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Public Health

journal homepage: www.elsevier.com/puhe

Review Paper

The health impacts of windstorms: a systematic literature review

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ARTICLE INFO

Article history:
Received 20 February 2013
Received in revised form
26 September 2013
Accepted 30 September 2013
Available online 15 November 2013

Keywords:
Windstorms
Health impacts
Morbidity
Mortality
Systematic literature review

ABSTRACT

Introduction: This systematic literature review aims to identify documented impacts that windstorms have on human health. Windstorms occur frequently and some researchers have predicted an increase in severe gales in the future, resulting in an urgent need to understand the related patterns of morbidity and mortality.
Study design: Systematic literature review.
Methods: A systematic literature review of international evidence on the impacts of windstorms on human health was conducted in May 2012.
Results: This review of published evidence demonstrates that human health can be severely affected by windstorms. Direct effects occur during the impact phase of a storm, causing death and injury due to the force of the wind. Becoming airborne, being struck by flying debris or falling trees and road traffic accidents are the main dangers. Indirect effects, occurring during the pre- and post-impact phases of the storm, include falls, lacerations and puncture wounds, and occur when preparing for, or cleaning up after a storm. Power outages are a key issue and can lead to electrocution, fires and burns and carbon monoxide poisoning from gasoline powered electrical generators. Additionally, worsening of chronic illnesses due to lack of access to medical care or medication can occur. Other health impacts include infections and insect bites.
Conclusion: Public health advice can reduce morbidity and mortality from windstorms. Findings from this review will provide material for increased awareness and education amongst the public and healthcare professionals to prevent and prepare for these health impacts. Nevertheless, more research is needed to identify more specific patterns of health impacts and how these could be reduced in the future.

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http://dx.doi.org/10.1016/j.puhe.2013.09.022

Introduction

Windstorms, in the forms of cyclones (including tropical, sub-tropical extra-tropical storms and polar lows), local windstorms (such as tornadoes), and downslope windstorms, occur worldwide, and events such as Hurricane Katrina and Hurricane Sandy have emphasized the high impact these events can have on public health.[1–3] Hurricanes, tropical storms and tropical cyclones occur infrequently in Europe. However, Europe is not immune from natural disasters of this sort, given that wind speeds in extra-tropical cyclones can reach 'hurricane force' according to the Beaufort wind scale. Although both the Special Report on Managing Risks of Extreme Events and Disasters to Advance Climate Change Adaptations[4] and the Climate Change Risk Assessment for the UK[5] are inconclusive with regards to the trend in frequency and intensity of windstorms in the UK, these events exist and have significant health impacts. According to the Department of Health,[6] 'floods and windstorms are a regular occurrence in the UK'. Baker and Lee[7] considered that over the last 18 years, windstorms had a greater impact in the UK than flooding.

The health impacts of windstorms have been discussed extensively with reference to developing countries[4] and the USA.[8–13] These impacts are generally separated into direct and indirect health impacts, thereby referring to the primary effect of the impact of the storm, causing injury and death, and the secondary effects of the impact, through the breakdown of infrastructure.[9,14] These health impacts can be severe,[15] and their effects on human health could be significantly reduced by a better understanding of their patterns, which would allow appropriate preparation, emergency planning and public education.[16] This paper is a response to the severe lack of peer-reviewed data in relation to events in the UK, where the majority of information is presented by the media,[17] rather than evidence-based research.

Definition of windstorm

An issue when researching the health impacts of windstorms is the lack of a consensus or consistent use of the definition of a windstorm. In this paper the following definitions are used:[18]

- *Wind*: motion of the air, described by the average motion over 10 minutes, in metres per second, miles per hour, kilometres per hour, knots (kn: nautical miles per hour) or Beaufort Force. Gale force is a wind speed of more than 34 kn (63 km/h). Storm force is a wind speed of more than 56 kn (103 km/h) (Box 1).
- *Storm*: a disturbed state of the atmosphere of sufficient intensity to present a hazard – always involves wind, but may also involve other weather phenomena.
- *Windstorm*: a storm in which the primary hazard comes from the wind speed. Three main categories may be identified: cyclones (including tropical and extra-tropical storms and polar lows), local windstorms (such as tornadoes) and downslope windstorms.

Box 1 Wind speed conversions.

Wind speed (ws) mph (miles per hour)	(ws) km/h (kilometres per hour)	(ws) m/s (metres per second)	(ws) knots
1	1.609	0.447	0.869
0.621	**1**	0.278	0.540
2.240	3.6	**1**	1.944
1.151	1.852	0.514	**1**

Wind and wind speed

Looking specifically at the correlation between wind and health impacts, it is useful to consider the scales used to classify windstorm events. They demonstrate the link between wind speeds and the effects on the environments (see Appendix 1–3) which in turn can have direct and indirect effects on human health. The impact of the wind force on building structures, for instance, will affect whether a person needs to leave their home.

Separating windstorm variables

In most windstorms the hazard does not come exclusively from the wind: much of the data in the literature incorporates the effects on humans caused by storm surges and subsequent flooding. The impacts would be more easily measured if the wind variable occurred in isolation during a windstorm, but this is unfortunately rarely the case. Two hurricane events, however, Ike (2008) and Andrew (1992) have frequently been singled out as predominantly 'dry' hurricanes. Thus, the conclusions drawn from these events are particularly pertinent to this paper.

Aim

This paper aims to identify and review current evidence of the impacts of windstorms on human health to support planning, preparation and education of the public and health professionals so as to reduce the adverse impact on health.

Objectives

The objectives of this paper are to

- identify and present evidence of the impacts of high winds on human health;
- provide evidence for reducing these impacts and making recommendations for planners and healthcare professionals; and
- document key themes and areas requiring further work.

Methods

A search strategy was developed to identify published literature relevant to the potential health impacts of windstorms.

The following databases were searched: Medline (OvidSP), EmBase (OvidSP) and the Cochrane library, using terms for windstorms and health impacts in the title (keywords and abstract search also used for Cochrane). Medical Subject Headings (MeSH) were used in the Medline database. Searches were also carried out for grey literature, on Google Scholar, CDC, WHO, World Meteorological Organisation, UK Met. Office, IPCC and EM-DAT.[22] References from key papers were also searched. Searches started from 1946 to 1980 for Medline and EmBase respectively and included searches up to May 2012 (Box 2).

Box 2 lists the search terms used:

Inclusion criteria for papers summarized in Appendix 7

1. Published papers on windstorms (included: hurricanes, tornadoes, cyclones and 'severe storms') and health in a developed country, which include, in line with the Organisation for Economic Co-operation and Development glossary: Japan, Canada, USA, Australia, New Zealand and Europe;[23] and
2. Papers in either English or German language.

Exclusion criteria

1. Papers in languages other than English or German;
2. Search results including letters, editorials, notes, news or erratum;
3. Articles on dust, ice, snow or electrical storms;
4. Events in developing countries, as they differ significantly in factors such as climate, culture, infrastructure and health system compared with developed countries;
5. Articles that focus on evacuees;
6. Articles that focus on response;
7. Articles that focus on disaster planning;
8. Articles that focus on floods and their health impacts; and
9. Articles on lab based research or wind tunnel experiments.

Box 2 Search terms.

Wind*	Public*
Storm*	Health*
Gale*	Injury
Gust*	Accident*
Downburst*	Death*
Tornado*	Morbidity
Cyclon*	Mortality
Hurrican*	Vulnerabl*
	Burden*
	Epidemiol*
	Risk*

wind* OR storm* OR gale* OR gust* OR downburst* OR tornado* OR cyclon* OR hurrican*
AND
public* OR health* OR injury OR accident* OR death* OR morbidity OR mortality OR vulnerabl* OR burden* OR epidemiol* OR risk*

The search found 2272 results (Medline 1026; EmBase 1246, Cochrane 0), of which 720 were identified as relevant based on their title. 124 papers were shortlisted based on review of their abstracts and 41 articles were read based on article review. 11 papers identified using Google Scholar adhered to the inclusion criteria and were read. Reference lists of key papers were individually analysed and seven relevant papers used, and experts at the HPA (now PHE) provided 10 references. A total of 69 papers were included in this review; see Appendix 4. Local authorities in the UK have reported extreme weather events, including windstorms, in Local Climate Impacts Profiles,[24] often by reviewing mainly grey literature and newspapers. Many of these LCLIPs can be accessed at a dedicated UKCIP web site.[24]

Results

The health effects of high-velocity windstorms range from direct impacts of the wind, including trauma, injury and drowning, to secondary, or indirect effects, including reduced access to healthcare or medicines (and thereby influencing chronic disease), as well as dangers associated with carbon monoxide exposure, electrical risks, psychological impacts and even infection. The health impacts are multifold and Appendix 5 summarizes the evidence providing the article, event, description of the paper, maximum wind speeds, as well as the mortality and morbidity for each.

Table 1 provides a compilation of significant windstorms that occurred in Europe, summarizing where available, their impacts on human health.

Wind hazard

Several references that relate specific wind speeds (Box 1) to outcomes of a windstorm were identified. Glass et al.,[19] for instance, argue that tiedowns anchoring trailers to the ground are only effective when wind speeds do not exceed 50 mph. Baker and Reynolds[20] reported impacts caused by higher wind speeds, where individual cases (all taken from local newspapers and eye-witness reports) with 40 m/s winds in Essex caused several cars and 20 lorries to be blown over and an aircraft to be blown onto a railway line. Additionally at 45 m/s, winds in Devon caused iron sheeting from a roof to be flung off and resulted in several road closures. Cugnoni et al.[21] found that wind gusts exceeding 60 knots were associated with an increased risk of injury. Interestingly, they argue that it is not the mean wind speed, but the speed of gusts of wind which is important in causing structural damage. This is in line with the findings provided by Baker and Lee.[7]

Both the Fujita Tornado Scale (see Appendix 1) and the Saffir—Simpson scale of Hurricane intensity (see Appendix 2) correlate specific wind speeds to expected damage. However, these scales analyse the impact of the force of the wind on infrastructure. Baker and Lee[7] provide a correlation between wind speeds and the direct risks to persons (see Appendix 3).

A significant shift in the cause of death during windstorms has occurred as a result of the improvements in forecasting and warnings,[33,10] resulting in the majority being caused by high-velocity winds, rather than drowning.

Table 1 – Examples of major windstorms in Europe.

Date, location	Details
The Great Storm of 1703, England	'On November 26, 1703, the most severe storm ever recorded in the British Isles struck southern England and the English Channel. Raging until December 2, it wrecked many ships, caused about 8000 fatalities, and felled 4000 oak trees in the New Forest alone. […] it was the only true hurricane ever to have made it all the way across the Atlantic Ocean at full strength. Barometric readings as low as 28 $^3/_4$ inches of mercury (973 hPa) were recorded. […] buildings, haystacks and even people were whisked into the air by roaring winds, estimated to have exceeded 120 miles per hour (190 km/h)'.[25]
Windstorm in Ireland, 16th September 1961, Ireland	'South and south-westerly gale force winds swept over Ireland for […] 10 hour, with recorded gusts of over 100 mph. […] In its aftermath, the gale left electricity and telephone services disrupted, roads blocked by fallen trees, buildings destroyed and forests and crops damaged. The storm was responsible for fifteen deaths and many injuries in Ireland'.[26]
Fastnet Race Gales, 13–14 August 1979, England	Wind speeds were measured up to 72 knots. 23 boats were abandoned and five of these lost. 15 deaths were reported. 'A total of 173 people were taken aboard other boats or rescued by helicopter.'[27]
Severe Gales, 1 February, 1983, Great Britain.	Maximum wind speed: 96 mph. Three deaths and 116 casualties[28]
The Great Storm of October 1987 Southeast England	'Some 15 million trees uprooted […] ships were driven ashore, buildings were destroyed, and 16 people killed. […] it started with an intense depression (28 1/3 inches, or 960 hPa) that developed so rapidly that it was almost impossible to predict the track and ferocity of the storm. […] The strongest winds occurred in the early hours of the morning, when few people were about, so the death toll was comparatively low'.[25]
Storms, January and February 1990 10 days when wind gusts of over 45 knots were recorded in London	Wind gusts >45 knots. 49 fatalities. 58 patients sustained 70 injuries, eight required hospital admission.[21]
The Burns' Day Storm of 25–26 January, 1990, Europe	'[…] it had one of the deepest depressions to affect the UK, falling to 28 inches (949 hPa) in pressure. Gusts of up to 108 miles per hour (174 km/h) were recorded. Altogether, 97 people died throughout northern Europe, including 47 in the United Kingdom, 19 in The Netherlands, 10 each in France and Belgium, and seven in Germany'.[25]
Birmingham Tornado, 28 July 2005, England	Maximum wind speed: 42–58 m/s. 20 Injured (three seriously). 420 damaged properties.[7]
Extra-tropical storm Kyrill, 17–20 January, 2007, Europe	Kyrill affected Britain, the Netherlands, Germany and Poland, and was reported to have caused 49 deaths.[29]
Tropical storm Grace 4–6 September 2009, Ireland, UK, Belgium	Records indicate that no other cyclone has become a tropical storm as far northeast over the Atlantic Ocean as did Grace. The storm accelerated eastward then northeastward over the northeastern Atlantic Ocean, and it reached its estimated peak intensity of 55 knots (65 m/h, 100 km/h; almost hurricane strength) around 0000 UTC 5th October, before weakening near Ireland/South-western UK.[30]
Remains of Hurricane Katia, Sep 2011 (and several other ex-hurricanes during last few years)	After becoming an extra-tropical system, it moved east-northeast towards the United Kingdom, and made landfall there with winds near 70 mph (110 km/h). It merged with a larger extra-tropical system at 0000 UTC on 13th September in the North Sea. At least one fatality in Ireland, a hospice ambulance driver, and his passenger was badly injured on the A688 in County Durham.[31,32]

Health impacts

A detailed description of the direct and indirect health impacts is provided below.

Direct impacts

Two papers were identified that analysed the health impacts of windstorms in the UK. Illingworth and Illingworth[28] reviewed Accident and Emergency (A&E) logs in two hospitals on the day of the gales in 1983 in Leeds, which reached up to 96 mph. There were three deaths, two of which were due to head injuries and one due to multiple fractures, including a crushed chest. They reported 116 casualties, the majority of which had fractures, lacerations, abrasions or contusions. They also reported five head injuries, one fractured skull, three shoulder dislocations, nine sprains and four eye injuries. Most casualties had more than one injury and all injuries and deaths were caused by the force of the wind either blowing people over, injuring them when parts of buildings collapsed, causing road traffic accidents or injuries from falling trees or flying debris hitting them. Cugnoni and Whitworth[21] conducted a retrospective study of injuries caused by high speed winds in the UK in 1990. They reported 49 fatalities and 58 casualties, eight of which required admission to hospital.

Most patients had several injuries, the majority of which were head injuries, fractures and foreign bodies in the eye. Additional injuries included lacerations, soft tissue injuries and abrasions. Again, these injuries and deaths were due to the impacts of the wind, caused by flying debris or masonry, or people physically being blown over by the wind.

The classification of direct impacts of storms is apparent throughout the literature.[9,10,34,35] However, there is no uniform consensus for a definition for a direct impact. In this paper, the classification of a 'direct' impact is as follows: direct health effects are immediately caused by the physical force of the windstorm. It is understood that the wind force of a windstorm influences human health during the impact phase of the storm. In this way, the classification of a direct impact is essentially linked to the temporal order of events of the storm. Windstorms (cyclones) cause injury and mortality due to strong winds and heavy rains, which can cause structural collapse and wind-strewn debris.[15] Additionally, these heavy rains have been associated with drowning during the impact phase.[38]

Falling trees

Falling trees are often implicated in causing direct deaths, by head injury, asphyxiation (after being trapped under a tree) or immediately by their physical impact.[35–39,12] Trees have been identified as a major source of danger to human health during windstorms. Schmidlin[40] for instance, showed that wind related tree failures were a significant cause of deaths in the US between 1995 and 2007.They identified risk factors for wind related fatalities, demonstrating that 35% of deaths from wind-related tree failures were due to non-convective high winds, 14% due to tropical cyclones and 7% due to tornadoes. They also found that at wind speeds of 70–90 mph, the risk of death from wind-related tree failure increases. Moreover, they highlight that this is 'a lower threshold than associated with risk of death from high winds due to destruction of houses or vehicles' (p.21). Furthermore, Schmidlin[8] argues that 'fallen trees are known to be the primary cause of inland wind-related deaths during tropical cyclones and account for a substantial percentage of deaths across all types of wind storms' (p. 241).

Flying debris

Deaths and morbidity occur due to debris flying at speed causing penetrating or blunt trauma.[41,42] Injuries, rather than mortality, were consistently higher throughout the literature. Millie et al.[43] identified a pattern of injury amongst tornado victims, where non-fatal injury was most commonly caused by fractures, while the most common fatal injury was cerebral cranial trauma. In addition, they found that people who were physically thrown had more severe injuries than those struck by airborne debris. Illingworth & Illingworth[28] also demonstrate the importance of the force of the wind on human health. In their review of hospital attendances during the 1983 storms in Leeds, they found that the majority of accidents occurred when people were blown over whilst walking outside. Flying debris is again identified as a considerable cause of injury.[28,21,44]

Road accidents

Edwards,[45] states that 'the weather influences the frequency of road accidents by affecting not only the volume of traffic, and therefore the number of road users exposed to risk, but also the risk per unit travel' (p.59). Moreover, she argues that high-sided vehicles are particularly susceptible to strong cross-winds, and smaller vehicles are at risk of deviating off-course when exposed to gusts.[46] Overturning accidents are the most common type of wind-induced accident.[45,20] Trees and fallen debris can be blown onto a vehicle, thereby directly causing death or injury.[45] Unfortunately, Edwards' data was collected using the coding for traffic incidents provided by the Department of Transport, which did not isolate wind as a separate factor. Therefore these results must be interpreted with caution. Relating risk specifically to wind speed, Baker and Reynolds[20] found that 90% of accidents occurred when the maximum gust wind speed was above 20 m/s. They therefore recommend traffic movement should be restricted when wind gust speeds are greater than 17–20 m/s. Flying debris can also pose a risk by obscuring the view of the driver.[28]

Buildings

The risk of injury frequently depends on the location of a person during the windstorm. Living in mobile homes was identified as a considerable risk factor for death or severe injury due to movement or overturning of the structure.[47,48] The collapse of all or parts of buildings was also a significant risk factor causing death and injury.[28,47,10]

Demography of impacts

Injury and death was shown to occur mostly amongst males in the majority of papers.[49–51,43,39] Although death was commonly reported amongst children and the elderly,[50,51,1] the median age was often shown to be between 40 and 50 years.[35,40]

Psychiatric impacts

There is little evidence-based data on the psychiatric impacts of windstorms. Some research has been carried out, looking at the impact of a tornado on the mental health consequences of casualties.[52] Penick et al.[52] found that 13% of their interviewees reported their children were getting on better, 25% that their children were getting on less well, and that 62% with two or more children reported the tornado had no effect on the children's interaction. Interestingly, 73% reported experiencing emotional changes in themselves. The psychiatric impacts of windstorms have also been identified by David,[53] who analysed the psychiatric impact of Hurricane Andrew (1992), which was deemed to be one of the driest hurricanes throughout the literature [50,40]. 'Severe damage', which was defined as destruction of major structures in homes, the need to relocate temporarily or permanently, and/or homes needing extensive repairs, were the risk factors most strongly associated with an increase in mental health problems. In particular, David[53] found that 51% of subjects met the criteria for a new-onset psychiatric disorder following the hurricane, predominantly Post-Traumatic Stress Disorder (36%). Reports have demonstrated incidents of suicide and homicide related to a hurricane[54,37,1] and one particular report of a large number of deaths due to dyadic deaths (homicide-suicide).[42] More extensive research has been carried out assessing the mental health impacts of flooding,[55] however when looking at windstorms, it is difficult to separate the effects of flooding, and subsequent displacement, from the impacts of the wind force on mental health.

Indirect impacts

Again, there is no uniform consensus on a definition of indirect impacts. In this paper they are defined as health impacts that were caused by the windstorm event, but did not occur during the active exposure to the wind force. Thus, indirect impacts occur predominantly in the pre-impact or post-impact phase of a storm.

Pre-impact health effects

Pre-impact injuries or deaths usually occur as a result of preparations for the storm.[50,48,10] Blunt trauma[50,10] falls, muscle strains, lacerations and stress-induced cardiac incidents[48] were reported to occur during storm preparation. These preparations included installing plywood and metal shutters to secure buildings, and reduce the risk of injury from potential projectiles.[10] Electrocutions have also been reported[56] in conjunction with pre-impact preparations. Several cases occurred when individuals were removing television antennae before a storm. Death and injury is also increased during the pre-impact phase amongst those evacuated or moved to shelters. This is especially the case in vulnerable groups, such as the elderly.[10]

Post-impact health effects

The post-impact phase can result in injury and even death, whilst cleaning up for instance.[33,10,57] Falls, lacerations puncture wounds and chain saw injuries are particularly frequent.[10] Additionally, some reports demonstrate an increase in infectious diseases, mostly in the form of self limiting gastrointestinal or respiratory illnesses.[10] Bayleyegn et al.[58] equally found an increase in acute illnesses as a result of inadequate food storage or poor environmental hygiene. This in turn had been caused by a power outage.

The inability to access medical care or medication is a significant cause of post-impact morbidity and mortality. The 2005 CDC Report[2] on the impacts of hurricanes on Florida in 2004 showed that chronic conditions were worsened due to prevention or delay in obtaining medication. Similarly, Rath et al.[59] reported that children with pre-existing medical conditions had increased experiences of asthma, shortness of breath, difficulty breathing, headache and blurred vision. Barriers to accessing essential medical equipment such as oxygen or dialysis were also found to be a cause of post-impact adverse health effects.[2,40] These barriers included physical obstacles such as fallen trees or debris, as well as the loss of power due to the storms.

Power outages

One of the most significant impacts of windstorms on infrastructure is the loss of electricity.[57,14,54,35,8] Power outages result in the use of alternative energy sources, such as generators and candles. Moreover, individuals reliant on electricity for medical reasons, such as oxygen for respiratory disease and refrigerators for insulin-dependent diabetes are negatively affected.[40] Hospitals become dependent on generators to remain operational.[40] Below, the consequences of power outages are described further. Impacts include:

Electrocution

Windstorms pose a significant risk of death and morbidity by electrocution. Death by electrocution is mostly seen in the pre- and post-impact phase of the storm and is increased amongst electricians in particular.[56,10,50]

Fires/Burns

When power outages occur, candles are often used as an alternative source of light. This has been shown to result in an increase in burns and death due to house fires.[35,50]

Carbon monoxide poisoning

Hampson et al.[34] provide a review of carbon monoxide (CO) poisonings secondary to power outages caused by storms. They present a clear association between increased mortality and morbidity due to CO following windstorms. Houck et al.[60] further analysed the cause of CO poisonings, and found that charcoal briquettes and gasoline powered electrical generators were the principle sources of CO. Similarly, Baker and Lee[7] describe CO poisonings due to the use of portable generators in enclosed and poorly ventilated spaces. Moreover, the risk is further increased when the storm occurs in the cold winter months, thereby increasing the need for generators.[7,60]

Infections

Reduced levels of hygiene and sanitation, due in part to the lack of electricity and water, can result in higher rates of infections.[15,10]

Ivy[61] demonstrated that tornado victims had a high proportion of infections, and that these were predominantly caused by Gram negative bacilli. These infections occurred in the wounds of the victims, and were attributed to the confluence of the high force wind speed causing injury and the rain driving mud into the wounds caused by the tornado in the first place.

Insect bites

Increased morbidity can be caused by insect bites. Malilay[15] argues that these increases were due to downed trees destroying insect nests; Brewer et al.[62] and Schultz[10] found that 21% of patients suffered insect bites during Hurricane Hugo (1992).

Sea spray

There have been studies that investigated higher aerosol loadings during windier conditions, which could have potential health impacts. Eakins and Lally[63] found transfer of radioactive actinide-bearing sediments from the Irish Sea by spray to land. During algae blooms, respiratory irritation (coughing, sneezing, and tearing) can be experienced by people living near the shore, when the organism (e.g. Karenia brevis, causing '*red tide*' events) is present along a coast and winds blow the toxic aerosol onshore.[64] Kirkpatrick et al.[65] noted in their extensive literature review that the correlation between wind speed and impact zone width along the coast is not known.

Discussion

This review aimed to assess the evidence base of the impacts of windstorms on human health. This is the only identified systematic review of the health impacts of windstorms, providing a compilation of data in one concise table. In addition, a deeper understanding of appropriate preparations and responses to windstorms, both by the general public and healthcare professionals, was sought.

Although the evidence regarding the frequency and intensity with which Europe will be exposed to windstorms in the future is inconclusive, the fact that they are occurring remains. Moreover, this review has been able to provide data demonstrating that their impacts on human health are significant.

Several central issues for discussion have been identified. Since the data has been collected in relation to windstorm events that occurred outside Europe, predominantly in the USA, it is unclear how applicable these data are to Europe including the UK. Although the UK experiences 'hurricane force' winds, the phenomenon of a hurricane is still relatively specific to the USA. In addition, although UK and US populations are fundamentally comparable given that they are both classified as developed nations, there are differences in environment and infrastructures, including the healthcare system. Of real note, however, is that only two peer reviewed reports on the health impacts of windstorms in the UK have been identified.

A further complexity encountered was the lack of a uniform definition of a 'windstorm'. Frequently, terms were used interchangeably and there was a lack of a concrete classification. As previously mentioned, it was difficult to disentangle the effects of the wind factor in a windstorm on human health, from the accompanying factors of rain and subsequent flooding. When looking at the data, there is a lack of uniformity in reporting morbidity and mortality in relation to windstorms, which makes comparisons difficult. Similarly, the units used for measuring wind speed are not uniform, again making comparisons more difficult.

The literature was rarely able to provide specific studies on the health impacts of windstorms, instead the majority relied on the impacts of wind in general, which then required extrapolation to infer their impacts on human health. Following on from this, only a minority of papers were recent, indicating a lack of current research or interest in this area. Although the classification of health impacts is frequently categorized into either direct or indirect, these terms are not discrete. In several cases, there is significant overlap, making it difficult to compartmentalize the health impacts of windstorms.

Nevertheless, several coherent findings can be extracted from the literature. The majority of deaths were consistently caused by indirect factors. Conversely, most injuries were caused by the direct impact of the windstorm causing morbidity by trees falling or flying debris. Vulnerable populations were predominantly identified as either young or elderly. Additionally, males were more often affected than females.

This literature review demonstrated that deaths and injury are preventable and that this is largely achievable through improved public education regarding the risks posed by windstorms.

Below the authors summarize the following:

- Evidence based public health recommendations;
- Summary of health impacts from windstorms for members of the public; and
- Summary of health impacts from windstorms for healthcare management.

Evidence based public health recommendations

The key messages from this review address behaviour that should be adopted before, during and after the impact of a windstorm. Although perhaps basic, an important aspect of public education is to provide early warning, available and accessible to all. Using the UK as an example, the two most important sources are the Met Office[66] and Public Health England.[67] Currently the Met Office[68] provides advice regarding the expected impacts during wind events (see Appendix 5), as well as advice on specific behaviours before, during and after 'severe gales'[69] (see Appendix 6). This advice refers to conditions when a Met Office warning of damaging winds has been issued, taking account of the differing vulnerability of different parts of the United Kingdom to high wind speeds. In terms of preparation, there is a large amount of advice on hurricane preparedness in the USA, where securing the home with shutters or protective window glass and stocking food and drink supplies is advocated.[10] In addition, the use of vehicles should be avoided in anticipation of a windstorm, as there is a significant risk to health if one is in a vehicle during the impact of the storm, as it is liable to overturn.

There is a general consensus that persons are most protected during the windstorm when they remain indoors, unless they inhabit mobile homes.[35,19,28,21,47] More specifically, it is recommended that people are safest when situated away from windows and in the basement of their houses. Additionally, driving in vehicles, and riding motorcycles or bicycles, as well as sailing is strongly discouraged. Protecting oneself with blankets and headgear is also advised to reduce traumatic injury due to flying debris.[19]

After the storm has passed, risks are posed by loose tree branches or partially uprooted trees, as well as unstable buildings or building material. Further injury may be sustained during clean-up efforts. The public also needs to be made aware of the risks of carbon monoxide poisoning, secondary to generator use indoors; fires, secondary to candle use; and the risk of electrocution while repairing electrical lines, when power outages occur.[50] Exposure to insects may result in increased numbers of insect stings.

Due to the disruption to transportation and healthcare provisions, chronic diseases may be exacerbated. In particular, the inability to access medications may worsen chronic illnesses.

A vital hurdle to overcome when providing advice to the public is which communication channel to use to reach the most number of people. This is further compounded by the fact that once the windstorm has hit, power outages render any television or radio broadcasts inaccessible. An interesting difficulty that was identified by both Schmidlin[40] and Ashley and Black[70] is the degree to which the public is receptive to storm weather warnings. Ashley and Black[70] argue that a tornado warning conveys a much greater sense of public urgency because it is a visibly tangible event (or people conjure up expectations, as opposed to 'high wind warning'). In contrast, other windstorms are viewed as ambiguous when they are not associated with clouds or precipitation[70]. Schmidlin[40] emphasize that 'severe weather safety recommendations should continue to emphasize seeking shelter in sturdy buildings when any type of high winds are expected' (p. 24). Similarly, Illingworth & Illingworth[28] argue that 'many people had underestimated the strength of the wind' (p.60).

Combs et al.[50] and Houck[60] identified populations that were unable to understand weather warnings or advice due to language barriers as particularly vulnerable. As a result they highlighted the need to provide multilingual information.

Summary of health impacts from windstorms for members of the public

To summarize, the following potential health impacts can be identified, in addition to those already available from the Met Office and summarized in Appendix 5:

Pre-impact

- Injuries, such as blunt trauma, falls and lacerations can occur when preparing housing for a windstorm.
- Electrocution is a risk when handling electrical equipment.
- Exacerbations of chronic illnesses, especially cardiovascular disease, can occur due to the stress of preparing for the storm.
- Death and injury secondary to chain saw use when pre-emptively cutting down trees can occur.

Impact

- Danger posed by flying debris and trees if exposed to the velocity of the wind during a storm.
- Danger posed by vehicles overturning when driving.
- Danger to people in mobile homes that are moved or blown over and from buildings wholly or partially destroyed.

Post-impact

- Danger posed during power outages when alternative energy sources are used. Fuel powered generators should never be operated in confined spaces given the risk of carbon monoxide poisoning: health professionals should consider carbon monoxide poisoning as a possible cause for patient illness upon presentation.
- The use of candles as alternative light sources during power outages can cause burns and fires. Their use should be avoided, and if used, should be monitored carefully.
- The risk of electrocution is posed by fallen power lines or during repair efforts.
- Injuries, in particular puncture wounds in the lower extremities, are common during the clean-up period after a storm. Individuals must be vigilant of possible risks, such as loose tree branches or building structures that may fall and injure.
- Wounds sustained from the storm may become infected.
- Increased exposure to insects may occur, which can result in greater numbers of insect stings sustained.

Summary of health impacts from windstorms for healthcare management

Although surveillance is not always available, trends in health impacts and hospital attendances have been presented in the literature. Looking at the pressure of patient load experienced by hospitals during and after windstorms, several key findings can be extracted. Peak hospital visits occurred in the days immediately following the storm.[62,71,72] This is in part considered to be because it is too dangerous to get to the hospital whilst the storm is occurring. Others, however, reported an increase both after and during a storm.[40] The overall increase in hospital visits due to windstorms highlights the need for hospital preparedness, and in particular the need for increased staffing.

Given the trends in morbidity and mortality, several areas within healthcare will be particularly burdened. The emergency services for instance, will have to be prepared to manage increased numbers of fractures, strains, sprains, lacerations, contusions or puncture wounds.[54] Patients reliant on electricity for medical supplies, such as oxygen for chronic respiratory disease,[36] insulin for Diabetes Mellitus[40] and dialysis for chronic kidney disease[2] will need to be cared for. This emphasizes the need for hospitals to have generators to be able to operate even during power outages. Houck[60] emphasizes the need for healthcare professionals to be able to recognize and consider carbon monoxide poisoning as a cause for their patient's presentation, when seen in association with a windstorm.

There are issues to be considered regarding the response of healthcare professionals to the healthcare needs that windstorms present. Gurd et al.[57] for instance, highlight the conflict of resource allocation when faced with a mass casualty situation. They describe the case of having to choose between treating the usually few severely injured with a poor prognosis, or giving priority to those with less urgent, but more treatable conditions. This is particularly the case for chain saw injuries, which, although only few, are extremely complex and time-consuming to manage.[71]

Areas for further work

There is a marked lack of published research on the health impacts of windstorms in the UK. Although research has been carried out more internationally, this literature review has identified further areas to be analysed.

Initial studies looking at specific wind speeds and their impacts on human health have provided useful data on planning for windstorms, as well as advice to be provided to the public. Nevertheless, differences in environmental factors, such as urban building, need to be taken into account. Moreover, further data on the impacts of warning about windstorms and their associated risks is required for improved communication with the public to increase their resilience to these events and to reduce human health impacts.

Additional research is also needed with regards to awareness of the health impacts amongst healthcare professionals. Again, emergency planning and response to windstorm casualties could be improved. Following on from this, improved surveillance of injury patterns due to windstorms is required in the UK. In particular, a uniform approach, in the form of national coding for instance, is needed for stringent data collection, which would allow comparisons between results to be made. Currently, reliance is placed on trends and assumptions. This paper calls for an active surveillance system and improvements in reporting to monitor the health impacts of windstorms in, for example, the UK and more widely if possible. This should improve awareness and knowledge amongst the public and healthcare professionals.

The authors also believe that evaluation of economic costing of windstorm related or induced health impacts are required. This, along with data on health impacts would provide robust evidence, which could be used to help to inform public health policy, which, ultimately, might improve patient care.

The meteorological literature contains research on the causes of local wind variability, while urban planning research has been undertaken into the impact of urban design on wind speeds. However, there are no papers known to the authors that systematically relate the health impacts of wind to its local or regional variability within a country. Recent advances in meteorological modelling mean that a synthetic dataset of high resolution wind can now be generated with some confidence for comparison with geographically referenced morbidity and mortality data. Such comparisons would be assisted if responders recorded the cause of an incident as wind when appropriate.

Limitations

The lack of peer-reviewed papers which explicitly link windstorms and health effects, limits the content of this paper. The authors also appreciate the difficulty of applying these results to different contexts.

Considerable strengths, on the other hand, are that advice could be sought from experts at the Met Office, as well as at PHE, which could recommend published and unpublished data. Given more time, further interviews would have been conducted to make even further use of these sources.

Conclusion

Windstorms have significant impacts on human health. These effects can be divided into direct and indirect impacts, which occur during the pre-impact, impact and post-impact phases of windstorms. Retrospective data collection and analysis of the referenced papers have provided patterns in mortality and morbidity, which can inform policy and decrease the magnitude of these impacts.

Public health advice can reduce morbidity and mortality from windstorms. Findings from this review provide material for increased awareness and education amongst the public and healthcare professionals to prevent and prepare for these health impacts.

Further studies within the UK are required to understand local patterns and impacts, thereby improving the evidence base, advancing public health policy and ultimately enhancing patient care and health. This paper calls for an active surveillance system and improvements to reporting to monitor the health impacts of windstorms in, for example, the UK and more widely if possible. This should improve awareness and knowledge amongst the public and healthcare professionals.

Author statements

Acknowledgements

Many thanks to Carla Stanke, Katie Carmichael, Sheila O'Malley and Kasia Markiewicz for their support during this project.

Ethical approval

None sought.

Funding

Dr. Anouchka Goldman was on an elective placement from St George's University of London with Extreme Events and Health Protection whilst undertaking the systematic literature review. The views expressed are those of the authors and not necessarily those of their funders or employers.

Competing interests

None declared.

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Appendix 1. Fujita tornado scale.

Category	Description	Wind speed (mph)	Example of damage
F-0	Gale	40–72	Broken tree limbs, small trees uprooted
F-1	Moderate	73–112	Roofs partially removed, mobile homes uprooted
F-2	Significant	113–157	Roof surfaces removed, mobile homes demolished
F-3	Severe	158–206	Roofs and walls removed, all trees uprooted
F-4	Devastating	507–260	Homes levelled, foundations removed
F-5	Incredible	261–318	Buildings destroyed, cars thrown >100 yards
Source: 43			

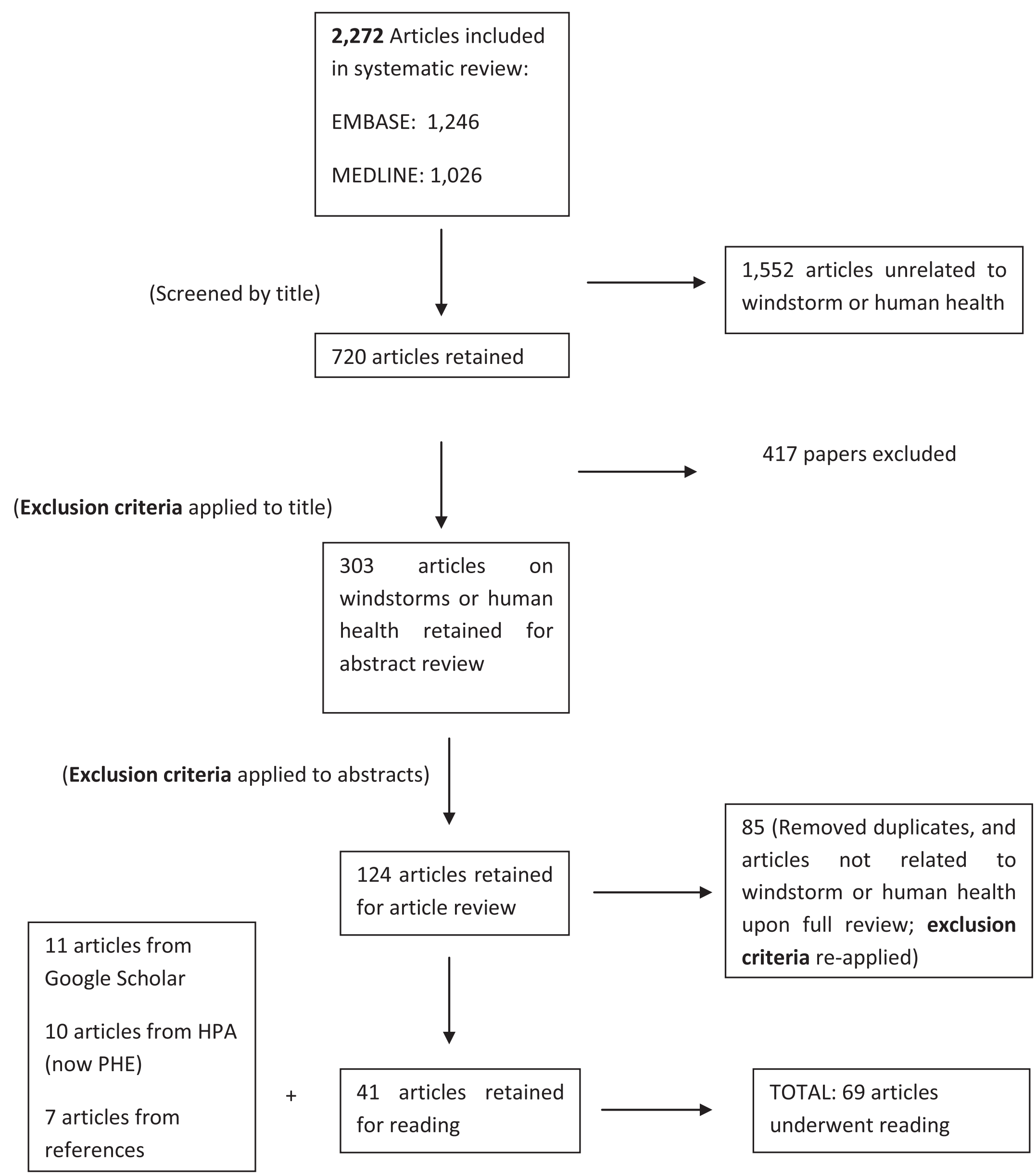
Appendix 2. Saffir–Simpson scale of hurricane intensity [excluding effects of flooding].

Category	Wind speed (ws) mph	(ws) kmh	(ws) knots	Storm surge (m above normal)	Expected damage
1	74–95	119–153	64–82	1.2–1.8	No real damage to building structures. Damage primarily to unanchored mobile homes, shrubbery, and trees.
2	96–110	154–177	83–95	1.9–2.7	Some roofing material, door and window damage to buildings. Considerable damage to vegetation, mobile homes and piers. Small craft in unprotected anchorages break moorings.
3	111–130	178–209	96–113	2.8–3.9	Some structural damage to small residences and utility buildings, with minor amount of curtain wall failures. Mobile homes are destroyed.
4	131–155	210–249	114–135	4.0–5.5	More extensive curtain wall failures, with some complete roof structure failures on small residences.
5	>155	>249	>135	>5.5	Complete roof failure on many residences and industrial buildings. Some complete building failures, with small utility building failures, with small utility buildings being blown over or away.
Source: 10					

Appendix 3. Wind gust speed taxonomy.

Wind gust speed		Possible effects
20 m/s	=39 knots	Elderly people could be blown over. Cyclists could be blown over. High-sided vehicles become unstable.
30 m/s	=58 knots	More serious incidents occur. ‘Threshold’ level; everyone should be warned to stay indoors.
45 m/s	=87 knots	Trees fall down. Building and structure damage.
Source: 7		

Appendix 4. Overview of the systematic literature review process for windstorms and health impacts.



Appendix 5. Met Office severe weather guidance – wind.

	Very low	Low	Medium	High
Impact and advice associated with WIND	Debris dislodged and some branches removed. Perhaps some very limited travel disruption. Difficulties on some prone routes e.g. cross winds on exposed or high level roads.	Some branches or trees brought down. Localized travel disruption. Localized problems for high-sided vehicles on prone routes. Drive with care, especially on exposed routes. **BE AWARE** of possible debris being blown around.	More widespread tree damage & other debris, slates etc dislodged from roofs. Some minor structural damage possible. Risk of injury from flying debris. **BE PREPARED** for some travel disruption e.g. closed bridges. Potential for some localized interruptions to power.	Widespread structural damage, e.g. roofs blown off, mobile homes overturned, power lines brought down. Risk to personal safety from flying debris. Potentially widespread and/or prolonged interruptions to power. Expect widespread transport disruption due to e.g. roads blocked by fallen trees.
Source: 68				

Appendix 6. Met Office storm weather advice.

Before the storm	During the storm	After the storm
Secure loose objects such as ladders, garden furniture or anything else that could be blown into windows and other glazing and break them. Close and securely fasten doors and windows, particularly those on the windward side of the house, and especially large doors such as those on garages. Park vehicles in a garage, if available; otherwise keep them clear of buildings, trees, walls and fences. Close and secure loft trapdoors with bolts, particularly if roof pitch is less than 30°. If the house is fitted with storm shutters over the windows then ensure that these are closed and fastened. If chimney stacks are tall and in poor condition, move beds away from areas directly below them.	Stay indoors as much as possible. If you do go out, try not to walk or shelter close to buildings and trees. Keep away from the sheltered side of boundary walls and fences – if these structures fail, they will collapse on this side. Do not go outside to repair damage while the storm is in progress. If possible, enter and leave your house through doors in the sheltered side, closing them behind you. Open internal doors only as needed, and close them behind you. Take care when driving on exposed routes such as bridges, or high open roads, delay your journey or find alternative routes if possible. Slow down and be aware of side winds, particular care should be taken if you are towing or are a high-sided vehicle. Do not drive unless your journey is really necessary.	Be careful not to touch any electrical/ telephone cables that have been blown down or are still hanging. Do not walk too close to walls, buildings and trees as they could have been weakened. Make sure that any vulnerable neighbours or relatives are safe and help them make arrangements for any repairs.
Source: 69		

Appendix 7. Articles included in windstorm literature review relating to mortality and morbidity.

Article	Event	Summary/design	Maximum wind speed	Mortality	Morbidity
Cruickshank, J.G. et al.[26]	Hurricane in Ireland, 16th Sept 1961, Ireland	Report	Gusts 100 mph	15 deaths	Not reported
Ivy, J.H. [61]	Tornado, 1965, Indiana, US	Routine survey by Hospital Infection Committee	Not reported	Six deaths: (2) head injury, (3) haemorrhagic shock, (1) infection	294 cases presented to hospital. (32%) admitted: (78) lacerations, (54) fractures (non-compound), (9) fractures (compound), (2) ruptured organs, (16) central nervous system injury, (6) amputations, (10) shock. Patients had multiple injuries (28) cases cultured organisms: (5.4%) Streptococcus, (15%) Staphylococcus, (65.6%) Enterobacteria, (1.7%) Gram positive bacillus, (9.7%) Clostridium perfringes, (4.3%) Yeast like fungus.
Gurd, C.H. et al.[57]	Cyclone Tracy, 1974 Darwin, Australia	Hospital inpatient data	150 mph	49 deaths (+16 missing at sea)	145 hospital admissions: (5) abdominal injuries, (1) penetrating chest wound with tension pneumothorax, (1) bilateral pedal amputation, (60) 'other severe lacerations', (5) paraplegias, (7) 'other spinal injury', (6) fractured pelvises, (2) major head injuries (both died), (50) 'other blunt trauma', (8) unspecified.
Penick, E.C. et al.[52]	Tornado, 1973, Missouri, US	Interviewed 26 victims to determine mental health consequences.	Not reported	Two deaths	87 hospitalizations Study: (62%) with 2 or more children reported tornado had no effect on children's' interaction, (13%) children getting on better, (25%) children getting on less well, (73%) emotional changes experienced in themselves.
Glass, R.I et al.[19]	Tornado, 1979, Wichita Falls, US	1.Interviews with families of deceased and those seriously injured. 2. Random survey in community and targeted survey of those in tornado's path	200 mph	47 deaths: (43) trauma – of these (60%) in motor vehicles, (1) heart attack, (1) sepsis, (1) tetanus, (1) gunshot.	59 seriously injured (remained in hospital >1 week): (8) head traumas, (8) lacerations/abrasions, (3) heart attacks, (29) fractures, (11) rib fractures with pulmonary complications. (51%) in motor vehicles. 110 injured (admitted or remained in hospital > 1 week): (41) fractures, (12) Rib fractures with pulmonary complications, (8) head traumas, (42) lacerations/abrasions, (3) heart attacks
O'Donnell, B.[27]	Fastnet Race Gales, 1979, UK	Report	72 knots	15 deaths	Not reported

(continued on next page)

Appendix 7. (*continued*)

Article	Event	Summary/design	Maximum wind speed	Mortality	Morbidity
Leibovich, M.[44]	Tornado, 1982, Arkansas, US	Review of all casualties in major medical centre	Not reported	Two deaths: (1) airborne, (1) struck by flying debris	24 patients treated at ED: Most common diagnosis: (58.3%) lacerations, (8.3%) blunt chest trauma. Most common secondary diagnosis: (21.4%) lumbar strain, (14.2%) rib fractures, (14.2%) foreign bodies, (14.2%) lacerations, (14.2%) cervical strain.
Illingworth, R.N. and Illingworth, K.A.[28]	Severe Gales, 1983, Great Britain, UK	Review of patients attending A&E in 2 hospitals on day of severe gales	96 mph	Three deaths: (1) crushed chest, (2) head injuries	116 casualties: (5) head injuries, (1) fractured skull, (22) 'other fractures', (3) shoulder dislocations, (9) sprains), (39) lacerations, (39) abrasions, (32) contusions, (4) eye injuries, (3) 'other injuries' PATIENTS HAD MULTIPLE INJURIES
Longmire et al.[72]	Hurricane Frederic, 1979, Mississippi and Alabama, US	Retrospective review of ED logs for one week prior and two weeks poststorm	111–130 mph (Class 3)	Not reported	Complaints showing statistically significant increase related to storm: stings, gasoline aspiration, gastrointestinal complaints, lacerations, chain saw injuries, puncture wounds, burns, spouse assaults. Increase in patients seen each day, starting directly after storm, lasting 2 weeks.
Longmire et al.[71]	Hurricane Elena, 1985, Mississippi, US	Retrospective review of ED logs for one week prior two weeks post storm	111–130 mph (Class 3)	Not reported	Complaints showing statistically significant increase related to storm: stings, gastrointestinal illness, lacerations, psychiatric problems and chain saw injury. Increase in patients seen each day, starting directly after storm, lasting 2 weeks.
Carter, A.O. et al.[16]	Tornadoes, 1985, Ontario, Canada	Case-control study to establish injuries and deaths resulting from tornadoes	250 kmh	12 deaths: all due to head/chest trauma. (92%) before reaching hospital. (83.3%) airborne, (16.7%) struck by objects.	48 seriously injured. (49%) head/neck primary injury site. Fractures (45%) and concussion/ brain injury (26%) most common diagnosis. (60%) struck flying/moving object, (25%) became airborne. 50 minorly injured. (45%) head/neck, (11%) back/spine primary injury site. (94%) struck by moving object, (mostly glass 32%).
CDC, 1989[55]	Hurricane Hugo, 1989, Puerto Rico, Puerto Rico	Medical Examiner records of deaths associated with the hurricane	100 mph with gusts of 140 mph	Nine deaths: (77.7%) electrocutions, (22.2%) drowning	Not reported
CDC, 1989[38]	Hurricane Hugo, 1989, South Carolina, US	Medical Examiner/Coroner Reports of Deaths	135 mph	13 deaths (impact phase): (46.1%) drowning, (53.8%) crushed by mobile homes/trees; 22 deaths (post-impact): (40.9%) smoke inhalation/burns, (18.1%) electrocution, (9.1%) falling tree, (4.5%) chain saw, (27.2%) not reported	Not reported

Duclos et al.[73]	Tornado, 1982, Marion, Illinois, US	Telephone survey and review of emergency room logs, records and admission files to establish injuries and their risk factors	Tornado travelled 10–15 mph	10 deaths	(50%) examined patients injured during impact phase. (31%) fractures, (11%) severe abdominal wounds, (6%) severe head injuries, (32%) lacerations. 36% of females had fractures compared to 9% males. (50%) injured during post-impact phase. (29%) pedal puncture wounds Telephone survey, interviewee results: (19%) injured – (44%) of these: deep cuts, (12%) blows to head, (12%) period of unconsciousness, (16%) broken bones, (17%) 'other severe injuries'. (45%) of injured treated at emergency room, (20%) admitted.
Eidson, M. et al.[47]	Tornadoes in North and South Carolina, USA 1984	Case-control study with questionnaire to assess risk factors for injuries and death	260 mph	59 deaths	>1000 casualties (includes deaths, serious injuries, minor injuries) 252 admitted to hospital
CDC, 1992[41]	Hurricane Andrew, 1992, Florida and Louisiana, US	Medical Examiner Reports of Deaths associated with Hurricane Andrew	145 mph with gusts of 164 mph (Category 4)	32 deaths: (37.5%) injuries trauma/falls, (12.5%) asphyxia, (3.1%) drowning, (25%) stress induced cardiovascular events, (6.2%) organic brain syndrome, (3.1%) intra-cerebral haemorrhage, (6.2%) died in fires, (6.2%) unknown.	Not reported
Cugnoni, H.L. & Whitworth, I.[21]	Storms, 1990, Great Britain, UK	Retrospective study of injuries caused by high wind speeds	Wind gusts >45 knots	49 deaths	58 patients presented to hospital: (15) head injuries (no fracture), (2) head injuries (compound), (18) fractures, (13) foreign body in eye, (9) lacerations, (8) soft tissue injuries, (4) abrasion, (1) 'other'. (13.8%) admitted
Noji, E. K.[12]	Cyclone Tracy (1974, Darwin, Australia)	Summary of cyclone-induced injuries	Cyclone Tracy 150 mph	Cyclone Tracy: 51 deaths	Tracy: 145 injuries: (3.4%) abdominal injuries, (0.7%) foot amputation, (4.1%) pelvic fractures, (1.4%) head injuries, (4.8%) spinal injuries, (41.4%) lacerations, (3.4%) paraplegias, (34.5%) blunt trauma, (6.9%) penetrating chest wound, (5.5%) unreported
	Hurricane Frederic (1984, USA)		Others not reported		Frederic: 248 injuries: (1.2%) gasoline aspiration, (1.2%) spousal assault, (6.5%) burns, (3.2%)chain saw injuries, (67.3%) lacerations, (6%) stings, (14.5%) puncture wounds
	Hurricane Elena (1988, USA)				Elena: 130 injuries: (10%) chain saw injuries, (79.2%) lacerations, (10.8%) paraplegias
	Hurricane Hugo (1992, Puerto Rico)				Hugo (Puerto Rico): 44 injuries: (22.7%) asphyxiation/fire/smoke, (2.3%) chain saw injury, (18.2%) drowning, (25%) electrocutions, (13.66%) heart attacks, (18.2%) blunt trauma

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Appendix 7. (*continued*)

Article	Event	Summary/design	Maximum wind speed	Mortality	Morbidity
	Hurricane Hugo (1992, St. Croix)				Hugo (St. Croix): 192 injuries: (10.4%) Ear, nose and throat, (8.3%) fractures, (68.2%) soft tissue injuries, (13%) puncture wounds.
Brewer. R.D et al.[62]	Hurricane Hugo, 1989, North Carolina, US	Descriptive study of emergency department visits September 22–October 6, 1989	Not reported	Four deaths: (1) falling tree, (1) intra-cranial haemorrhage, (2) drowning	2090 cases: (88%) injuries – of these, (28%) wounds, (21%) insect stings, (13%) contusions, (8%) fractures, (6%) 'other injury', (8%) 'other non-injury', (4%) unknown.
Henderson et al.[49]	Hurricane Iniki, 1992, Hawaii, US	Prospective study describing use of disaster medical assistance teams (DMAT) field clinics	145 mph (gusts up to 175 mph)	Two deaths	During acute phase: three DMATs Sep 16–19 treated 614 cases: (40.4%) injury: (28.2%) laceration, (27%) puncture wound, (19.8%) blunt trauma, (12.5%) abrasion, (12.5%) miscellaneous injury. (38.6%) medical illness: (56.6%) infectious disease – of these: (69.4%) upper respiratory illness. (59.9% male, average age 34 years). (5.4%) referred to higher medical care.
CDC, 1996[74]	Hurricanes Marilyn and Opal, 1995, US Virgin Islands, Florida respectively	Surveillance for injuries and illness and rapid health needs assessment September–October 1995 in healthcare facilities	Marilyn: 80 mph–100 mph with gusts of 125 mph Opal: 115 mph	40 deaths combined	Marilyn: 3265 patient visits: (33%) injuries, (0.2%) burns,(12%) upper/lower respiratory tract illnesses, (6%) dermatological, (5.1%) GI disorders. Opal: 1135 cases: (6.2%) laceration/wound, (6.8%) sprain/strain/fracture, (1.6%) motor vehicle related injury, (1.7%) insect bites, (2%) 'other injuries'. (4%) GI illness, (1%) Respiratory, (1.2%) skin rash, (0.4%) psychiatric symptoms
CDC, 1996[75]	Hurricanes Marilyn and Opal, 1995 US	Review of medical examiners' and coroners' data	Marilyn: 105 mph (Category 2) Opal: 115 mph (Category 3)	Marilyn: 10 deaths: (1) electrocution, (8) drowning, (1) unspecified. Age range 17–107, mean 56.6, (80%) males. Opal: 27 deaths: (1) exacerbation of chronic obstructive pulmonary disease, (2) myocardial infarctions, (13) falling trees, (1) carbon monoxide poisoning, (3) fire, (1) drowning, (1) electrocution, (4) vehicle related, (1) hit by mobile home	Not reported
Combs, D.L. et al.[50]	Hurricane Andrew, 1992, Louisiana, US	Retrospective analysis of medical examiners' and coroners' data	Florida: 145 mph (gusts of 175 mph) (Category 4) Louisiana: 120 mph (Category 3)	Florida: 15 direct deaths: (9) blunt trauma, (4) asphyxia, (2) drowning. 29 indirect deaths: (2) blunt trauma, (3) falls, (3) transportation related, (2) fire, (1) electrocution, (1) lightning	Not reported

				strike, (1) asphyxiation, (12) stress induced cardiac events, (1) volume depletion/hypoglycaemia, (1) hyperkalaemia/schizophrenia, (1) organic brain syndrome, (1) foetal death. (70%) of decedents male, age range 31 weeks gestation-94 years. Louisiana: 2 direct: (2) crush injuries. Nine indirect: (3) motor vehicle collision, (2) electrocutions, (1) fire, (3) stress-induced cardiac events, (1) unspecified. (82%) decedents male, age range: 2–86 years.	
David et al.[52]	Hurricane Andrew, 1992, US	Study to evaluate nature/ range of psychiatric morbidity following hurricanes	164 mph	Not reported	61 subjects. (51%) new-onset disorder: (36%) Post-Traumatic Stress Disorder (PTSD), (11%) Generalized Anxiety Disorder (GAD), (10%) Panic Disorder, (8%) Agoraphobia, (2%) Alcohol Dependence.
Lew, E.O. & Wetli, C.V.[42]	Hurricane Andrew, South Florida, 1992	Review of Medical Examiner Department Data on deaths	145 mph (gusts 175 mph), 93 dB sustained wind noise	15 direct deaths: (53.3%) blunt trauma, (26.6%) asphyxiation, (20%) drowning 15 indirect deaths: (6.6%) myocardial infarction, (6.6%) unknown, (6.6%) intra-cerebral haemorrhage, (80%) cardiovascular 32 delayed indirect deaths (6 months poststorm): (34.3%) motor vehicle related, (19%) falls, (15.6%) fire-related, (6.2%) CO poisoning, (9.3%) electrocutions, (6.3%) tree cutting, (9.4%) miscellaneous Four suicides within 67 days of storm. two homicidal incidents 20 and 36 days post storm. 23 deaths due to dyadic deaths (homicide-suicide) in six months following storm.	Not reported
Houck, P.M. and Hampson, N.B.[60]	Winter Storm, 1993, Washington State, US	Retrospective review of ED log books, assessing CO poisoning	Gusts up to 88 mph	No fatalities	81 cases received treatment for CO poisoning, representing 30 separate incidents. (10%) hospitalized. Median patient age 26 (range 1–87 yr), (61%) female.
CDC, 1998[76]	Hurricane Georges, 1998, Puerto Rico, Puerto Rico	Medical Examiner Report on Deaths associated with the hurricane	115 mph (Category 3)	Eight deaths: (25%) carbon monoxide poisonings, (50%) fire, (12.5%) fall, (12.5%) electrocution	Two people hospitalized due to carbon monoxide poisoning
CDC, 2000[51]	Hurricane Floyd, 1999, North Carolina, US		96–110 mph	52 deaths. (69%) drowning, (13%) motor-vehicle crash, (8%) myocardial	Not reported

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Appendix 7. (*continued*)

Article	Event	Summary/design	Maximum wind speed	Mortality	Morbidity
		Review of deaths according to state medical examiner's officer		infarctions, (4%) burns/fire, (2%) hypothermia, (2%) electrocution, (2%) fall. Decedents age range 1–96 years. (73%) male.	
CDC, 2000[77]	Tornadoes, 1998, Texas, US	Review of Bexar and Travis county medical examiners', Justice of the Peace and Department of Public Safety officers' data on storm-related death	Not reported	31 deaths: (77%) drowning, (10%) cardiac, (10%) multiple trauma, (3%) hypothermia	Not reported
Millie, M. et al.[43]	Tornadoes, 1998, Georgia, US	Retrospective review of trauma registry and medical records	F2 and F3 storms	15 deaths	11 cases: (45.5%) fractured ribs, (70%) multiple fractures, (45.5%) thoracic trauma, (45.5%) closed head injury, (27.3%) traumatic intra-abdominal injuries, (27.3%) developed SIRS/sepsis syndrome. Patients did not have only one diagnosis (73%) male, age range 5–54 years.
Jacobson, J.[11]	Not specified	Review of windstorm related disaster deaths in US 1994–1998	Not reported	Between 1994 and 1998 total of 490 deaths due to windstorm events. Decedents more likely male or elderly (RR 1.73) than women and children. Deaths occurred primarily in single family homes and outdoors. Tornadoes had higher risk of death from trauma. Hurricanes had higher risk of death from drowning.	Not reported
CDC, 2004[14]	Hurricane Isabel, 2003, North Carolina, US	Interviews to establish post disaster needs assessment	100 mph (Category 2)	Not reported	(1%) of households had member with hurricane-related injury, (5%) had a member with hurricane-related illness. (8%) had member requiring medical care. (29.5%) experienced stress, (4.9%) problems obtaining medical care, (6.0%) problems obtaining medication.
CDC, 2004[36]	Hurricane Charley, 2004, Florida, US	Medical Examiner Reports of Mortality associated with Hurricane Charley	145 mph (Category 4)	31 deaths: (55%) trauma [(12.9%) motor-vehicle crashes, (12.9%) falls, (9.6%) shelter collapse, (6.4%) falling trees, (6.4%) flying debris, (3.2%) crush injury, (3.2%) uncertain cause]. (10%) carbon monoxide poisoning, (3%) drowning, (3%) electrocution, (3%) suicide, (19%) exacerbation of medical condition [(12.9%) cardiac, (6.4%) pulmonary]. (7%) two or more causes. Decedents age range 6–87 years, (77%) male.	Two persons lost power during storm and did not have access to their needed oxygen.

CDC, 2005[78]	Hurricane Katrina, 2005, New Orleans, US	Surveillance for illness and injury of patient visits to healthcare facilities in Jefferson, Orleans, Plaquemines, St. Bernard (September 8–25, 2005)	Not reported	Five deaths	7508 health related events: (55.6%) illnesses, (26.9%) injuries, (17.5%) non-acute health-related events. (9%) admitted to hospital. Of the illnesses: (15.4%) skin/wound infection, (12.1%) acute respiratory infection, (3.5%) diarrhoea, (6.9%) 'other infectious disease', (7.2%) rash, (5%) heat related, (5%) non-diarrhoeal gastrointestinal, (2.1%) renal, (3.9%) 'other classifiable illness' and (39%) 'other illnesses'. Of the injuries/exposures: (23%) falls, (15.4%) bites/stings, (7.2%) motor vehicle crash, (2.1%) intentional injury, (35.5%) 'other unintentional injury', (14.8%) undetermined aetiology. (0.7%) carbon monoxide poisoning, (1.3%) 'other toxic exposure'.
CDC, 2005[2]	Hurricanes Charley, Frances, Ivan, Jeanne, 2004, Florida, US	Review of impact of four hurricanes in Florida in 2004	Charley: (Category 4) Frances: (Category 4) Ivan: (Category 3) Jeanne: (Category 3)	Total of all four hurricanes: 124 deaths	Total of all four hurricanes: (4.6%) injured in hurricane path, (3.8%) injured out of hurricane path. (5.4%) chronic health conditions worsened – of these (13.6%) prevented/delayed from obtaining medication, (9%) barriers to essential medical equipment (oxygen, dialysis).
Daley, W.R. et al.[48]	Tornadoes, 1999, Oklahoma, US	Review of hospital records of visits and admissions. Case-control study to ascertain risk factors for injury and death	F5 (most powerful one)	45 deaths: 40 direct 5 indirect: (3) cardiac events, (1) fall, (1) fire	265 Emergency Department visits: (50.2%) admitted
Shultz et al. [10]	1980–2004, US	Review of literature on public health consequences of tropical cyclones	Not reported	Alicia, 1983: 21 Elena, 1985: 4 Juan, 1985: 63 Hugo, 1989: 89 Bob, 1991: 18 Andrew, 1992: 61 Iniki, 1992: 7 Tropical Storm Alberto, 1994: 32 Marily, 1995: 13 Opal, 1995: 27 Fran, 1996: 37	Injury is major cause of death and primary cause of morbidity: three main cyclone-related injuries: lacerations, blunt trauma and puncture wounds. (80%) of injuries confined to feet/lower extremities.

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Appendix 7. (*continued*)

Article	Event	Summary/design	Maximum wind speed	Mortality	Morbidity
				Georges, 1996: 16 Bonnie, 1998: 3 Floyd, 1999: 77 Tropical Storm Allison, 2001: 43 Isabel, 2003: 55 Charley, 2004: 34 Frances, 2004: 38 Ivan, 2004: 52 Jeanne, 2004: 28	Hurricane Hugo – South Carolina: (21%) of all hurricane related inland ED visits due to insect stings.
Smith, C.M. and Graffeo, C.S.[79]	Hurricane Isabel, 2003, Virginia, US	Observational cohort study, daily ED patient visits and admissions through the ED tracked from day of landfall to day 5 post landfall	79 mph (gusts up to 103 mph (Category 2)	30 deaths	Day of landfall: 359 cases presented to Emergency Department: (2) major traumas, (263) medical complaints, (88) minor traumas, (6) psychiatric complaints. Post landfall (1–4 days): 840 cases presented to Emergency Department: (3) major traumas, (10) psychiatric complaints, no further breakdown.
Bayleyegn, T. et al.[58]	Hurricane Ivan, 2004, Florida, US	Questionnaire: Santa Rosa and Escambia Counties (Florida) on health status/needs, one week after hurricane	130 mph (Category 3)	24 deaths	Santa Rosa: (12%) of households at least one person with injuries, (17%) of households one ill member. Escambia: (14%) of households at least one person with injuries, (18%) of households one ill member. Potential health implications included insect stings, allergic response, and heat-related illness or injury. Common findings in both counties: posthurricane sleep disturbances, respiratory illness, gastrointestinal illness, and skin conditions or rashes.
CDC, 2006[54]	Hurricane Katrina, 2005, New Orleans, US	Surveillance for illness and injury of patient visits to healthcare facilities in Hancock, Harrison and Jackson counties.	Not reported	Five deaths	Active surveillance 5-11 Sept: 11,424 cases: (57.3%) illness, (38.4%) injury, (3.7%) admitted. (5) non-fatal posthurricane carbon monoxide (CO) poisonings. Trends in most common illnesses were stable. After active surveillance 12 Sept–11 Oct: 27,135 cases: (21.8%) injuries: (8.4%) 'major injuries', (91.6%) minor injuries.

					(6.8%) skin/wound infections, (9.3%) upper/lower respiratory infections, (4.5%) rashes and insect stings/bites. Illness: (2.7%) nausea/vomiting, (1.1%) watery diarrhoea, (0.1%) bloody diarrhoea, (50.3%) 'other illness'. (2.5%) mental health concerns, (43) suicide attempts.
CDC, 2006[37]	Hurricane Katrina, 2005, US	Review of mortality records of Florida's Medical Examiners Commission and the Alabama Department of Forensic Science to assess mortality related to Hurricane Katrina	Florida: 80 mph (Category 1) Louisiana: 125 mph (Category 3)	Florida – 14 deaths: (21.4%) drowning, (28.5%) crushed by trees, (21.4%) car collisions with fallen trees, (7.1%) fall, (14.2%) CO poisoning, (14.2%) undetermined. (79%) of deaths during impact phase. Age range of decedents 17–79 years, (71%) male. Alabama – 24 deaths. (50%) underlying disease [nine cardiac, two neurological, 1 alcoholism], (4.1%) sepsis, (29.1%) trauma: [(8.3%) suicide, (4.1%) car collision, (4.1%) head injury, (4.1%) drowning, (4.1%) suffocation, (4.1%) tree falling]. (12.5%) gunshot, (4.1%) undetermined. Decedents 6 months–77 years, (88%) male.	Not reported
CDC, 2006[3]	Hurricane Season 2003–2005, [Charley, Frances, Jeanne, Dennis, Katrina, Wilma] Florida, US	Retrospective Review of data collected by Florida Poison Information Centre Network (FPICN) to identify hurricane-related exposures and health hazards	Not reported	Not reported	CO exposure in 2004: (38) Hurricanes Charley, (49) Hurricane Frances, (42) Hurricane Jeanne CO exposure in 2005: (8) Hurricane Dennis, (28) Hurricane Katrina, (58) Hurricane Wilma September 2004 increased exposures to hydrocarbon fuels before and after Hurricane Frances. October 2005 increased exposures to hydrocarbon fuels after Hurricane Wilma.
Coenraads et al.[25]	The Great Storm of October 1987, UK	Records	Not reported	16 deaths	Not reported
Coenraads et al.[25]	Burns' Day Storm, 1990, Europe	Record	Gusts up to 108 mph	97 deaths total: (47) UK, (19) Netherlands, (10) France, (10) Belgium, (7) Germany, (4) unspecified	Not reported
Coenraads et al.[25]	December storms, 1999, Europe	Record	Gusts up to 107 mph	At least 79 deaths: (34) France, (45) unspecified	Not reported
Hampson, N.B. and Stock, A.L.[34]	Winter Storm, 1993, Washington State, US	Review of CO poisoning due to storms	Winter Storm: gusts up to 94 mph	Winter Storm: no fatalities	Winter Storm: 81 non-fatal cases

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Appendix 7. (*continued*)

Article	Event	Summary/design	Maximum wind speed	Mortality	Morbidity
	Hurricane Isabel, 2003, North Carolina, US Four Hurricanes, 2004, Florida, US Hurricane Katrina, 2005, New Orleans, US		Isabel: 100 mph Four hurricanes: not specified Katrina: not specified	Isabel: eight fatalities Four hurricanes: six fatalities Katrina: five fatal cases	Isabel: Not reported Four hurricanes: 161 non-fatal cases Katrina: 46 non-fatal cases
Jani, A.A.[35]	Hurricane Isabel, 2003, US	Review of Medical Examiner and Office of Vital Records/ Health Statistics	96–110 mph (Category 2)	32 deaths: 12 direct: (7) drowning, (5) head injuries from falling trees 20 indirect: (6) motor vehicle crashes, (3) head/neck fractures, (1) crush injury, (2) exertional myocardial infarction, (4) CO poisoning, (2) falls, (1) fire, (1) suicide. Median age 48 years (range 7–85).	Not reported
Brunkard, J.[1]	Hurricane Katrina, 2005, New Orleans, US	Assessment of mortality data using Louisiana, out-of-state death certificates and Disaster Mortuary Operational Response Team's confirmed victim's database	(Category 3)	971 deaths in Louisiana: (40%) drowning, (25%) injury/trauma: [(0.6%) heat exposure, (0.4%) unintentional firearms, (0.2%) homicides, (0.4%) suicides, (0.3%) gas poisoning, (0.1%) electrocution, (23%) unspecified]. (11%) heart conditions, (5%) 'other illness', (19%) unspecified. (49%) of victims age >75 years. (53%) of victims male. 15 deaths among evacuees in other States.	Not reported
Cretikos, M. A. et al.[13]	Long-Weekend Storm, 2007, New South Wales, Australia	Report of presentations to Emergency Departments (ED)	Wind gusts > 130 kmh	10 deaths: (4) road collapse, (2) drowning, (4) unreported	180 presentations to EDs: (34) hypothermia, (31) fractures, injuries/lacerations, (18) dyspnoea, (10) joint/limb pains. (21%) admitted to hospital. (62) assessed by medical teams at evacuation centre. (29) highly dependent people whose therapy was interrupted by the storm (patients dependent on oxygen, dialysis and those receiving enteral feeds or intravenous therapy at home) admitted.
Rath, B. et al.[59]	Hurricane Katrina, 2006, US	Cross sectional survey, evaluating differences between children/adolescents	Not reported	Not reported	531 participants. Those with pre-existing conditions more likely than those without to be at clinic for non-chronic health condition

		with and without chronic conditions, postHurricane Katrina			(43.5 vs. 16.2%), take asthma medication (37.4 vs. 3.9%), have asthma worsen (16.3 vs. 1.9%), miss a visit (49.2 vs. 39.8%), run out of medication (33.9 vs. 7.9%), live with flood damage (19.7 vs. 11.3%), or mould (23.6 vs. 15.8%), experience disruption of care (58.4 vs. 38.3%) or negative psychological consequences (range 2.5%–12.9%).
Ashley, W.S. and Black, A.W.[70]	Not specified	Fatalities associated with non-convective high winds in US, 1980–2005	Not specified	616 fatalities	2865 injuries
Kennedy et al.[30]	Extra-tropical storm Kyrill, 2007, Europe	Report	Not specified	49 deaths across Britain, the Netherlands, Germany and Poland	Not reported
Ragan, P. et al.[33]	Review of eight hurricanes from 2004 to 2005 in Florida	Review of Medical Examiners Commission over two years	Not reported	2004: 144 deaths: (59%) during post-impact phase; (76%) accidents – of these (>50%) trauma. Other causes: drowning, other injury, electrocution and CO poisoning 2005: 69 deaths: (61%) during post-impact phase; (86%) accidents – of these (>50%) trauma. Other causes: drowning and CO poisoning. (79%) of deaths in persons >40 years of age.	Not reported
Schmidlin, T.W.[40]	Not specified	Review of deaths by wind-related tree failures, US 1995–2007	Not specified	407 deaths. (44%) struck by fallen tree/limb in vehicle, (38%) outdoors, (18%) at home. Median age 44 years (range 1–91), (62%) male.	Not reported
Norris, F.H. et al.[80]	Hurricane Ike, 2008, Texas, US	Random population survey 2–6 months posthurricane Ike	Not reported	Not reported	Sample: 658 adults. (4%) personal injury, (16%) household illness – indicates approximately 7700 adults injured and 31,500 adults with household-level illness
McKinney, N. et al.[9]	Hurricanes Charley, Frances, Ivan and Jeanne, 2004 Florida, US	Quantifying direct/indirect deaths through cumulative sum of deviation plots	Not reported	624 total direct/indirect deaths: (4%) trauma related, (9%) accident related, (5%) diabetes, (19%) cancer related, (34%) heart related. Larger total number than official count: 31 direct, 113 indirect deaths.	Not reported
Schmidlin, T.W[8]	Hurricane Ike, 2008, Ohio, US	Data collected from Situation Reports, National Weather Service, print/online news reports, city/council health departments, government/agency reports and interviews	120 mph (gusts 66–84 mph) (Category 2)	Seven deaths: (1) head injury, (4) fallen/falling trees, (1) drowning, (1) electrocution	603 injuries: hospitals treated for – falls, chain saw injuries, puncture wounds, bee stings, ‘other trauma’. Persons with allergies/asthma suffered from higher levels of mould, pollen, and smoke. 15 people on oxygen supply lost power and had to move to shelters with power.

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Appendix 7. (*continued*)

Article	Event	Summary/design	Maximum wind speed	Mortality	Morbidity
Zane, D.F. et al.[39]	Hurricane Ike, 2008, Texas, US	Texas Department of State Health Services (DSHS) data collection by surveillance form	110 mph (Category 2)	74 deaths: (11%) drowning, (9.5%) falling tree, (64%) injuries, (31%) illnesses, (8.1%) undetermined, (18%) carbon monoxide poisoning, (2.7%) burns, (4.1%) firearm related, (2.7%) falls, (2.7%) drug/substance ingestion, (1.4%) inhalation (fumes/smoke/dust), (1.4%) suffocation/asphyxia, (1.4%) electrocution, (1.4%) pedestrian/bicyclist struck, (1.4%) motor vehicle accident. (10.8%) cardiovascular failure, (1.4%) respiratory failure, (2.7%) renal failure, (5.4%) 'other illness'. Deceased age range<1 year–85 years (average 46 years), (70%) male.	Not reported

Reference numbers in superscript.