant difference for men.

A study of the Lewes 2001 floods, referred to in the Infectious disease section, reported fourfold increase in psychological distress (RR 4.1, 95%CI: 2.6, 6.4) among adults whose homes were flooded compared with those whose homes were not (Reacher et al., 2004). Psychological distress was defined as a score of 4+ using the well-established the 12-item General Health Questionnaire (GHQ-12) scale administered 9 months after the flood event.

A few limitations should be noted in interpretation of this result as discussed above: measured psychological distress is prevalent cases, not new onsets of the cases after the flood event (incident cases); estimated relative risk is a cross sectional comparison between flooded and non-flooded postcodes after the flood event, thus we cannot exclude the possibilities of baseline areal differences in the prevalence of psychological distress or socioeconomic status that might exist regardless of the flooding; both physical and mental health outcomes were ascertained by self-report retrospectively.

Tunstall et al. (2006) had conducted a systematic interview survey on 30 different locations affected by different fluvial flood events in England and Wales since January 1998. This suggested two thirds of the flooded population indicated mental health problems (measured by scores of 4+ on the GHQ-12) at their worst time after flooding with some reporting long term effects. The study also examined the influence of a wide range of factors (characteristics of the flood event, types of property, and socio-demographic and the intervening factors such as family or community support) to reveal the further systematic investigation. Another cross-sectional survey of flooded adults in the UK reported the prevalence of PTSD symptoms to be 27.9%, anxiety symptoms to be 24.5%, depressive symptoms to be 35.1% with higher symptom scores in females than males (Mason et al., 2010). A qualitative longitudinal study following up those affected by the 1998 flood in Oxfordshire reported some psychological effects could be prolonged over 4 years (Tapsell and Tunstall, 2008).

According to the population-based survey carried out in 2 regions (South Yorkshire and Worcestershire) following the summer 2007 floods, the prevalence of mental health symptoms (psychological distress, anxiety and depression) was 2-5 times higher among individuals whose houses were flooded compared to the non-flooded (Paranjothy et al., 2011). Reporting health concerns and perceived negative impact on finances were independent predictors of psychological distress (OR 95%CI: 3.5, 6.4 and 1.8, 3.4 respectively). Individuals who were evacuated from their homes were also at higher risk of psychological distress.

A followed-up study of 87 community mental health team (CMHT) patients whose residences were flooded in 2007 highlighted the impact of flooding on the elderly with mental illness and dementia, particularly in the days and weeks after the water levels had receded but the repairs to the flood damage are awaited (Hayes et al., 2009). Regardless of the simple statistic report without comparison group (i.e. non-flooded patients), it implies crucial clinical messages: the possibility of delayed problems, the need of personal evacuation plans, the effects of overcrowding care homes on pre-existing dementia.

There are methodological complexities in measuring the mental health impacts of flooding, including low response rates and the difficulty of reliably measuring change in conditions (such as anxiety and depression) that have a substantial, but un-measured, prevalence in the pre-exposed population. Additionally, published studies have used a variety of measurement tools, which makes comparison between studies (and populations) difficult. Nevertheless, taken together, evidence form the UK indicates that flooding can exacerbate or provoke mental health problems. Indeed, these adverse effects of flooding on mental health are likely to confer a greater health burden that the non-fatal impacts on physical health, due to the relatively high prevalence of psychiatric symptoms. Physical and psychological effects of disasters such as flooding can be interlinked in complex ways (Reacher et al., 2004, van den Berg et al., 2005). Standardized measurements of mental health problems that separate psychological distress, mental illness and other mental disorders are required (Stanke et al., 2012b). In terms of timescale of mental health effects of flooding, ‘the secondary stressors’ (Lock et al., 2012), such as a lack of financial assistance, the taxing process of insurance claims and continued lack of infrastructure, could manifest long after the flood onset and persist for long periods. Further research is thus needed on the longitudinal effects of flooding on mental health, the effects of successive flood events, and the mental health effects for children and the elderly who are considered to be vulnerable.

2.2 Vulnerable groups

All populations could be affected by flooding directly or indirectly during and after the event. Certain groups are, however, thought to be at higher risk than general population for morbidity and mortality associated with flooding. For example, Tunstall et al. (2006) suggested people with limited physical capacity or limited mobility, those who rely on medication, who require home care or regular visits to health care facilities, and who have weak social networks, poor flood awareness, few resources and little access to flood warnings are at particularly high risk. Specific vulnerable groups identified by chemical incident cases (Edkins et al., 2010) and adapted to flooding include children, pregnant women, the elderly, people with physical/sensory/cognitive impairment, people with chronic illnesses, tourists, homeless, and people with cultural and language vulnerability (WHO, 2013, Stanke et al., 2012a).

There is some evidence on socio-economic differentials in exposure to flood risk in the UK. Research for Environment Agency investigated the population living in the flood plain and their neighbourhood socio-economic status referring to Index of Multiple Deprivation, and found the higher proportion of the population living in the flood plain reside in the more deprived area. Such socio-economic gradient was clearly observed for the tidal flood plane in all regions in England and Wales but not for the fluvial flood plains with great regional variation (Walker, 2006, Walker et al., 2003). Fielding and Burningham (2005) applied a spatial method to redistribute population characteristics in smaller areal units, reported those in lower social classes and unemployed experienced a greater flood risk but no distinction was made between tidal and fluvial risk. An updated analysis, using the latest available data at that time (i.e. 2001 Census and Environment Agency flood maps 2004), demonstrated overall inequality in both the fluvial and tidal flood plains, although it is more significant and pronounced in the latter, especially in the eastern region of England (Fielding, 2007).

Whether these differentials observed in exposure to flood risk are apparent in health impacts of flooding remains unknown. A recent systematic study examined long-term impacts on mortality of 319 flood events reported little apparent differentials in the ratio of after/before change in flooded/non-flooded areas when stratified by deprivation quintiles (Milojevic et al., 2011). Little clear relationship was observed between socio-economic status and the timing or duration of displacement resulting from the 2007 Hull floods, except that the most deprived group had a slightly longer displacement time (Milojevic et al., 2014). The second paper suggested that it would not be simple to design a study to examine socioeconomic inequalities in health impacts of flooding if linkages between a flood incident, impacts and recovery might not follow a neat linear progression. However, this research gap needs to be addressed with continuation of improvement in measurement of flood-exposure, outcomes, and neighbourhood socio-economic status.

People’s awareness of flood risk is another aspect in considering flood risk management. The latest work by Fielding (2012) examined region-specific socio-economic differentials in flood awareness as well as exposure to flood risk: in all areas except the Midland, the working classes were more likely to reside in the flood plains; the greatest inequality in exposure to flood risk was seen in the North East and Anglian; flood awareness in the Anglian was much lower than average, but no significant differences between classes; in the Thames region, despite equal flood risk exposure between classes, the most deprived showed the least awareness of flood risk; in the North East, differentials in flood risk exposure were accompanied by those in risk awareness, which means the least aware and most deprived group experiences the greatest flood risk.

3. Review of studies on the current burden attributable to observed climate change (1970-2013)

Limited evidence is available and little attempt has been done to evaluate the current health burden in the UK attributable to observed climate change since 1970. Given little information on well-quantified relative risks of flooding, the estimates of current burden would include great uncertainties, especially with an attempt to separate attribution of climate change. Regardless of such potential uncertainties, this knowledge gap has a potential to be addressed using, for example, a methodological approach suggested by Campbell-Lendrum and Woodruff (2006). Needless to say, it is important that all estimates need to be declared with related uncertainties.

4. Review of studies on future health impacts (2010-2050 and 2050-2100)

Climate change is very likely to affect river and coastal flood risk in the future decades. Estimating the population exposure to flooding in the future is, however, even more challenging due to a range of additional factors to be considered such as improvements in forecast, mitigation measures, land-use change, and localized population growth. Thus few studies have attempted this (Hames and Vardoulakis, 2012, Maaskant et al., 2009).

4.1 Projected health impacts of future flooding impacts by the UK CCRA 2012

The UK Climate Change Risk Assessment (CCRA) 2012 reported the projected impacts on mortality, injuries and mental health in the Health Sector report (Hames and Vardoulakis, 2012), by linking currently available baseline risk, response functions to exposure, and the change in the number of people at significant risk of flooding estimated in the Flood and Coastal Erosion Sector report (Ramsbottom et al., 2012). The projections assumed no adaptation or deterioration of current flood defences. Change in population growth was considered by three scenarios, namely low, medium and high population growth. The projected results were presented under three different emission scenarios based on the UKCP09 climate projections (low, medium and high emission scenarios, corresponding to IPCC B1, A1B and A1FI respectively) and three future 30-year time periods (centred on the 2020s, 2050s and 2080s) for three probability levels (cumulative 10, 50 and 90%, except for mental health which only considered 50%). The main results of the projections are summarised below.

Mortality

In the UK CCRA 2012, fatalities related with fluvial and coastal flooding were assumed to be proportional to the number of people exposed to risks in any particular year due to inland or tidal flooding. This proportional relationship is based on the report from Frieser et al. (2005) investigated both high and low income countries. With limited records from the past UK flood events and Western Europe, a baseline fatality rate on annual basis was assumed to be 8 deaths per year for fluvial flood and 3 deaths per year for coastal flood (with long returning period of sever coastal flood events). Besides, additional deaths owing to coastal wave action during storms were included in the total number of estimated deaths, with baseline fatality rate, 7 deaths per year and its exponential increase in relation to changes in mean sea levels. Thus, baseline fatality rate due to extreme event flooding and storms were given as 18 per year. With the current population, 4-17, 6-34, and 13-69 additional deaths were estimated to occur on annual basis by the 2020s, 2050s, and 2080s, respectively, due to with climate change. These increased to 5-21, 8-49, and 14-98 when the population growth estimates were taken into account. No attempt was made to break these estimates down to regional revel due to lack of localized baseline flood-related mortality and climate projection data.

These figures appears to be over-estimated: First, baseline mortality due to fluvial flood, 8 deaths per year was exaggerated from observed average (3 deaths per year) in the UK and Western Europe considering possible unreported deaths. Second, deaths due to storm activity was based on the presumption that all of the reported deaths in referred storm activities relate to storm conditions. This also raises possibilities to double count the effects in storm-serge flooding. Third, the estimation does not take into account of improvement of flood protection or warning systems that is obvious since 1953 till the present.

Injuries

The number of injuries to be sustained during future flood events and to require medical attention from hospital admissions was also targeted for this projection. Due to lack of recorded data on flood-related injuries as described in Section 2.1, a simple linear relationship between flood-related injuries and exposure to floods was applied with rate of 20 injuries to one death, based on previous reports (Defra / Environmental Agency, 2003). Suggested estimation was, with the current population, 80-340, 120-680 and 270-1,380 additional injuries may occur annually by the 2020s, 2050s and 2080s respectively. After taking into account of population growth, these estimation increased to 100-420, 160-980 and 290-1,960 respectively. Again, these estimations seem to be over-reported as the same reasons with mortality.

Mental health

Similar to the estimation of flood-related mortality and injuries stated above, mental health impact of flooding as a result of climate change were assumed to be proportional to the number of people at risk due to fluvial or tidal flooding. The measurement for psychological distress used in the CCRA 2012 report was score of 4 or above in GHQ-12 referring to Reacher et al. (2004) and Tunstall et al. (2006).

The CCRA 2012 reported additional 3,000 to 4,000 people were anticipated to be affected by `new onsets’ of psychological distress (described as changes of GHQ-12 score from below 4 to 4+) due to flooding in the 2020s in England and Wales, and suggested it to be increased to between 4,000 to 7,000 by the 2050s and 5,000 to 8,000 by the 2080s. These estimations need to be carefully interpreted in light of the original research findings.

First, the original report by Reacher et al. (2004) did not measure new onsets of psychological distress (namely, incident case) but psychological condition of only post-flood event (namely, post-flood prevalent case): 48% of flooded population and 12% of non-flooded population indicated GHQ-12 score 4 or 4 + at the time of 9 months after the flood event. Thus, the prevalence rate of psychological distress in flooded population was 4.1 (95%CI: 2.6, 6.4) times higher than that in non-flooded population in their study. Generally, such prevalence is much higher than incidence for non-common disease, and hence the description in the CCRA 2012 implying `incidence’ is misleading. Second, the CCRA 2012 interpreted the results from Reacher et al. (2004) as `36% of flooded residents’ had `new onsets’ of psychological distress. However, there is no reason why the subtraction of prevalence rates with different denominators (i.e. 48% of the flooded population vs. 12% of the non-flooded population) could be linked with one of them, the flooded population. Third, intrinsically the results from Reacher et al. (2004) had not been adjusted for areal socio-economic status and the observed difference in the prevalence of psychological distress in the flooded area and non-flooded area might be attributed to the areal socio-economic differentials regardless of flooding or as an effect modifier. This possibility cannot be excluded as the British Housing Survey found consistent association between poverty and unemployment and the prevalence of CMD, anxiety and depression (Weich and Lewis, 1998). Fourth, again it needs to be noted the original research is based on the retrospective use of self-report interview and subject to recall bias (see above), although the CCRA 2012 tried to give justification regarding this. Nonetheless, it is correct there are very few studies that quantify the risks of flooding on mental health (Reacher et al. (2004) and Paranjothy et al. 2008) and this important research gap needs to be addressed with urgent priority.

4.2 Uncertainties in the UK CCRA 2012

Future actual flood risk and its impact on health depend on a range of factors including the severity of the flooding, its nature, particularly speed of onset (fluvial, flash, coastal etc), time of day, effectiveness of warning, emergency preparedness, existing socio-economic structures, and maintenance and strengthening of flood defences. Nonetheless, the UK CCRA 2012 was the first attempt in this country and the overall findings suggested it is very likely that health effects of storms and floods will increase this century if no adaptation measures are taken.

There are noticeable limitations in the UK CCRA 2012 projections which need to be elucidated by addressing knowledge gaps (discussed in the next section). Firstly, baseline risk of mortality and injuries and those response functions to flooding were not derived from scientific researches specific to the recent high-income countries setting. Some of them were based on implicit judgements due to lack of evidence. Well-quantified relative risks for target health outcomes and subgroups are essential for this sort of projection process. Especially in response to glowing concerns on mental health impacts of flooding, more evidence on these relationship needs to be gathered in the light of: the potential use of clinical records, approach to capture incident cases rather than prevalent cases, and adjustment for areal characteristics such as socio-economic status that could distort direct flood impact. Considering such insufficient evidence on baseline risk and response function to flooding, the confidence level for the estimated projection on health in the UK CCRA 2012 should be close to *low* rather than *medium* according to the definition described in the CCRA: *Low* for expert view based on limited information; and *Medium* for estimation of potential impacts of consequences, grounded in theory, using accepted methods and with some agreement across the sector (Appendix 3 in Hames and Vardoulakis (2012)). Secondly, crude burden of health impacts by flood and storms were estimated without considering distribution by age, gender, socio-economic status, or urban/rural area. Projections focusing on possible vulnerable groups (discussed in Section 2.2) could provide useful information for policy interventions to mitigate future flood impacts, especially the elderly generation subject to potential vulnerability and substantial demographic growth in future. Thirdly, regional differences within the UK should not be neglected as some areas have been identified as particularly high risk to coastal flood, including South Wales, Yorkshire and Lincolnshire (especially the Humber Estuary), East Anglia and the Thames Estuary. Finally, no adaptation or deterioration of current flood defences was assumed in the current projection. With engagement of governmental bodies such as the Environment Agency or Public Health England, the latest discussion or development plan of flood defences and warning system could be integrated as selected policy scenarios. This will inform and support evidence-based policy making.

5. Potential for impacts to be avoided by adaptation measures

The recent IPCC assessment report states that the impacts of sea level rise on populations and infrastructure in coastal regions can be reduced by adaptation [medium confidence] and that populations in urban areas are particularly vulnerable to climate change impacts due to the high density of people and built infrastructure [medium confidence] (IPCC, 2014).

Following the 2012 UK CCRA that identified flooding as one of the most significant climate risks faced now and in the future, the Adaptation Sub-Committee (ASC) in the Committee on Climate Change (CCC) assessed the current progress in preparing for such flood risk. The assessment focused on the following key adaptation measures to manage long-term flood risk in a changing climate: 1) design of new development and land use planning; 2) protection of existing properties from flooding; 3) managing surface water flow in urban areas; and 4) emergency planning and responses (ASC, 2012). Key results specific to these adaptation measures are outlined in Table2. Overall ACS (2012) concluded the UK has become more exposed to future flood risk through continued development in the floodplain and paving over of front gardens. As such, despite recently increased investment in flood defences, water supply infrastructure and the design of new development, current efforts to manage flood risk may not be sufficient, given the combined effects of climate change and economic development in the future. The ACS (2012) also provides advice on the UK National Adaptation Programme in relation to flooding, such as transparent implementation of planning policy in flood risk areas, sustained and increased investment in flood defences, and property-level protection against flooding. Given the storms and flooding witnessed in the winter 2013/14, the latest report added an updated analysis on adapting to flood risk and raised a serious warning that current under-investment in flood prevention, together with a reliance on defences to protect new development, will increase the potential for avoidable flood damage (CCC ASC, 2014). It also highlighted a number of areas where further action appears to be justified in order to mitigate the future flood risk: regarding funding and resources, managing local flood risk, flood insurance and property resilience, new development, and sustainable drainage.

The CCC ASC (2014) argued the lack of public awareness of local flood risk might partly be explained by households not currently bearing the true economic costs of living on the floodplain. The cost of home insurance in flood risk areas is subsidised by other policyholders and the prices currently paid by householders for buildings and contents policies generally do not reflect the chance of claim requests. It suggested changes in the provision of home insurance in flood risk areas might help build much greater awareness of flood risk and create stronger incentives for cost-effective action. The new flood reinsurance pool system, called a `Flood Re’ is due to be introduced in 2015. This system will continue to subsidise flood insurance for high risk households on a time-limited and transitional basis. Specifically, the price of flood insurance will be capped according to the council tax band of a property and these caps will increase each year to allow a free market for flood insurance to emerge gradually over the twenty-five year lifetime of the policy. Over the lifetime of Flood Re, owners and occupiers are likely to find insurance increasingly more expensive in flood risk areas than elsewhere.

On another front, access to affordable flood insurance seems to be crucial in reflection to anticipated significant impacts on mental health (Section 2.1 and 4.1). O'Neil and O'Neil (2012) argued that social justice demands an insurance regime based on principles of solidarity (whereby those at lower risk contribute to support those at higher risk) rather than market-based *individualist* (whereby individual payment is proportional to the level of risk), which guarantees access to flood insurance for vulnerable households. The balance between flood awareness and fair and sustainable insurance systems need to be deliberated.

6. Conclusions and Evidence Gaps

Climate change is very likely to affect river and coastal flood risk in future decades and hence the impacts on both physical and mental health are globally anticipated. However, it is a significant gap in research that little is known about health impacts of flooding in the UK. This lack of evidence is largely attributable to the fact that flooding is comparatively rare in any given location and unpredictable in timing, making it difficult to capture evidence on the status of outcomes before as well as after flooding on large population samples. Other difficulties include insufficient surveillance system, high population mobility during and after the flood event, barriers of generalizing due to flood event specific effects, and little knowledge on how long the effects prolong.

The UK CCRA 2012 made the first attempt to project the flood impacts on mortality, injuries and mental health under different emission and population growth scenarios for 2030s, 2050s, and 2080s. The reported projections are currently subject to over-estimate and expected to be improved.

The government has recognized significant climate risk of flooding and a numbers of actions towards adaptation and mitigation are in process: for example flood warnings, protections, spatial planning such as land use allocations, and insurance system. By filling the current evidence gaps on human health impacts, such policy planning is expected to be able to entail more evidence-based discussion. For instance, the national indicators used in the first ASC assessment of preparedness for flooding based on the number of properties or infrastructures could be transformed into the health and wellbeing indices, such as year life lost (YLL) or avoidable deaths/injuries or the disability-adjusted life year (DALYs).

The current review on health effects of flooding in the UK identified the following knowledge gaps:

- Prospective epidemiological studies and opportunistic retrospective studies should be conducted on the health effects of flooding. The latter study needs to have double controls by flooded and non-flooded comparison and by before and after the event comparison using baseline data.
- For mental health effects, standardized systematic methodology (such as the use of routine clinical health records) needs to be developed to fill a gap in retrospective self-reporting survey.
- Understanding of vulnerable sub-group and their health needs is required. While certain vulnerable groups have been recognized (the elderly, those with chronically illness, low socio-economic status group), there is some inconsistency between studies. Little investigation on children has been conducted.
- Little attempt has been done to quantify regional differences within the UK.
- It is unclear how long the various health effects prolong after the floods. Especially, mental health effects (expected to be longer) need to be investigated for implications for health service and hence its cost.
- Development of flood surveillance system can be considered with the balance of its maintenance cost. The system needs to record health status at baseline/during/after the floods on various types of health outcome, including deaths and injuries. For deaths, definition of direct/indirect and immediate/delayed deaths due to flooding is needed. For injuries, complete information on the causes and types are required. Other attributable data will be useful, such as population displacement (timing, duration and places), related interventions or repair work (timing) and insurance claims. Well-designed surveillance system enabled well-controlled epidemiological study design, which is expected to improve epidemiological knowledge and thus confidence level in estimating the current and future health burdens.

- Most of the reported studies are about slow onset floods. The impacts of flash flood are anticipated to be more significant especially in physical health effects.
- The current projection of health impacts of flooding needs to be improved. No projections have been carried out in relation with pluvial flood risk.

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Table 2. Key results from the ASC assessment of preparedness for flooding under climate change.

Adaptation measures	Key results
New development & land use planning	• Development in the flood plain grew at a faster rate than outside the floodplain (12% vs 7%) in England over the past 10 years. While ≥80% of these new development is protected from flooding with community defences, one in five properties built in the floodplain were in areas of significant flood risk. • Approval process is not sufficiently transparent or accountable. Local authorities as well as Environment Agency need to be involved. • The current “build and protect” approach to floodplain development is likely to increase costs of flood protection and recovery from damage in the face of climate change, of which long-term costs may outweigh the benefits of developments in some areas.
Protection of existing properties from flooding	• Investment in flood defences has helped to reduce flood risk to 182k homes in the last 3 years and improved the condition of some defences. • However, the EA estimates investment needs to increase by £20 million above inflation every year to keep risk levels constant in the face of climate change and deterioration of flood defence assets. • Property-level protection measures (door guards and air-brick covers) could benefit properties in lower population density area, but may not be cost-effective. However, such measures are expected to make 20-35 times lower than the rate required to reach all 200-330k properties that could benefit within a meaningful timeframe (25 years). • By 2035, the combined effect of increased investment in flood defences (£20 million per year on top of inflation) and property-level measures could reduce the number of properties at significant risk by half from current levels accounting for climate change. The potential impact of climate change means that increased investment could lead to a four-fold reduction in risk when compared with a scenario of no additional action.
Surface water flow management (urban area)	• Surface water flooding in urban area is already increasing as a result of paving over green spaces in towns and cities. Despite the scale of the risk, knowledge of the impacts of climate change on surface water flooding remains poor. • The current deployment of sustainable drainage systems is unlikely to be sufficient to reduce the increasing risk from surface water flooding.
Emergency planning / responses	• A single statutory framework for civil protection in the UK has been in place since 2004 (e.g. The Civil Contingency Act 2004, the National Flood Emergency Framework in 2010). • Some national critical infrastructures are located in areas with significant or moderate flood risk. • Vulnerable groups: over 1,000 care homes (with 30k residents) and 1,600 schools (with 500k pupils) located within the floodplain in 2011. • Flood warning: less than one-quarter of all properties in the floodplain have registered for the EA flood warning direct service, which is particular in many built-up parts of the flood plain including London, Hull and Newcastle-upon-Tyne. • Insurance: up to 200k homes could face problems in seeking insurance cover after the termination of agreement between the Government and the insurance industry in 2013.

Source: ACS (2012)