

Climate change adaptation in the health sector -  
a literature review

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## Introduction

Climate change is a globally pervasive phenomenon that represents a significant threat to human health (5). Climate changes observed in Ireland to date include a change in rainfall patterns, extremes of weather and an increase in average temperatures (8). Such changes can impact the physical and mental health and wellbeing of the population whilst potentially also negatively impacting on the operational delivery of the healthcare system (15,16). While measures to reduce greenhouse gas emissions at both the national and international levels have been implemented, the impacts of climate change are expected to progress due to the inertia in climate systems (12,17-19).

Relatively recent weather events worldwide demonstrate that countries that are under-prepared for climate-related events can be severely impacted (20-22). The need to adapt to these changing climate conditions is widely acknowledged within the international literature, and the recent publication of the National Adaptation Framework in Ireland sets out the requirements for all governmental sectors to assess key risks and vulnerabilities of climate change in their respective sectors, to identify and implement adaptation measures and to embed climate adaptation approaches into all local, regional and national policies going forward (12). Against this backdrop, the question of how climate change will impact on health and the health sector in Ireland comes to the fore. A review of the national and international literature to examine the impact of climate change on health and the delivery of healthcare services, with a particular focus on Ireland, was therefore undertaken to inform the adaptation planning process for the Irish healthcare sector.

## Methodology

The peer-reviewed and grey literature was examined to identify the current evidence base pertaining to climate change and its potential impact on health and the delivery of healthcare services in Ireland and further afield. The objectives of this review were:

- To examine the relationship between climate and health;
- To explore the observed and projected climate changes within the Irish setting and the impacts they have had/may have on the population living in Ireland;
- To identify the experiences, policies and practices in other jurisdictions in relation to climate change adaptation to support the development of potential adaptation options for the Irish health sector.

A comprehensive search of the international literature was undertaken using Medline, Embase, CINAHL and the Cochrane Library electronic databases. A search of the grey literature was also performed using the Google and Google Scholar websites. The search strategies were constructed using free text searches and also MeSH terms and were designed to identify papers related to the impact of climate change on population health and the delivery of healthcare services. The search terms included:

Search #1: climate change OR global warming OR climate variability OR greenhouse effect\* OR GHG\*

Search #2: (MM "Health+") OR (MM "Environmental Health+") OR (MM "Health Planning+") OR (MM "Health Policy+")

Search #3: disease\*

Search #4: mortality or morbidity

Search #5: S3 OR S4

Search #6: S1 AND S2 AND S5

Search #7: S1 AND S2 AND S5 <Published Date: 19900101-20181231; English Language; Human; English Language; Human>

The inclusion criteria were as follows:

- High income country
- Primary focus was on the impact of climate change on health and wellbeing
- Papers published between the years 1990 – 2018.

The exclusion criteria were as follows:

- Low/middle income country
- Studies with a primary focus on the impact of climate change on the occupational health of workers
- Articles for which access to full article could not be obtained and where the abstract contained insufficient information
- Studies published in a language other than English.

## Results

The above search, or variants thereof, yielded a total of 418 articles, of which the titles and abstracts were scanned for suitability. In total, 340 were found to be unsuitable, while 78 were deemed suitable based on inclusion of literature pertaining to the impact of climate change on health and/or healthcare service provision.

Ancestor referencing was used to identify further articles. A search of the grey literature was also performed to access policy and guideline documents. Free text searches were performed on the Google websites using combinations of the keywords: “climate change”; “global warm\*”; “health\*”; “health service\*”; “adapt\*”; and associated synonyms. An additional 94 suitable publications were identified in the grey literature search and ancestor referencing and, in total, 172 papers were included in this review.

### Effect of climate change on human health

The most basic needs for human health are air, water, food and shelter (134). These needs are directly influenced by the quality of the environment into which people are born and in which they live, work and age (129). The link between climate and disease has long been recognised, although our understanding of the relationship between climate and health has deepened as more research has emerged to inform the fields of environmental health, global climate modelling and how the social, cultural and political landscapes influence our environment and our health (28). While humans are directly exposed to climate change through alterations in the frequency and severity of weather patterns, the role of climate on health extends beyond this as it influences most systems that are essential for supporting life (28). Consideration of the extent and breadth of this influence, against the backdrop of the unpredictable nature of extreme weather events, highlights the potential vulnerability of society to the risks of climate change (28).

Climate change has been heralded as “the biggest global health threat of the 21<sup>st</sup> century” with the World Health Organization (WHO) estimating that there will be an additional 250,000 deaths per year from 2030 to 2050, likely secondary to malnourishment, diarrhoea, malaria and heat exposure (23,24). The Health Protection Agency has predicted a 70% increase in premature deaths secondary to heatwaves in the coming decade (2020 and beyond) (25). Although all populations will be affected by climate change, vulnerable populations such as the elderly, children, and those with chronic illnesses will be disproportionately affected (26,27). The extent of an individual’s vulnerability to

climate change will depend on their socio-demographic characteristics, the social infrastructure, access to resources such as health services and their level of exposure to climate change (93).

A description of the predicted climate changes for Ireland, and their potential impacts on health, follow hereunder. However, it is worth noting from the outset that there is a level of uncertainty associated with both climate change projections and the relationship between climate change and health and further research is most certainly required in these areas (12,27). Despite this, there is a general consensus on the future direction of climate change and its potential to cause adverse effects on population health, and such uncertainty should now be used to drive adaptation measures to build resilience to climate change across the health sector (12,27).

### Temperature changes

Mean temperatures in Ireland have increased by an average of 0.07°C per decade since 1900 (4). Ireland has seen an increase in the number of warm days while the number of cold days has concomitantly decreased (30). National projections for 2050 and beyond indicate that an increase in mean annual temperatures (1-1.6°C) is projected and that all seasons could potentially become warmer (13,31). Furthermore, an increase in the frequency of heatwaves has been projected (8).

### Heatwaves

While warmer weather may reduce the risk of cold-related morbidity and may potentially improve wellbeing and physical activity levels, recent weather events across Europe and further afield have demonstrated the capacity that extreme heat can have on population health (15,32-34). The health effects of extreme heat include rashes, cramps, dehydration, syncope, heat exhaustion and heat stroke whilst also aggravating pre-existing health conditions including cardiovascular, respiratory, cerebrovascular and neurological disorders (35-37). Moreover, there appears a higher level of healthcare service utilisation during periods of extreme heat (38,39). Heat waves are responsible for excess deaths every year: 70,000 premature deaths were attributed to a heatwave across Europe in 2003 while extreme heat was associated with 7,400 deaths in the United States (US) from 1999 to 2010 (33). The *“Projection of Economic Impacts of Climate Change in Sectors of the European Union based on Bottom-Up Analysis Project II”* (PESETA II) has projected 100,000 additional deaths per year across EU countries with a global mean temperature increase of 3.5°C for the time period 2071 - 2100 relative to 1961 – 1990 (40). It is likely that the burden of mortality will be disproportionately carried by more vulnerable groups within the population such as the elderly, children and those with chronic diseases (37,40,41).

In Ireland, the evidence examining the relationship between temperature and mortality is inconsistent. A European-wide study undertaken in 2008 studied meteorological and mortality data and concluded that there was no excess mortality from excess heat in Dublin (42). Conversely, an examination of the age-standardised daily mortality rates over the course of 17 years in Dublin found a 0.4% increase in mortality associated with an increase in temperature of 1°C (43). These effects were restricted to the population aged over 65 years (43). A more recent study found that 294 excess deaths were attributed to heatwaves that occurred between 1983 and 2006 in Ireland with the majority of these deaths occurring during the 1980s (44). Based on the 2016 Irish Census data and under the M2F2 scenario, the population of Ireland aged over 65 years is expected to increase significantly from 629,800 persons in 2016 to nearly 1.6 million by the year 2051 (45). Similarly, the numbers living with a chronic disease are expected to rise in the coming decades as the population ages (46,47). It is therefore possible that extreme heat secondary to climate change could place an additional burden on healthcare services in Ireland and there is a clear need for the implementation of adaptation measures going forward.

Matthies *et al.* highlight the importance of the development and implementation of health action plans that guide on issues such as (48):

- Weather alerts that are timely and accurate
- Approaches to reduce exposure to heat at both the individual and community level, with a particular focus on vulnerable populations
- Strategies for the provision of health care, social services and infrastructure during heat waves. These strategies should include measures such as: the provision of thermometers within health care buildings and the identification and installation of efficient cooling mechanisms; the provision of special care to patients identified as vulnerable to heat extremes in terms of revision of medications and home supports; the appropriate rostering of staff during heatwaves; and staff training to support the identification of heat-related illnesses and their appropriate management
- Heat-related health information strategies to raise awareness amongst the public and healthcare professionals
- Health surveillance during heat wave events and the evaluation and monitoring of the impact of interventions in real-time.

The absence of such a plan in Ireland is a significant unmet need. Public Health England describes a heatwave alert service (“Heat-Health Watch”) which comprises four main levels of planning to reduce the health impact of extreme heat events and touches on well-described evidence-based adaptation measures focussing on early-warning systems, increasing hospital preparedness and increasing public awareness of health protective measures (37-41,135,136). “Level 0” describes a long-term cross-sectoral planning approach to ensure appropriate adaptation measures are in place (37). This includes the need to adapt urban planning and architecture and energy and transport policies (48,52). A focus on reducing the heat island effect through increasing green infrastructure, reviewing transport policies to encourage active transport and increasing passive cooling through the use of green space and water are all recommended approaches (37,135). Increasing the resilience of the health sector to heatwaves includes reviewing buildings where healthcare is provided and identifying design measures to aid passive cooling and targeting particularly vulnerable areas where air conditioning may be required (135). Actions to support active transport and the protection of green spaces (e.g. at the expense of car parking) should also be prioritised (37). “Level 1” describes the maintenance of awareness and preparedness for extreme heat events during the summer months through education and training for healthcare professionals in identifying vulnerable individuals and undertaking preventive action and in recognising and treating heat-related illness (37). Information resources have been made available that can be readily accessed and adapted by health and social care professionals in the context of a heatwave (136). Level 1 actions also include mobilising the community and voluntary sectors to identify and support vulnerable individuals and to raise awareness of the heatwave guidance in other institutional establishments such as schools or prisons (37). “Level 2” actions are triggered once the Met Office issues a forecast of a 60% chance of having temperatures high enough to impact on health on at least two consecutive days (37). Actions include risk communication with healthcare professionals and with the public, with a particular focus on communication reaching the most vulnerable groups (37). Business continuity plans are also implemented at this level (37). “Level 3” involves targeted actions for high-risk groups and is triggered once threshold temperatures have been reached in one or more regions (37). Actions include issuing media alerts about how to stay cool and mobilising community and voluntary support (37). A “Level 4” alert constitutes a national emergency and occurs when a heatwave is so severe or prolonged as to have impacts reaching beyond the health

and social care sectors (37). Central Government will declare this level of alert if a multi-agency response is deemed necessary and the Level 3 actions are continued into this phase (37).

Consideration also needs to be given to the development of a suite of heat-related indicators as part of a real-time syndromic surveillance system in Ireland (172). Such a system would support early warning of the occurrence of health impacts during heat waves, facilitate a speedy and appropriate public health response and facilitate health service planning for similar subsequent weather events (137,138). Examples of health-related indicators used in the UK that could be considered in the Irish setting include number of ED presentations or out of hours GP consultations for heatstroke/sunstroke (138).

#### *Increased exposure to ultraviolet radiation*

Climate change may result in the Irish population having increased exposure to ultraviolet radiation (UVR) due to higher levels of ambient UVR as well as due to changes in human behaviour (e.g. more time spent outdoors in the warmer weather, variation in the measures taken to protect oneself from UVR) (53,54).

Increased exposure to UVR has been demonstrated to cause DNA damage and immunosuppression in the short-term and can have longer-term consequences such as increased risks of cataracts and various forms of skin cancers (55).

Intermittent or recreational UVR exposure is the main risk factor for basal cell carcinomas and malignant melanomas, while the main risk factor for squamous cell carcinomas is chronic sun exposure (139). Caucasian populations are the most vulnerable to skin cancers, particularly those of Celtic descent (54,140).

An increasing trend in malignant melanoma has been observed over the past few decades and is responsible for the vast majority of deaths due to skin cancer (53). A study published by the United Nations Environment Programme undertaken in 1998 projected an additional 90 per million cases of skin cancer per year by 2050 in north-west Europe (141).

Just under 1,000 melanoma skin cancers and over 9,000 non-melanoma skin cancers were diagnosed per year in Ireland between 2011 and 2015 (139). The National Cancer Registry of Ireland has released cancer projections to 2040 for Ireland (56). The model projects an increase in melanoma skin cancers in women by a factor of 93% to 175% between 2010 and 2040 and an increase in male cases by 134% to 327% (56). Similar increases in non-melanoma skin cancers were projected for the same time period (56). These projections are based on past trends and do not take into account additional risks such as climate change. A survey undertaken in Ireland among 200 participants demonstrated a high level of awareness regarding the link between sun exposure and skin cancer but despite this, less than 20% reported using sunscreen regularly (57). This suggests that much work needs to be done to promote the use of sunscreen and other personal protective measures (57). However, there were significant limitations with this study which must be considered when examining these findings: participants were recruited through a dermatology outpatients clinic in one hospital in Ireland which raises questions about the external validity of the results as well as the potential introduction of selection bias and response bias. A survey of young adults across Ireland was undertaken between 2007 and 2008 which found that 20% never use sunscreen and that just over half use sunscreen on a sunny day (58). No data on the rigour of application or re-application habits were collected. Up to date data on Irish peoples' knowledge, attitudes and practices regarding sun protection measures would be important to inform population-based adaptation measures in this area going forward.

Adaptation measures that have been implemented in other countries include a programme of education for the public to raise awareness of the dangers of UVR and protective measures that can be taken to limit exposure (142,143). The positive impact that campaigns such as the *Slip! Slop! Slap!* campaign and the *SunSmart* programme have had on changing social attitudes towards tanning and UV exposure have been demonstrated over the past number of decades (144,145). Multicomponent campaigns delivered over a prolonged period appear most effective (146). The National Institute of Clinical Excellence (NICE) suggest adopting a consistent, multiagency approach when communicating the risks of UVR exposure to the public with a particular focus on tailoring messages to high-risk individuals and those caring for individuals from high-risk groups (147). Additional measures such as increasing the provision of shade, particularly in areas where high-risk populations may be exposed (e.g. schools, playgrounds) should also be considered (142,143,148,149). NICE also suggest using epidemiological data to identify which groups, behaviours or activities are high-risk for over-exposure to UVR and to inform on the barriers to behaviour change (147).

#### *Air quality*

Climate change is expected to aggravate existing health risks secondary to poor air quality due to weather-driven increases in air pollutants such as ozone and particulate matter (PM) (59). Exposure to PM is associated with increased all-cause and cardiovascular mortality and morbidity, respiratory disease in childhood and adverse birth outcomes (59). Exposure to ozone is also associated with cardiovascular and respiratory morbidity and mortality (59).

Aeroallergens such as pollens from trees or dust-mites have the potential to trigger an allergic response when inhaled by a vulnerable individual. An increase in aeroallergen levels can be linked to aggravation of respiratory diseases such as asthma and may lead to an increase in healthcare service utilisation (60). Climate change may increase aeroallergen levels through higher temperatures, a prolongation of the pollen season and through an increase in indoor growth of mould and fungus secondary to increased precipitation and flooding (27). Older adults, individuals with chronic disease and children are particularly vulnerable to the health impacts of poor air quality (150). Moreover, UK evidence highlights that deprived communities are more likely to be situated near busy roads and are more likely to experience adverse health impacts secondary to air pollution (154).

Within the EU, it is estimated that long-term exposure to the concentrations of PM<sub>2.5</sub> (particles with a diameter  $\leq 2.5$  microns) and ozone recorded in 2014 were responsible for 399,000 and 13,600 premature deaths, respectively (61). In Ireland, it is estimated that 1,050 premature deaths occurred in 2014 secondary to PM<sub>2.5</sub> and 20 premature deaths secondary to ozone (61).

An earlier onset in the pollen season (by about 15 days over the last three decades) has been noted in the northern hemisphere which has been attributed to climate change (41). It is likely that this has impacted on the patterns of allergenic disease caused by pollen with earlier onset of symptoms in vulnerable individuals possible (48). In Ireland, evidence of an earlier budburst for birch has been observed over the course of 46 years from 1954 to 2000 and this raises issues regarding the birch allergy season (62). Nolan *et al.* project an increase in the average length of the growing season in Ireland by over 35 days by 2050 which could have implications for pollen season in Ireland (12).

There are approximately 450,000 people with doctor-diagnosed asthma in Ireland and there are indicators that the prevalence is rising (63). The age-sex standardised rate of hospitalisation was 45 per 100,000 population in 2017 against a backdrop of a consistent increase in the rate over the preceding three years from 41 per 100,000 population in 2014 to 46 per 100,000 population in 2016 (63,152). Based on the OECD age-sex standardised rates for 2015, Ireland ranks below the OECD average of 46.7 hospitalisations per 100,000 population with 43.7 hospitalisations per 100,000

secondary to asthma (63). In 2011, the Health Service Executive (HSE) reported that approximately 20,000 Emergency Department attendances and 50,000 out of hours GP consultations were due to asthma (64). COPD is another prevalent respiratory disease in Ireland with an estimated 500,000 people aged over 40 years in Ireland living with COPD (63). The national age-sex standardised rate for COPD hospitalisations fell during the period 2008 to 2017 with a rate of 370 per 100,000 of the population in 2017 compared to a rate of 404 hospitalisations per 100,000 in 2008 (63). Based on OCED age-sex standardisation, the rate of hospitalisation for COPD in Ireland in 2015 was 367 per 100,000 of the population – significantly higher than the OECD average of 190 per 100,000 of the population (63). Cardiovascular disease continues to account for a large proportion of morbidity and mortality in Ireland and by the year 2020 it is projected that the number of Irish adults living with a diagnosis of coronary heart disease will exceed 103,000 (63,151). While it must be acknowledged that these chronic diseases are multifactorial in origin, it is apparent that they already represent a significant burden on the acute health services in Ireland. It is possible that climate change may contribute further to this burden and it is therefore important that adaptation measures be considered in an effort to reduce further strain on the healthcare services.

Reducing the incidence of exacerbations of respiratory diseases secondary to climate change means reducing exposure to air pollution, anticipating events that may be hazardous to human health and increasing health service preparedness (41). Existing international legislation on air quality requires ongoing enforcement – while improvements have been made in emission levels across Europe, exceedances are still occurring (61,65,67). Ireland's air quality remains good relative to other European countries but challenges to maintaining this standard include increasing levels of PM and nitrogen dioxide, particularly in urban areas due to the burning of solid fuels and the high level of dependence on cars (66). At the national level, a *National Clean Air Strategy* is being developed to provide a framework for cross-sectoral collaboration to identify and implement measures to improve air quality (67).

At the local level, Local Authorities can contribute to adaptation measures through considering the health impacts of their decisions regarding areas within their remit such as traffic and parking management, street design and road networks, public transport policies and supporting electric car usage through the installation and maintenance of electrical vehicle charging points (154). Raising awareness within the population, with a particular focus on identifying and reaching vulnerable populations, of the measures they can take to reduce their exposure to pollen and air pollution as part of health promotion campaigns may support individuals to limit exacerbations of their illness during extreme weather events (8,41). For example, in the UK a daily air quality index and air quality forecast provide real-time monitoring data and air pollution forecasts which are often picked up and communicated by the media (154). In some areas of the UK, people particularly vulnerable to the health impacts of air pollution can sign up to text alerts which notify them when air pollution levels are high (154).

The preparedness of health services may be improved through the use of early warning systems for heat wave and pollen events (41,68,154). Monitoring of air quality is often undertaken to identify exceedances in standards or guidelines, while the need to measure exposure to air pollution and the potential consequent impacts of air quality on population health are often overlooked (153). In the UK, DEFRA has published a briefing document for Directors of Public Health which supports them to undertake an assessment of the impact of air pollution on health and facilitates the prioritisation of actions to address air pollution in their local area (154).



### *Changes in vector-borne diseases*

Climate change may affect the exposure, and therefore level of risk, to health from vector-borne diseases in a number of ways: through changes in the geographic distribution of the transmission cycles; changes in the numbers of pathogens and vectors; evolutionary changes of pathogens with the potential for a subsequent increase in transmissibility to humans and increased capacity to cause disease; and changes in level of exposure of individuals to vector-borne diseases secondary to changes in human behaviour due to climate change (69).

A review examining the projected effects of climate change on vector-borne disease incidence in Europe suggests a higher risk of West Nile Fever associated with milder winters, drier spring and summer seasons and wetter autumn seasons (166). Warmer weather is also associated with an increase in the length of the transmission season for Dengue Fever with an increase in humidity also having the potential to impact on the geographic footprint of Dengue vectors (166). While the potential for indigenous malaria transmission in Europe secondary to climate change was recognised, Semenza *et al.* concluded that the developed socio-economic and healthcare sectors in European countries would likely limit its re-emergence (166). With regard to ticks, projected temperature rises in Europe may alter their seasonal activity whilst also increasing the geographic areas of potential disease transmission (167). Furthermore, changes in vegetation to favour ticks' habitats also have the potential to impact on their abundance (167). Indeed, changes in tick distribution secondary to climatic changes have already been described in parts of Europe (169).

In response to climate change and the potential changes in patterns of vector-borne diseases, the ECDC has put forward a number of recommendations to enhance preparedness which include the implementation of exotic vector surveillance at potential ports of entry; the identification of target diseases and the use of common case definitions for endemic infectious diseases; and the identification of syndromes which would support the monitoring of emerging or re-emerging infectious disease and should therefore be recorded (168). Furthermore, in anticipation of the effects that climate change will have on the transmission patterns of communicable diseases, including vector-borne diseases, the ECDC has published a handbook to guide EU Member States in undertaking national vulnerability, impact and adaptation assessments in relation to communicable diseases in response to projected climate change (170).

In Ireland, warmer winters have the potential to support increased numbers and increased levels of activity of ticks, whilst also potentially extending their lifespan (171). While a combination of warmer summers with reduced rainfall may have an adverse effect on tick survival, the availability of an appropriate habitat will support continued tick activity and a projected increase in forest cover will also support the survival of host animals (171).

A risk assessment of the potential emergence or re-emergence of indigenous vector-borne disease in Ireland that was undertaken by the HPSC in 2016 recognised the impact of climate change on potentially increasing vector density for malaria and the ongoing surveillance and treatment of imported cases is identified as likely to be effective in reducing the risk of indigenous transmission (165). In preparation for climate change, a formal mosquito surveillance project should be established in Ireland to inform on the potential emergence of a suitable vector for chikungunya and dengue transmission in Ireland and the necessary actions required if such events were to occur (165). The ECDC suggests that the current health risks from vector-borne disease and how these effects are likely to change into the future need to be considered (170). Adaptation actions include vector control programs, education campaigns to raise awareness of the risks of vector-borne diseases and protective actions that can be taken and the provision of education and training for healthcare providers to provide health-promoting advice in this area and to equip them with the

knowledge and skills to recognise and appropriately treat vector-borne diseases. These actions should be built upon a strong foundation of a robust considered surveillance system and early warning systems (170).

### Precipitation

Ireland has experienced an increase in the average annual national rainfall of approximately 60mm during the time period 1981-2010 when compared with the time period 1961-1990, with the largest increases observed in the west of Ireland (12). Projected changes for Ireland include significant reductions in average levels of spring, summer and annual rainfall, whilst a notable increase in the frequency of heavy rainfall events for winter and autumn is also possible by mid-century (12).

### Drought

Water scarcity presents significant threats to public health, business and industry and agriculture (41,69,156). A reduction in precipitation can lead to altered waterborne disease patterns and water contamination which may result in increased incidence rates of gastroenteritis (20, 41). Further compounding the situation, hand hygiene may become compromised during water shortages leading to increased rates of gastroenteric and respiratory diseases due to a real or perceived lack of available water (70). The use of recycled water to irrigate crops during times of water shortages can contaminate foods and also increase the risk of foodborne outbreaks of illness (70). Furthermore, a lack of rainfall may impact negatively on crop yields leading to a loss of income for farmers, food shortages and increased food costs (70). Such weather-related events have been shown to impact negatively on mental health (70). Finally, drought-like conditions may lead to the contamination of surface waters or other waters used for recreational purposes (41,70). Individuals who use such waters are potentially at increased risk of contracting waterborne infections (41,70). Climate change against a backdrop of expected population growth may also put greater pressure on water availability and increase risk of drought (156). Children, the elderly population, individuals with weakened immune systems, individuals whose livelihoods are sensitive to extreme weather conditions and individuals with private wells may be particularly vulnerable to drought conditions (70,156,158).

Droughts can have significant impacts on health and wellbeing, as demonstrated by the impacts reported during a severe drought in the US in 2012 (157). Drought-related declarations were made by over half of the counties to facilitate emergency payments for farmers, crop yields were down and the cost of food rose (156,157). The European Drought Impact Report Inventory indicates that the most commonly cited impact category during droughts has been the agriculture and livestock category, followed by public water supply, energy and industry, wildfires, water quality, freshwater ecosystems and human health and public safety (159). In Ireland, past droughts have caused notable agricultural and water resource challenges (160).

In the context of the projected climate changes, drought preparedness and planning requires cross-sectoral communication and collaboration (70). Vulnerability assessments to drought should be undertaken to inform adaptation actions (70). The preparation of clear, consistent and timely messages to the public to raise awareness of the issue and the health protective measures to be taken should be communicated through a variety of media with special attention given to reaching vulnerable populations (70). Education and training for key stakeholders involved in disaster response and water-related issues (including those involved in water treatment and supply and healthcare professionals) should be provided and should focus on the public health implications of drought and ways to minimise the adverse outcomes (70). Drought and water conservation plans aim to increase the efficiency of water use and the resilience of supplies and are recommended by

the European Commission (161). Appropriate drought planning begins with understanding the nature and extent of the impacts of past events. However, few studies have been carried out to date in this area in Ireland (160).

### *Flooding*

The IPCC project an increase in the frequency of heavy precipitation events across Europe in the coming decades and it is considered very likely that the projected rise in sea levels will contribute to increases in extreme high water levels in coastal regions going forward (5). While sea levels have not been accurately measured in Ireland, UK data deemed to mirror the situation in the South of Ireland have shown a sea level rise of 1.7cm every decade since 1916 and Irish sea levels are expected to rise in all coastal areas by up to 0.8 metres by the year 2100 (12).

Flooding has affected 50 of the 53 countries in the WHO European Region over the past ten years (93). Population groups most vulnerable to the health effects of floods include the elderly, children, pregnant women, people with disabilities, tourists, members of ethnic minority groups and people who are homeless (93). The potential health effects of flooding can be divided into direct health effects (the immediate effects from flood waters such as drowning and injury) and indirect health effects (the consequences of flooding including impacts arising from damage to infrastructure) (71).

It is estimated that two-thirds of flood deaths worldwide are due to drowning with over 1,000 people in Europe estimated to have lost their lives secondary to flooding in the past decade (72,73). Observational studies indicate that the greatest contributors to flood-related deaths include drowning, myocardial infarctions, hypothermia and trauma, including road traumas (41). There is a lack of certainty regarding the long-term health effects of flooding (25,41). Flood-related injuries may occur due to direct contact with flood waters or during the clean-up phase following a flood (71,72). It is likely that such injuries are under-reported in the literature (25). The occurrence of death and prevalence of injury secondary to flooding in Ireland is unknown.

An increase in vectorborne diseases such as leptospirosis in the aftermath of heavy flooding has been observed in European countries in recent decades and this risk could potentially increase with a warmer climate (72). An association between symptoms of gastroenteritis and flooded households was observed in Lewes in the UK in 2001 (74). Disturbance of the sewage disposal and water treatment infrastructure was identified as a contributory factor to this issue (74). Further papers reporting on the occurrence of outbreaks of diarrhoeal illnesses following flooding in high income countries present conflicting findings (72). However, the Health Protection Agency in the UK concludes that outbreaks of infectious disease secondary to flooding are a rare occurrence (25). Of note, the integrity of private wells may become compromised due to flood damage and this could potentially lead to an increase in waterborne illness (77). In Ireland, it is estimated that approximately 720,000 people obtain their drinking water from a private supply and that there are in excess of 100,000 private boreholes, dug wells and springs in use (78,79). VTEC outbreaks have been consistently associated with private wells in Ireland (80-82). The storms that occurred during the winter of 2015/2016 resulted in a notable rise in the number of boil water notices issued due to *Cryptosporidium* contamination secondary to inadequate water treatment infrastructure (129). Research is underway to examine the links between flooding and the incidence of outbreaks of waterborne infectious diseases in Ireland (83). Ongoing efforts to raise public awareness of the need to site and maintain wells appropriately will be required going forward against the backdrop of an increased risk of flooding in Ireland (129,130).

There is a risk to human health from chemical contamination of water due to displacement of chemicals during a flood with overloaded sewers, storm water floods and landfill sites identified as

potential sources of chemical contamination (25). While it is likely that such sources of contamination would be diluted in flood water, Vardoulakis *et al.* suggest that improvements in environmental sampling following a flood event should be considered (25).

Carbon monoxide poisoning secondary to the indoor use of generators or other equipment to pump out waters or to dry the interior of houses in the aftermath of a flood is also recognised as a significant public health hazard (75,76). The health effects of exposure to carbon monoxide include mild symptoms such as fatigue, dizziness and headache to more severe symptoms such as cardiorespiratory failure and death (109). The silent nature of carbon monoxide poisoning, along with the nonspecific symptoms, often lead to under-diagnosis of the condition and poorer health outcomes (109). The evidence base highlights the role of effective risk communication in raising public awareness of the health risks of carbon monoxide before, during and after an extreme weather event (109,128). Iqbal *et al.* acknowledge the challenges in the systematic collection of data in relation to carbon monoxide poisoning and highlight the need for improved surveillance in this area in an effort to better understand the burden of carbon monoxide poisoning, to identify high-risk populations and to develop targeted risk communication messages (109). The identification of appropriate data sources, communication channels and data-sharing agreements as part of an extreme weather event response plan is recommended (109).

A further consideration is the effect of flooding on mental health: the impact of the loss of personal belongings, the potential loss of livelihood and displacement can impact negatively on both short- and long-term mental health (25,84). The available evidence regarding predisposing risk factors for mental distress following flooding is conflicting (85). Moreover, much of the available evidence is cross-sectional in nature with little long-term follow-up of subjects and no discussion of the impact of confounders on the findings (85). It appears that the social context in which flooding occurs may play a role in the experience of mental distress and recovery (84,86). Recovery in the aftermath of flooding depends on the extent of damage and the availability of individual and community resources to deal with the consequences (84). The “recovery gap” is the period of time after the emergency services have completed the acute phase of the response to flooding and when affected individuals are faced with having to complete the recovery process themselves (25,85). Difficulties with insurers, disruption to daily routines and loss of services can increase the risk of mental health difficulties in populations affected by flooding (85). The importance of embedding the provision of acute and long-term mental health care services into flooding response plans is highlighted within the literature (87).

Flooding can cause damage to healthcare infrastructure and limit access to healthcare services (88). Furthermore, loss of paper-based notes, a loss in electrical power and interrupted access to electronic records and laboratory systems have occurred secondary to flooding (25,89). An increase in Emergency Department (ED) presentations is also possible, as was seen during Hurricane Sandy flooding in the US (89,90). In situations where infrastructure is disrupted, patients who are routinely cared for in the community may require admission to hospital due to an inability to provide the service in the community or due to a disruption in the provision of the service aggravating a pre-existing medical condition (84). In Ireland, flooding at Letterkenny General Hospital in July 2014 caused significant disruption to the infrastructure and healthcare service provision to the region (91). While there were no injuries, the media reported that the hospital lost 40% of its capacity, elective surgeries and outpatient clinics were cancelled, and medical records were damaged (91). The identification of healthcare facilities that are in flood risk zones, in addition to mitigation and adaptation measures to avoid/reduce the impact of future weather-related disruptions is an

important requirement that should be addressed in emergency preparedness plans, healthcare facility risk registers and national and regional adaptation plans (16).

The WHO advocates a shift from a focus on the acute response to a disaster to a long-term risk management approach (93). Flooding is projected to remain a significant risk in Ireland until at least 2050 and there are evidence-based approaches that can be taken to manage the threat posed to public health and infrastructure including health impact assessments of structural measures taken to prevent flooding, adapting building regulations for areas prone to flooding and improving Ireland's flood forecasting capabilities and early warning systems (78,93). Land use is an important adaptation strategy in reducing flood risk (25). The Environment Agency in the UK has identified that between 10 to 14% of emergency service stations and 6 to 8% of hospitals, care homes and surgeries are at risk of river and coastal flooding (16). Risk mapping of health and social care facilities in relation to flood zones should be considered in Ireland to inform the allocation of resources for adaptation planning (41). The Irish guidelines on '*The planning system and flood risk management: guidelines for Local Authorities*' advise on the appropriate siting of buildings (95). Engineers Ireland, in their recent review of Ireland's infrastructure, recommend that measures such as the *National Planning Framework*, *Regional Spatial and Economic Strategies* and *Flood Plans* be implemented in order to achieve the objectives of the national guidelines (78). The Office of Public Works recognise the need to revise the flood risk management plan to account for the impacts of climate change in order to fulfil their statutory requirements in relation to national adaptation planning. Flood-proofing infrastructure and raising public awareness, particularly in areas at risk are also important considerations (84).

Due to the limitations of the available epidemiological studies examining the health impacts of flooding, the WHO has advised a standard reporting system be developed to report on the health effects attributable to each flood event in order to build evidence on the immediate-, medium- and long-term effects of such events on health (84). Measuring the health effects serves two purposes: to provide information on public health in the immediate aftermath of a flood to guide the provision of health and social care interventions; and to provide epidemiological evidence on the health impacts of flooding to inform future research directions and long-term mitigation and adaptation measures (96). Public Health England has developed a set of indicators to monitor the health effects of flooding (96). It is anticipated that having a pre-prepared set of indicators and an analysis plan will serve to enhance the ability to identify and respond to outbreaks of infectious disease or events of public health importance more swiftly (96). The use of a standardised set of indicators may also facilitate the evaluation of public health interventions (96). A longitudinal study of flooding and health has also been established in the UK to investigate the long-term health impacts of flooding on the population (97). In light of recent flooding in Ireland secondary to Storms Eleanor, Ophelia and Emma, consideration should be given to the development of a suite of indicators and appropriate data sources to support the early identification of, and intervention in, events of public health concern, to evaluate the effectiveness of interventions and to assess and address unmet need within the Irish population.

#### Wind speed and storms

The increasing risk of extreme weather events such as windstorms are of particular concern in Europe (111). The direct and indirect impacts of windstorms on morbidity and mortality have been demonstrated in Europe and further afield (102, 112,113). In Ireland, data on injuries and deaths attributable to windstorm events are not formally collated. However, information on mortality during extreme events is often available in media reports. For example, Hurricane Ophelia was implicated in the deaths of three people and caused significant disruption in road infrastructure and

public services and resulted in power outages in over 300,000 homes across the country (114). Disruptions in the provision of outpatient services, hospital procedures and discharges secondary to the hurricane were also reported (115).

The review of hospital presentations at two UK hospital EDs during a windstorm concluded that many of the injuries could have been prevented, particularly if elderly people had remained indoors during the peak of the storm (103). There is a dearth of peer-reviewed literature examining the health impacts of windstorms with much of the available information on how windstorms have affected the health of the Irish population presented by the media. The impact of such extreme weather events on human health could potentially be reduced by a better understanding of their past and projected patterns, which would facilitate appropriate emergency planning, the introduction of adaptation and mitigation measures and public education campaigns (102). An examination of patient attendances to Irish hospitals during and after windstorms could help inform on hospital and emergency service preparedness. Research to examine the direct and indirect impacts of high winds on human health in Ireland, and indeed to examine the level of awareness of healthcare professionals on the health impacts of windstorms, needs to be undertaken to identify unmet service and educational needs.

Adaptation measures should address behaviours that need to be adopted prior to, during, and after a windstorm (102,107). Early warning systems are essential in minimising the impact of severe weather events on human health (116,117). There is also evidence to suggest that vulnerable groups such as the elderly and those of lower socioeconomic status may be impacted disproportionately by windstorms and require particular consideration in the formation of communication campaigns (107). A standardised approach for sharing emergency information during an extreme weather event should be in place, particularly when information from a variety of sources is required (107,117). In Ireland, Met Éireann issues a weather warning to Local Authorities where wind gusts of 110 kilometres per hour or greater are expected with a structure in place for cascading this message to all appropriate stakeholders (118,162,163). People need to be kept informed of what to do in response to a windstorm including staying indoors, avoiding driving, inspecting personal properties for vulnerabilities to extreme weather events and taking measures to address them (104,112). Similarly, there is a lack of information about the vulnerabilities of state-owned critical infrastructure to climate change (8). A review of the Irish building stock, such as has been done in the UK, could inform on buildings at highest risk of damage (112). Such a review would inform on adaptation options to increase the climate resilience of vulnerable buildings (117). A review of neighbourhoods (e.g. caravan sites, older council housing stock) deemed at high risk of adverse effects from windstorms should also be considered to identify vulnerabilities and appropriate adaptation measures (107). Further risk communication during the recovery phase of a storm is also required to highlight risks of carbon monoxide poisoning from generators, unstable buildings or fallen trees or the increased risk of electrocution from damaged power lines (104).

#### Risks to health services

The projected increase in the frequency and severity of extreme weather events may place additional demands on the health service in two ways (16):

- A change in health service patterns
- Threats to the health service infrastructure.

It is possible that the health impacts of climate change will lead to an increase in demand for services (16). Health risks associated with climate change, such as injuries and outbreaks of infectious disease secondary to extreme weather events, are projected to increase in frequency and

severity leading to potential sudden and overwhelming levels of demand on health services (41). The ageing population is likely to further compound this risk (16,45). Aside from the potential change in the levels and patterns of service utilisation, it is possible that the healthcare system will need to adapt to changing health needs secondary to climate change such as changing infectious disease epidemiology (16,84,99,107,121). The aforementioned points have significant implications for workforce planning, capacity and education and training needs within the health sector.

As previously discussed, climate change projections present a significant threat to the critical infrastructure in Ireland (16,84,102). Desmond *et al.* point to a lack of data on the vulnerability of Ireland's state-owned critical infrastructure and call for attention to be given to this area (8). Media reports during the recent heatwave in Ireland suggest that healthcare facilities are not suitably equipped to deal with extreme weather events and this may impact negatively on the health of patients as such events become more frequent and severe (119,120). Data on the impact of extreme weather events such as flooding or extreme temperatures on Irish healthcare facilities is not collected in a systematic way. Further research on the impact of extreme weather events on the Irish healthcare service infrastructure in order to learn from experience is required to identify vulnerabilities and appropriate adaptation options going forward. Moreover, the use of climate-related health surveillance indicators may support swift and focussed public health action to minimise the adverse health effects of an event within the population, in addition to aiding health service planning (137,138).

Further potential challenges presented by a disruption in critical infrastructure include difficulties in transporting staff into work in the aftermath of an extreme weather event (e.g. flooding), disruption of the operation of emergency services, supply disruption and challenges in the safe storage of medications and other necessary supplies and the impact of an extreme event such as flooding on a healthcare facility leading to the need to evacuate patients, diverting emergency response vehicles and the need to rapidly recover vital hospital infrastructure following an event to restore continuity of essential services for patients (16,121).

The HSE and other public sector bodies with health-related responsibilities already plan their responses to extreme weather events such as flooding, under business continuity and emergency planning which incorporates and establishes resilience and emergency preparedness (15).

At the national level, the Government Task Force on Emergency Planning supports a co-ordinated approach across the whole of Government through the Office of Emergency Planning (122). In the inter-agency field, the HSE co-operates with An Garda Síochána and the Local Authorities in:

- Annual local and regional risk assessments (including the risk of flooding) in accordance with the major emergency management (MEM) guidance document on risk assessment (123); and
- Planning for, and responding to, severe weather events in accordance with the MEM guidance document on severe weather emergencies (124).

Within the HSE, a National Emergency Office has been established which takes an inter-agency approach to ensuring that emergency plans are developed, updated and tested on a regular basis, whilst also advising on contingency and business continuity planning, to enhance the preparedness of the health services in the event of an emergency (125). A template for drafting a major emergency hospital plan will continue to be rolled out nationally during 2018 with support from the National Emergency Office (125). This office has also developed a guide on severe weather planning specifically for the HSE (126). Moreover, all health services within the HSE are required to develop

and maintain a risk register specific to their individual service which should include all formally assessed risks, robustness of measures in place to protect against these risks and any additional measures required to address these risks (127). There is potential to extend these arrangements to take account of incidents likely to be driven by climate change (17). Based on past weather events, risk assessment of the increased likelihood of flooding will form an important part of such an approach. Projected climate changes need to be taken into account during the planning phase of new healthcare facilities and in the review or redevelopment of existing health facilities to identify appropriate adaptation measures that need to be implemented (17). Consideration also needs to be given to the location of current and future healthcare facilities, so as to ensure that existing facilities in locations subject to flooding are protected and future facilities will not be located where they may be vulnerable to river or coastal flooding.

### Conclusion

Climate is inextricably linked to human health and addressing the health impacts of climate change represents a formidable challenge to the health sector in Ireland. Climate-related illnesses are likely to place an added burden on the healthcare system, against a backdrop of rising prevalence rates of chronic diseases within an ageing population. Using climate-related projections, it is now important to consider how the health of the Irish population, healthcare service utilisation patterns and the provision of a consistent, safe and high-quality health service might be affected in the coming decades, with a particular focus on identifying and addressing the needs of vulnerable populations and regions. While it is difficult to accurately forecast the occurrence of extreme weather events in the medium- to long-term, recent weather events indicate that flooding and storms represent ongoing and likely threats to the health sector and such events should be prioritised in terms of adaptation planning for the period 2019 – 2024 (1,17).

Many of the adverse health impacts of climate change can be addressed through the implementation of mitigation and adaptation measures. It is clear that Ireland lacks reliable data pertaining to the impact of extreme weather events on population health and critical infrastructure. The systematic collection of such data, its analysis, interpretation and the dissemination of findings is necessary to learn from past experience and to use this knowledge to inform the planning of appropriate climate change adaptation actions. The threats posed by climate change to the health sector are inherently linked to the threats posed in other sectors (e.g. transport, energy, agriculture) (129). Cross-sectoral communication and collaboration are therefore essential when it comes to adaptation planning (131-133). This includes actions to strengthen the mechanisms for early warning and action across agencies whilst also ensuring that population health is firmly on the agenda in all sectors through the use of evidence-based tools such as health impact assessment when developing and implementing adaptation actions (131-133). Finally, long-term planning to prevent and prepare for environmental crises is essential (41). This approach should focus on addressing the wider determinants of health that contribute to vulnerability (41).

Health sector adaptation will require investment in personnel, infrastructure and inter-agency partnerships, with such investment required in the face of uncertainty regarding the nature and severity of climate change and its impact on health (128). However, it is clear that mitigation measures alone will not be sufficient in protecting public health from the effects of climate change. Building on existing policies, strategies, health services and emergency response systems, with strategic allocation of resources and the introduction of adaptation measures in a prioritised, evidence-based manner is recommended.



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