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Title: Floods and human health: A systematic review

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Keywords: flood; health; disease; wounds and injuries; death

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Abstract: Floods are the most common type of disaster globally, responsible for almost 53,000 deaths the last decade alone (23:1 low- versus high-income countries). This review assessed recent epidemiological evidence on the impacts of floods on human health. Published articles (2004-2011) on the quantitative relationship between floods and health were systematically reviewed. 35 relevant epidemiological studies were identified. Health outcomes were categorized into short- and long-term and were found to depend on the flood characteristics and people's vulnerability. It was found that long-term health effects are currently not well understood. Mortality rates were found to increase by up to 50% in the first year post-flood. After floods, it was found there is an increased risk of disease outbreaks such as Hepatitis E, gastrointestinal disease and leptospirosis, particularly in areas with poor hygiene and displaced populations. Psychological distress in survivors (prevalence 8.6% to 53% two years post-flood) can also exacerbate their physical illness. There is a need for effective policies to reduce and prevent flood-related morbidity and mortality. Such steps are contingent upon the improved understanding of potential health impacts of floods. Global trends in urbanization, burden of disease, malnutrition and maternal and child health must be better reflected in flood preparedness and mitigation programs.

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[Footnotes Page]

Running Head: Floods and human health: A systematic review

Abbreviations used:

ARIs- upper respiratory infections

CDRCs- chronic disease and related conditions

CI- confidence interval

GI- gastrointestinal disease

MCH- maternal and child health

NCDs- non-communicable diseases

PTSD- post-traumatic stress disorder

SES- socio-economic status

WHO- World Health Organization

OR- odds ratio

RR- relative risk

[Abstract]

Floods are the most common type of disaster globally, responsible for almost 53,000 deaths the last decade alone (23:1 low- versus high-income countries). This review assessed recent epidemiological evidence on the impacts of floods on human health. Published articles (2004-2011) on the quantitative relationship between floods and health were systematically reviewed. 35 relevant epidemiological studies were identified. Health outcomes were categorized into short- and long-term and were found to depend on the flood characteristics and people's vulnerability. It was found that long-term health effects are currently not well understood. Mortality rates were found to increase by up to 50% in the first year post-flood. After floods, it was found there is an increased risk of disease outbreaks such as Hepatitis E, gastrointestinal disease and leptospirosis, particularly in areas with poor hygiene and displaced populations. Psychological distress in survivors (prevalence 8.6% to 53% two years post-flood) can also exacerbate their physical illness. There is a need for effective policies to reduce and prevent flood-related morbidity and mortality. Such steps are contingent upon the improved understanding of potential health impacts of floods. Global trends in urbanization, burden of disease, malnutrition and maternal and child health must be better reflected in flood preparedness and mitigation programs.

Keywords (MeSH): flood, health, disease, wounds and injuries, death

1. INTRODUCTION

In the ten years prior to 2011, flooding has been the most common type of disaster globally, responsible for almost half of all victims of natural disasters and for economic losses of nearly US $185 trillion (EM-DAT, 2011). Flooding events are expected to increase in frequency and intensity due to rising sea levels and more frequent and extreme precipitation events (IPCC, 2007; Ramin and McMichael, 2009). In addition, increasing levels of urbanization mean that more people will be exposed to flooding events (Du et al., 2010).

It is thought that floods will increase the global burden of disease, morbidity, mortality, social and economic disruptions, and will place a continuing stress on health services, especially in low-resource countries. It is in these countries where most major floods occur and where vulnerability is the highest (Abaya et al., 2009; Ahern et al., 2005; Assanangkornchai et al., 2004; Fundter et al., 2008). Health consequences of floods depend on geographic and socio-economic factors, as well as the baseline vulnerability of the populations affected (Ahern et al., 2005; Du et al., 2010). The characteristics of floods and their significant impact on human health over the last decade have been examined in epidemiological studies conducted in both high and low-resource countries. Additionally, reviews of epidemiological (Ahern et al., 2005) and other (Du et al., 2010) evidence of flood-related health impacts have been conducted. However, there remains a need to improve the understanding of "the health risks in different settings and of the social and cultural modifiers of those risks" (Ahern et al., 2005, p. 46), longer-term health impacts of floods (Ahern et al., 2005; Carroll et al., 2010; Milojevic et al., 2011) and effective methods to mitigate these impacts.

The aims of this paper are twofold:

1. To add to existing international evidence of the impacts of floods on human health (Ahern et al., 2005; Du et al., 2010) by reviewing the recent literature.

2. To identify knowledge gaps in research and practice to improve health outcomes for flood impacted communities.

2. MATERIAL AND METHODS

A literature search using Medline, Proquest, Informit and ScienceDirect was conducted in September 2011. We limited the search to peer-reviewed articles in English published between 2004 (when the review of Ahern and colleagues was published) and 2011. In Medline a combination of terms defining exposure (flood and flood like events) and health outcome were used (Table 1) in key-word, title, abstract and Medical Subject Headings (MeSH; National Library of Medicine). Search terms for the other three databases included flood and a selected few health outcomes. In addition to limits set for Medline, these searches were limited by subject, classification and sources (excluding disciplines not related to public health). The initial search generated references for which abstracts were reviewed to exclude any studies which clearly did not meet the inclusion criteria, defined as: epidemiological study, related to floods (as opposed to other natural disasters), describing health impacts rather than other flood impacts (i.e. excluded emergency preparedness or management, statistical modelling of risk, methods to assess exposure, strategies to improve community resilience). Full texts of the remaining articles were then critically reviewed by the first author (Figure 1).

3. RESULTS

The initial search generated 6,939 potentially relevant references (Figure 1). After removing duplicates and articles not related to flood impact based on review of the abstract, 569 references were identified for inclusion. Upon further review, 433 references not meeting inclusion criteria were excluded. The full-text of all remaining 139 studies were critically analysed and the key 35 epidemiological studies were included in the review (Table 2). Reported health outcomes of floods were divided into short-term and longer-term.

3.1. Short-term health outcomes of floods

3.1.1. *Mortality due to drowning and acute trauma.* Floods are estimated to have caused almost 53,000 deaths globally over the last 10 years (EM-DAT, 2011). Most flood-related fatalities have occurred in resource-poor countries and communities, primarily due to greater vulnerability to disasters and poor disaster management systems (Ahern et al., 2005). The Centre for Research on Epidemiology of Disasters estimates the ratio of deaths related to floods in years 2002–11 in developing versus high resource regions worldwide to be almost 23 to 1 (EM-DAT, 2011). Profiles of fatalities vary based on the characteristics of the flood and personal vulnerability. The majority of immediate fatalities occur in flash and coastal floods, often due to drowning and acute trauma (Brunkard et al., 2008; Haines et al. 2006; Jonkman and Kelman, 2005; Ragan et al., 2008; WHO, Flood-Technical Hazard Sheet). Historically (i.e. 1953 floods in the Netherlands, 1959 floods in Japan, 2005 floods in Louisiana), the highest levels of flood-induced mortality occurred near breaches and in areas where flood water is deep and swift (Brunkard et al., 2008; Jonkmann et al., 2009). Patterns of fatalities differ between low and high-income countries and between Eastern and Western cultures, depending on environmental, socio-economic and cultural factors (Shimi et al., 2010; Yeo and Blong, 2010). In low-income countries those at higher risk of flood-related death tend to be from ethnic minorities who are poor, live on floodplains and in unstable dwellings, females and the very young and elderly (Jonkman et al., 2009; Yeo and Blong, 2010, Pradhan et al., 2007). In a 1931 flash flood in Fiji the risk for fatality increased among Indian farmers (living predominantly on floodplains and in grass huts) and children under 11 years old (Yeo and Blong, 2010). In a 1993 flash flood in Nepal the risk for fatality increased among people living in houses constructed of thatch as opposed to brick (relative risk (RR)=5.1, 95% confidence interval (CI): 1.7, 24.5) and those of low socio-economic status (SES) (RR=6.4, 95% CI: 2.7, 20.0) (Pradhan et al., 2007). Gender differences were also observed: girls were at double risk of fatality as compared to boys (13.3/1000 versus 9.4/1000) and at each age group women were at a double risk compared with men, adjusted for age (RR=1.5, 95% CI: 1.1, 2.1). There were strong similarities in the profiles of fatalities observed in Nepal to those observed in Bangladesh following the 1970 cyclone (Pradhan et al., 2007).

Reports from medium and high-income countries show that the elderly, males, and poor communities of colour experience more flood-related casualties compared with other communities (Brunkard et al., 2008; Yeo and Blong, 2010; Zahran et al., 2008). In the two months following hurricane Katrina in Orleans Parish, blacks were overrepresented among fatalities above the age of 18, with a mortality rate up to four times higher than that of whites (Brunkard et al., 2008). Analysis of flood-related casualties in East Texas revealed that the risk for death or injury in a county increased by 42% with every unit increase in representation of a socially vulnerable population (Zahran et al., 2008). Large and unexpected floods put the elderly, who need assistance with evacuation and access to medical services, and who may be reluctant to abandon their home, at greater risk of harm and fatality (Jonkman and Kelman, 2005; Yeo and Blong, 2010). Analyses of mortality patterns following hurricanes Katrina and Rita show that the elderly were significantly overrepresented among fatalities (Brunkard et al., 2008), with 85% over the age of 50 and almost half over the age of 75 (Jonkman and Kelman, 2005). A third of all deaths occurred in flooded areas inside residences which were spared from the floodwater. Those fatalities were due to “dehydration/heat stroke, heart attack/stroke, or other causes associated with lack of sustaining medical supplies” (Jonkman et al., 2009, p. 687).

3.1.2. *Injuries.* Nonfatal injuries together with exacerbation of chronic illness are the leading causes of morbidity among affected residents and relief workers immediately following floods (Diaz, 2004; Sullivent et al., 2006). Injuries can occur before, during and after the flood, throughout the clean-up phase and finally during repopulation (Abaya et al., 2009). The most common reasons for flood-inflicted nonfatal injuries are cuts, falls, being struck by falling debris or objects moving quickly in flood water (Abaya et al., 2009; Ahern et al., 2005), and being bitten or stung (Diaz, 2004; Sullivent et al., 2006). Motor vehicle injuries sustained during repopulation are also common (Sullivent et al., 2006).

In hurricane Hugo (USA, 1989) almost 90% of over 2000 patients treated in emergency departments were hospitalized for injuries, resembling the pattern observed in previous US hurricanes (i.e. hurricane Andrew, 1992, hurricane Opal, 1995) (Diaz, 2004). Surveillance conducted post-Katrina/Rita in Greater New Orleans recorded over 7,500 nonfatal injuries among residents and relief workers. In both groups young to middle aged males were most at risk, partly due to the fact that they were the ones most actively participating in the relief and clean-up efforts (Sullivent et al., 2006). While patterns of injuries varied between residents and relief workers, in both groups most injuries occurred during the clean-up phase with cuts as the leading mechanism of injury (27% and 19% respectively (Sullivent et al., 2006). A greater number of residents compared to rescue workers were injured during the repopulation period, primarily due to falls (23% versus 10%) and motor vehicle crashes (9% versus 4%) (Sullivent et al., 2006).

3.1.3. *Toxic exposure.* Flood waters may act as trigger, releasing chemicals that are already stored in the environment. Toxic exposure-related health impacts are therefore greatest in populations living near flood-impacted industrial or agricultural areas (Euripidou and Murray, 2004; Fox et al., 2009). However, the causal pathway between floods, contamination and related health outcomes in affected populations is yet to be scientifically verified (Haines et al., 2006; WHO, Flooding and communicable diseases fact sheet). For instance, a review of longitudinal data on flood-related chemical contamination incidents in the United Kingdom revealed that the relationship between these incidents and population morbidity and mortality remains inconclusive (Euripidou and Murray, 2004). In the past flood waters and land have been contaminated with carbon monoxide, pesticides, agricultural chemicals, dioxin and a number of heavy metals (Euripidou and Murray 2004; Fife et al., 2009; Fox et al., 2009). Exposure to such contaminants is known to be associated with cancer, cardiovascular, gastrointestinal, kidney, liver, and neurological diseases (Euripidou and Murray, 2004; Fox et al., 2009).

Elevated baseline soil toxicity not attributed to floods was responsible for elevated soil concentration of lead and arsenic following hurricanes Katrina and Rita (Schwab et al., 2007). In the weeks following that disaster the main change in toxic exposure was related to a shortage of energy sources, resulting in a seven-fold increase in carbon monoxide and gasoline exposure and a 13-fold increase in exposure to lamp oil (Cox et al., 2008). Incorrect use of portable power generators during Katrina was responsible for a majority of cases of carbon monoxide poisoning in affected areas (Cox et al., 2008).

3.1.4. *Communicable diseases.* Floods are associated with an increased risk for water- and vector-borne diseases (WHO, Flooding and communicable diseases fact sheet). Health risks associated with handling the bodies of deceased people remain minimal if appropriate hygienic precautions are taken (Ligon, 2006; Morgan, 2004; WHO, Flooding and communicable diseases fact sheet) and therefore will not be reviewed here. The World Health Organization (WHO) has noted that immediately following floods, despite a higher risk of communicable disease transmission, outbreaks rarely occur (WHO, Flooding and communicable diseases fact sheet). The risk increases when infrastructure is heavily impacted, populations are displaced and water supply systems are damaged, leading to the contamination of drinking water facilities (WHO, Flooding and communicable diseases fact sheet; Watson et al., 2007). Generally, diseases resulting from water contamination include cholera, diarrheal disease, hepatitis A and E, leptospirosis, parasitic diseases, rotavirus, shigellosis and typhoid fever (Ligon, 2006). Specific water-borne diseases related to floods include wound infections, dermatitis, conjunctivitis and ear, nose and throat infections (WHO, Flooding and communicable diseases fact sheet).

3.1.5 Water-borne diseases: a) Gastrointestinal diseases. The risk for gastrointestinal disease (GI) following floods is higher in environments with poor hygiene and inadequate provision of clean drinking water (WHO, Flooding and communicable diseases fact sheet) and thus greatest in low-income countries. Power shortages during floods may result in increased risk for water-borne disease (WHO, Flooding and communicable diseases fact sheet). Threats to human health also exist in relation to consuming crops grown on soil which was contaminated during flood with wastewater (municipal and livestock operations). In the last 10 years exacerbation of diarrheal disease and related mortality following floods has been observed in some African countries (Abaya et al., 2009), Bangladesh and Indonesia (Schwartz et al., 2006; Vollaard et al., 2004). Post-flood resettlement, overcrowding and compromised quality of water and hygiene in Ethiopia, contributed to a high incidence of diarrheal disease (Abaya et al., 2009). The 2008 floods in Mozambique resulted in a cholera outbreak (Sidley, 2008). It has been found that 70 million people in Bangladesh are exposed to drinking water that does not meet WHO standards, and floods, which inundate 30% of the land area for half of the year, exacerbate shortage of clean water (Shimi et al., 2010). In Bangladesh during the floods of 1998 and 2004, most of the badly affected villages suffered inundation of two thirds of drinking water sources and 97% of latrines, which led to diarrheal disease and fever in over half of the affected population (Shimi et al., 2010).

In high-income countries the risk of post-flood GI disease outbreak is low; however, it increases with the depth of flooding (Reacher et al., 2004), crowding and unhygienic conditions (Murray et al., 2009; Yee et al., 2007). Following the 1999 hurricane in the United States, samples of agricultural soil revealed contamination by faecal waste from municipal wastewater and livestock operations (Casteel et al., 2006). A minor increase in Medicaid outpatient service utilization for waterborne illness was observed (Setzer and Domino, 2004). In the days following Katrina, 4% of all sheltered evacuees fell ill during an outbreak of norovirus-based gastroenteritis which was attributed to over-crowding, poor sanitation and compromised health levels of evacuees (Yee et al., 2007). Contact with flood waters was also associated with an increased risk for GI disease during the 2002 floods in Germany (Schnitzler et al., 2007).

b) Hepatitis A and E. Hepatitis A and E, transmitted through the faecal-oral route by ingesting contaminated food or water, are endemic in many low resource countries (Watson et al., 2007, WHO, Hepatitis E Fact Sheet). Outbreaks of Hepatitis E following floods are frequent in endemic areas and attributed primarily to contamination of water sources (person-to-person transmission accounts only for up to 2.2% of new cases) (Aggarwal and Krawczynski, 2000). Hepatitis E outbreaks are often large, posing a severe burden on the population (Aggarwal and Krawczynski, 2000). They may be particularly dangerous for pregnant women, as seen in 1991 in Kaupur, India, where out of 79,000 cases of waterborne viral Hepatitis E, 13 out of 48 recorded deaths occurred among pregnant women (case fatality rate of 25%) (Watson et al., 2007). Outbreaks of Hepatitis A are infrequent because most of the population in low resource countries are immune (Watson et al., 2007).

c) Respiratory and skin infections. Reports from the United States (Diaz, 2004) and from South Asia (Ligon, 2006) revealed that upper respiratory infections (ARIs) were the most common type of infectious disease occurring after floods. During the 2005 floods in England, recurring flu-like symptoms including throat infections, coughs and general sickness were reported by people whose homes had been affected (Carroll et al., 2010). Flu-like symptoms were also the most frequently reported symptoms among 29,478 sheltered evacuees in the days following Katrina (sore throat 3.5% out of 2,165 surveyed, cough 7.6% out of 487 surveyed, runny nose 9.9% out of 916 surveyed) (Murray et al., 2009).

Besides exacerbation of ARIs, earache and skin rashes are common post-flood complaints (Reacher et al., 2004). In the month following the 2005 floods in Thailand, out of 102 patients complaining of skin problems 59 were diagnosed with inflammatory dermathoses (58%) and 40 with infectious skin conditions (39%) (Vachiramon et al., 2008). Skin rash was also confirmed in over 40% of construction workers repairing buildings damaged in hurricane Katrina (Noe et al., 2007). Epidemiological investigation revealed that, after adjusting for race and occupation, there was a 20-fold increase in the risk of contracting skin disease among workers who slept in previously inundated huts as compared to others (95% CI: 5.9, 70.2) (Noe et al., 2007). It was suggested that rashes may have been caused by mites, known to breed in flood-impacted buildings (Noe et al., 2007).

Studies have shown a significant growth of indoor mould following floods, demonstrated by high indoor/outdoor ratios of mould spores (Schwab et al., 2007, Barbeau et al., 2010; Hsu et al., 2011). Different species of mould can impact health either through direct respiratory infection, generation of a harmful immune response or severe reactions when the toxins produced by mould (mycotoxins) are ingested (Brandt et al., 2006; Bush et al., 2006; Metts, 2008). However, while other factors (such as seasonality) are known to be significantly associated with the indoor mould growth, the role of floods in this process is not well understood (Hsu et al., 2011). A 2004 Institute of Medicine report concluded that serious adverse effects of indoor mould following floods among healthy adults were rare and occurred mainly in susceptible persons, such as asthmatics and children (IOM, 2004). Studies conducted in the aftermath of hurricanes Katrina and Rita also failed to show fungal infections among residents whose homes were flooded (Barbeau et al., 2010, Rao et al., 2007, Rabito et al., 2008). The „Katrina cough', a widespread dry cough observed following the disasters, was attributed to a number of factors and not exclusively to indoor mould (Barbeau et al., 2010). Mycotoxins were found in previously inundated homes even two years post-Katrina (Bloom et al., 2009), however there was no evidence of health effects from indoor airborne exposure to these (Metts, 2008, Brandt et al., 2006)). In a recent study, Hsu and colleagues (2011) for the first time quantified the change in the ratio of indoor microbial levels before and after floods (Hsu et al., 2011). They demonstrated that the 2009 flood in Taiwan's metropolitan area resulted in a significant increase in concentration of indoor fungi, some of which (*A. versicolor*) are known to be associated with negative health outcomes (Hsu et al., 2011).

d) Leptospirosis. Leptospirosis, an acute febrile illness contracted through direct skin contact with the areas contaminated with the urine of infected rodents is the only flood-related water-borne disease that has proven to be epidemic (WHO, 2003). Outbreaks of leptospirosis following floods have been observed in a variety of environments globally in both rural and urban areas (WHO, 2003; Gaynor et al., 2007; Lau et al., 2010), although highly populated areas with suboptimal drainage (i.e. urban slums) (Gaynor et al., 2007; Lau et al., 2010), low-lying areas and small island states (Lau et al., 2010) have been found to be most at risk. Initial symptoms of leptospirosis may resemble those of other diseases often occurring after floods (Gaynor et al., 2007; Lau et al., 2010; Maskey et al., 2006). In the past a resemblance to other febrile diseases, inappropriate sample collection and a lack of testing facilities have resulted in a severe under-diagnosis of infection (Gaynor et al., 2007; Lau et al., 2010; Maskey et al., 2006). Prompt diagnosis and dispatch of appropriate antibiotic therapy are essential in preventing disease progression, which can lead to acute system failure and fatality (Gaynor et al., 2007). WHO has reported that the incidence of leptospirosis may reach over 100 per 100,000 with case fatality rate ranging from less than 5% to 30% (WHO, 2003).

Leptospirosis is endemic in much of South-East Asia and floods have been shown to increase the risk of infection (Kawaguchi et al., 2008). Leptospirosis incidence in Mumbai, India, increased eight-fold as a result of the 2005 floods (Lau et al., 2010; Maskey et al., 2006). In rural areas of Lao PDR, recent flooding on one's property was associated with a two-fold increase in infection (odds ratio (OR)=2.12, 95% CI: 1.25, 3.58) (Kawaguchi et al., 2008). In Argentina (1999-2005) over 75% of all new cases of leptospirosis were detected during the rainy season, when flooding is common (Vanasco et al., 2008). In that study, contact with contaminated flood waters increased the odds of infection more than four-fold (Vanasco et al., 2008). At the university campus in Honolulu at least two students contracted leptospirosis following the 2004 flood, which was due to poor drainage on the campus and wound exposure to flood water (Gaynor et al., 2007).

3.1.6. Vector-borne diseases. Mosquitoes transmitting diseases often breed in receding flood waters. Floods can therefore potentially increase the spread of vector-borne diseases such as malaria, dengue, dengue haemorrhagic fever, yellow fever and West Nile fever (WHO, Flooding and communicable diseases fact sheet). However, dengue transmission is seasonal and not directly attributed to floods (Watson et al., 2007). Vector-borne diseases are transmitted to humans through the bites of mosquitoes carrying the virus, and onset of the disease in humans usually occurs several weeks following the floods (WHO, Flooding and communicable diseases fact sheet). In addition, vector-borne diseases may also occur when the flood- impacted individuals and rescue workers are bitten by animals, usually bats or skunks (Ligon, 2006). The risk for flood-related vector-borne disease outbreaks can be influenced by factors such as increasing exposure to vectors (i.e. by sleeping outside and overcrowding), changes in vector habitat (WHO, Flooding and communicable diseases fact sheet) and compromised vector control programs during floods (Watson, et al., 2007). Flood-related malaria epidemics have occurred in malaria-endemic countries, such as African countries (Abaya et al., 2009, Sidley, 2008), the Dominican Republic (WHO, Flooding and communicable diseases fact sheet), and elsewhere, such as the dry coastal region of northern Peru (Watson et al., 2007) and Pakistan.

3.2. Longer-term impacts of floods

The long-term impact of floods on mortality is complex and not well understood. Long-term mortality may be attributed to floods directly, such as increases in diarrheal deaths in low-income countries (Ramin and McMichael, 2009, Schwartz et al., 2006) or indirectly, by impacting health, food and economic systems, exacerbating poverty, malnutrition and non-communicable diseases. During the first year following a flood, the mortality rate in affected populations may continue to increase by up to 50% (Fundter et al., 2008), as confirmed with the 47% increase in proportion of deaths in the first year following hurricane Katrina (1317 deaths per month versus 924 per month relative to a four year baseline) (Stephens et al., 2007). Retrospective analysis of the burden of floods on health in China revealed that two years post-flood the all-cause mortality and years of potential life lost for five leading causes of death were significantly higher in groups exposed to floods (Li et al., 2007).

3.2.1. *Non-communicable diseases.* In 2008, 36 out of 57 million people in the world died from non-communicable diseases (NCDs) (63% all deaths), in particular from cardiovascular disease, cancer, chronic lung diseases and diabetes (Friel et al., 2011; WHO 2011). Low and medium-income countries have experienced 80% of all NCD-attributable deaths, with this trend expected to continue (Friel et al., 2011; WHO 2011). Chronic disease and related conditions (CDRCs) can be worsened by disasters, increasing a person's vulnerability to adverse health outcomes following a flood (Sharma, et al., 2008).

Reports from the United States show that CDRCs account for one of the largest proportion of flood-related hospitalizations, particularly among the elderly. In the immediate post-flood period this burden has been found to outgrow that related to non-fatal injuries (Diaz, 2004), (Centers for Disease Control and Prevention, 2006; Sharma et al., 2008). Surveillance data from New Orleans two months post Katrina and Rita showed that of 21,673 health care visits, almost 60% were for illness (24.3% CDRCs) (Sharma et al., 2008), with heart disease accounting for 11% of CDRCs (Brunkard et al., 2008). Inability to maintain a stable medication uptake was the main barrier to continuity of care for chronic conditions during the disaster, with inadequate information and financial constraints as contributing factors (Arrieta et al., 2009). In the Japanese flood of 2006, individuals 75 years or older and those receiving long-term care service were more likely to have their medications interrupted as a result of floods (OR= 3.6, 95% CI: 1.0, 12.6 and OR=4.6, 95% CI: 1.1, 19.1, respectively), with the interruption causing a four-fold risk of worse health outcomes as compared to patients with continued care (OR=4.5, 95% CI: 1.2, 17.6) (Tomio et al., 2010). No similar surveillance data appear to have been collected in low-resource countries, however, with low-income countries carrying the largest burden of chronic disease globally, a substantial impact of floods on NCDs would be expected.

3.2.2. Psychosocial health. Physical and social functioning deteriorates as a result of direct and longer-term losses and stress caused by floods (Desalvo et al., 2007; Heo et al., 2008; Norris et al., 2004) and these effects have been well documented in low and high-resource countries. Mental health disorders most commonly found in people affected by natural disasters such as floods are post-traumatic stress disorder (PTSD), followed by depression and anxiety (Liu et al., 2006; Mason et al., 2010; Norris et al., 2005). Psychosocial symptoms often reported are earache, headache and bodily pain (Carroll et al., 2010, Reacher et al., 2004, Chae et al., 2005). Studies of floods report prevalence of mental health disorders ranging from 8.6% (Liu et al., 2006) to 53% (Heo et al., 2008) in the first two years following floods. Psychological distress may also account for a portion of the physical illness experienced following floods (Reacher et al., 2004) and together these have a lasting impact on the quality of life of survivors. The most profound psychosocial effects are long-term, gradual and co-morbid (Friel et al., 2011) and may be more prevalent in poor resource environments (Norris et al., 2004).

Several risk factors for the development of psychological disorders following natural disasters have been identified, such as the degree of exposure (Assanangkornchai et al., 2004; Reacher et al., 2004; Heo et al., 2008; Norris et al., 2004, Mason et al., 2010, Liu et al., 2006, Neria et al., 2008) previous flood experience and disaster preparedness (Assanangkornchai et al., 2004, Morrissey and Reser, 2007; Paranjothy et al., 2011), female gender and older age (Desalvo et al., 2007; Mason et al., 2010; Liu et al.,2006; Neria et al., 2008), socio-economic status (SES) (Assanangkornchai et al., 2004), family structure, religion (Assanangkornchai et al., 2004), social support (Neria et al., 2008), self-reported physical health (Desalvo et al., 2007; Mason et al., 2010; Paranjothy et al., 2011; Galea et al., 2005; Tapsell et al., 2002), and personality factors (Assanangkornchai et al., 2004; Mason et al., 2010; Neria et al., 2008; Morrissey and Reser, 2007). It is also suspected that psychosocial impacts may be higher in rural as compared to urban communities due to older age, lower education level of the rural population (Heo et al., 2008, Berry et al., 2008; Berry et al., 2011;) and living with the constant threat of severe climate events (Morrissey and Reser, 2007).

Direct trauma exposure has been consistently reported as a risk factor for developing adverse psychosocial outcomes in both high and low-resource countries (Assanangkornchai et al., 2004; Reacher et al., 2004; Norris et al., 2004; Heo et al., 2008; Mason et al., 2010; Liu et al., 2006; Neria et al., 2008). Following the 1999 floods in Mexico, the 6 month post-disaster symptoms of trauma and depression were found in 25% of the impacted population overall, and in over half of those who experienced flash flooding, unexpected mudslides, mass casualties and displacement (Norris et al., 2004). Ten weeks following an unexpected, severe flood in Thailand, subjects who reported their loss as severe were four times more likely to report PTSD symptoms (Assanangkornchai et al., 2004). In a remote village in Korea, flood-related injury, relative's deaths or damage to possession were significant risk factors for depression (51%) and PTSD (22%) at 18 months post-disaster (Heo et al., 2008)). Longitudinal studies of mental impacts of floods provide insights into the nature of long-term psychiatric co-morbidities (Ahern et al., 2005; Du et al., 2010). In a longitudinal study of trauma and depression following the 1999 floods in Mexico, Norris and colleagues found that despite the initial decline in symptoms, in the longer term (2 years) the prevalence of trauma and depression stabilized at levels much higher than those in the general population (Norris et al., 2004). Similar findings were reported in Thailand (Assanangkornchai et al., 2007), where in addition, an „anniversary reaction' was observed– an increase in psychiatric symptoms one year following the flood, despite a significant downward trend in mental health symptoms in the first year (Assanangkornchai et al., 2007). This may be because floods can result in acute and delayed onset of PTSD, with different symptoms emerging at short and long-term (Vachiramon et al., 2008).

3.2.3. Malnutrition. As seen in Bangladesh, Africa and some parts of Australia, floods inundate land and destroy crops. While in high-resource countries crop destruction impacts the economic and mental wellbeing of farmers and their families (Berry et al., 2008; Berry et al., 2011), in low-resource countries it depletes the already low baseline levels of resources and population health (Abaya et al., 2009; Friel et al., 2011; Bourque et al., 2006; Goudet et al., 2011). When Hurricane George struck the Dominican Republic in 1998, 300 people died and many were affected by severe food and medication shortages; when it struck the American territory of Puerto Rico, it claimed eight post-disaster fatalities (Bourque et al., 2006). In countries such as Bangladesh or Ethiopia, where baseline malnutrition is among the highest in the world (in both countries nearly half of children under five are stunted) flood-related destruction of crops has aggravated an already dire food supply (Abaya et al., 2009; del Ninno and Lundberg, 2005). As a result, floods have been associated with malnutrition in infants and young children in rural areas (del Ninno and Lundberg 2005) and urban slum dwellings in developing countries (Goudet et al., 2011).

A two year longitudinal study following the 1998 floods in Bangladesh revealed that children in flood-affected households were systematically smaller than those not impacted (del Ninno and Lundberg, 2005). Pregnant mothers from urban slums in Dhaka identified flood as a root cause of malnutrition in infants and young children, helping to clarify the complex relationship between floods, food shortage, maternal malnutrition, decreased levels of breastfeeding, diarrheal disease among children, and child malnutrition (Goudet et al., 2011). Based on these findings, it was argued that natural disasters need to be considered within the existing causal models of malnutrition (Goudet et al., 2011).

3.2.4. Birth outcomes. By affecting physical and mental health of pregnant mothers and their ability to access health services, floods may impact on the health of newborns. Studies of women with prenatal disaster exposure have indicated that high levels of prenatal stress are associated with poor pregnancy outcomes (Tong et al., 2011) and negative health outcomes in children, including behavioural problems and psychiatric disorders (Kinney et al., 2008). The risk of negative impacts on birth outcomes and child's health increases with the level and timing of disaster exposure within the gestational period (Kinney et al., 2008).

In post-disaster interviews, women who were pregnant during hurricanes Katrina and Rita expressed feelings of loss and uncertainty that were attributed to disaster experience, and worry about the potential impacts of disaster on their pregnancy outcome (Badakhsh et al., 2010). A study conducted with women who became pregnant within six months following Katrina showed that severe hurricane exposure was significantly associated with worse birth outcomes (Xiong et al., 2008). In that study, severe hurricane exposure was a risk factor for low birth weight delivery (OR=3.3, $p<.01$) and preterm birth (OR=2.3, $p<.05$) after adjusting for maternal characteristics, smoking and alcohol use and medical history (Xiong et al., 2008). In North Dakota exposure to floods was similarly associated with maternal medical risks, along with low and preterm births, after adjusting for maternal characteristics and smoking (Tong et al., 2011). Another study revealed that hurricane exposure during pregnancy was significantly associated with the risk of child being born with autism spectrum disorder if exposure occurred during a more sensitive gestational age as compared to less sensitive gestational period (prevalence rate 26.6 versus 3.9, respectively) (Kinney et al., 2008).

4. DISCUSSION

This paper extends previous work (Du et al., 2010, Ahern et al., 2005) by systematically reviewing recent evidence related to the impacts of floods on human health. We identified 35 key studies, which reported on the categories of flood-related health outcomes described in existing reviews, and some new categories. The latter included communicable and non-communicable diseases, toxic exposure, adverse birth outcomes and malnutrition. We divided health impacts into short and long-term. We found that while most of short-term impacts are well documented, longer-term impacts need to be better understood.

4.1. Differential vulnerability to flood exposure and health outcomes. Differential vulnerability among low and high-income countries and communities to flood exposure and its associated negative impacts is a key issue to address when discussing the floods impact on human health. Developing as opposed to high-income countries face ongoing pressures which render floods particularly devastating, such as low baseline health and poor infrastructure (Shimi et al., 2010), changing disease patterns, conflict, poor government, high debt burdens (Ramin and McMichael, 2009) and the negative impacts of economic globalization (Leichenko and O'Brien, 2002). Floods exacerbate these ongoing pressures and in the long-term deepen the poverty and vulnerability of the people (Shimi et al., 2010).

Nevertheless, even within medium- and high-income countries existing disparities place vulnerable groups (i.e. poor communities of colour, ethnic minorities, the urban homeless and people with chronic diseases) at a higher risk of severe flood exposure and related negative health outcomes (Assanangkornchai et al., 2004; Zahran et al., 2008; Barbeau et al., 2010; Chen et al., 2007; The Henry J. Kaiser Family Foundation, 2007; Guidry and Margolis, 2005; Ramin and Svoboda 2009). Although difficult, these differences in vulnerability to floods need to be addressed via an environmental approach combining social and physical environmental factors (Yeo and Blong, 2010).

As such, preventive measures and adaptation planning to reduce post-flood mortality and morbidity must be context specific. In low-resource settings, promotion of equitable and sustainable economic growth is a necessary first step toward building population's adaptive capacity to severe weather events, including floods (Ramin and McMichael, 2009; Paul and Routray, 2010). In higher-resource countries, epidemiologic evidence points to the effectiveness of specific preventive measures, such as early warning systems and dissemination of alerts in remote areas (Assanangkornchai et al., 2004), timely evacuation (Fundter et al., 2008; Bourque et al., 2006), timely flood remediation and promotion of positive coping strategies (Assanangkornchai et al., 2004; Mason et al., 2010). Some of these have been shown to not only save lives but also help offset associated short- and long-term health impacts (Fundter et al., 2008; Assanangkornchai et al., 2004). However, several barriers to implementation of preventive measures exist, including availability of emergency shelters, flood awareness, residents' ability and willingness to evacuate, and the cost of the operation (Assanangkornchai et al., 2004; Mason et al., 2010).

4.2. Addressing immediate and future needs. This review demonstrated that several short and long-term health impacts of floods could significantly contribute to the global burden of disease and therefore need to be addressed. Outbreaks of communicable diseases, although uncommon unless accompanied by heavy population displacement (WHO, Flooding and communicable diseases fact sheet; Watson et al., 2007), have been reported after floods. For example, the risk of contracting leptospirosis increases during floods even in high-income urban environments, with the potential to significantly increase morbidity and mortality if left untreated (Gaynor et al., 2007; Lau et al., 2010; Maskey et al., 2006). Consequently, appropriate public health messages, combined with improved surveillance programs for the detection of disease should be introduced as part of flood emergency preparedness (Gaynor et al., 2007; Lau et al., 2010). Also, anticipated increases in urbanization and inhabiting of flood-prone areas (Du et al., 2010) require further epidemiological research on the association between exposure to indoor mould following floods and short- and long-term health effects. This is particularly true for children and other vulnerable populations (Barbeau et al., 2010; Hsu et al., 2011). Floods will continue to increase the burden of non-communicable diseases (NCDs) and poor mental health globally, particularly in low and medium-income countries where such issues receive less attention. Surveillance data from the United States have repeatedly demonstrated that exacerbation of chronic diseases is one of the most common reasons for presentation to emergency facilities during and immediately after natural disasters (Sharma et al., 2008). Consequently, any flood-related disruptions to infrastructure can contribute to negative health outcomes in individuals with unmanaged chronic conditions. In light of the growing global epidemic of NCDs (WHO, 2011) and the aging of populations, it will become increasingly important to ensure that patients with CDRCs are monitored and their medication sustained during floods. Psychological distress may account for a portion of the physical illness experienced following floods (Reacher et al., 2004), thus exacerbating overall flood-related morbidity and mortality. In addition to direct trauma (Assanangkornchai et al., 2004; Reacher et al., 2004; Heo et al., 2008; Norris et al., 2004; Mason et al., 2010; Liu et al., 2006; Neria et al., 2008), other factors associated with psychiatric vulnerability following floods (Assanangkornchai et al., 2004; Mason et al., 2010; Liu et al., 2006; Neria et al., 2008; Galea et al., 2005; Morrissey and Reser, 2007; Tapsell et al., 2002) need to be further investigated to identify high-risk groups (Neria et al., 2008). In order to lower flood-related psychiatric morbidities, outreach strategies to affected communities, mental health surveillance, and the availability of appropriate services should be improved. The indirect impacts of floods on human health require further investigation. For instance, the impact of floods on maternal and child health (MCH) and child nutrition needs to be better understood (Goudet et al., 2011). This is especially true in urban poor areas which are often located on floodplains (Yeo and Blong, 2010; Norris et al., 2004). In addition, pregnant women are a population that may be particularly vulnerable to disasters. Women's elevated risk for worse mental health outcomes following disaster exposure (Mason et al., 2010; Liu et al., 2006), combined with negative impacts of prenatal stress on MCH (Kinney et al., 2008; Tong et al., 2011; Xiong et al., 2008), call for a greater attention to women's reproductive health following flood events.

In order to better understand flood-related health risks, we identified the following knowledge gaps:

- What are the effective context-specific preventive measures to lower flood-related mortality and morbidity?
- What is the impact of floods on pregnancy?
- What is the impact of flood on child nutrition, particularly in urban poor?
- Is there epidemiological evidence for the role of floods in indoor mould growth and toxic contamination? If so what are the long-term health impacts of these exposures?
- What is the long-term impact of floods on non-communicable diseases, including chronic disease and mental health illness?

4.3. Limitations. There are some limitations in this review. Firstly, the health outcome categories used here may not illustrate the full extent of the potential direct and indirect health impacts of floods. However, the categories presented here emerged in previous (Ahern et al., 2005; Du et al., 2010) and current literature reviews on the topic. Secondly, global epidemiological data were reviewed but flood exposure and health consequences vary greatly between low and high-income countries. Therefore caution is needed in drawing general conclusions.

5. CONCLUSIONS

Reported flood-related impacts on human health are widespread and complex. Floods continue to impact communities unequally and in different ways, with effects ranging from short to longer term, direct and indirect. Health outcomes depend on both the characteristics of the flooding event and people's vulnerability. The risk for disease outbreaks increases with population displacement and poor hygiene. Psychological distress in survivors is well documented and accounts for a portion of all physical illness. Trends in urbanization, burden of disease, malnutrition and maternal and child health globally mean that the urban poor, women and children, the elderly and those with chronic conditions will need to be better protected with flood preparedness and mitigation programs. Epidemiologic evidence can inform the policy and emergency preparedness, ultimately contributing to better health outcomes for flood impacted communities.

6. APPENDICES

Appendix A Table 1. Medline search strategy used to identify studies for inclusion

Appendix B Figure 1. Flow chart of article selection process

Appendix C Table 2. Characteristics of key studies

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Table 1. Medline search strategy used to identify studies for inclusion

Key words relating to flood and flood-like disasters [exposure] flood* OR disaster* OR tsunami* OR health disaster OR natural disaster OR storm* OR hurricane* as Medical Subject Headings (MeSH) or keywords in the title, abstract or subject heading AND *Key words relating to health outcomes [outcome]* health* OR public health*OR diseas* OR infectio* OR mortalit* OR morbidit* OR illness OR epidemic* OR injur* OR health status OR health impact* OR health effect* OR mental health* OR stress* OR anxiet* as Medical Subject Headings (MeSH) or keywords in the title, abstract or subject heading limits: [Date of Publication: 2004–2011; Abstract Available; English Language; Human]

Table 2. Characteristics of key studies

Authors, year	Location & year of flood	Study design	Main results
		SHORT TERM Short-term mortality	
Li et al., 2007	Hunan, China, 1998	Cross-sectional, cohort study 1 year post-flood. Household survey supplemented with review of death certificates. 117,692 cases (exposed to flood or drainage issues) and 104,368 controls.	Standard MR[1] of the flood group (697.14/105) and drainage group (683.90/105) higher than control (611.67/105, $p<0.05$). All cause MR and YPLL[2] for 5 leading death causes higher in cases than in the controls, and in the flood group versus drainage group.
Pradhan et al., 2007	Nepal, 1993	Cross-sectional study 1 month post-flood, survey among children aged 2-9 (n=41,501) and their adult parents (n=7,252) for which pre-flood longitudinal data existed.	Flood-related fatality rates (per 1000) 13.3 (girls), 9.4 (boys), 6.1 (women), 4.1 (men). Risk of fatality higher when house swept away (RR[3]=57.1, 95% CI[4]: 38.0, 84.3), lower SES[5] (RR=6.4, 95% CI: 2.7, 20.0) and house constructed of thatch versus brick (RR=5.1, 95% CI: 1.7, 24.5). Risk of fatality higher in all children 1 month post-flood versus before (RR=5.9, 95% CI: 5.0, 6.8), in girls age 2-5 versus boys (RR=1.7, 95% CI: 1.1, 2.8) and in women versus men at each age group (RR=1.5, 95% CI: 1.1, 2.1).
Brunkard et al., 2008	Louisiana, USA, 2005 (Hurricane Katrina)	Retrospective cohort study. Mortality data collected in the first 2 months from Louisiana and evacuees to other states	1440 deaths. Major causes of death: drowning (40%), injury and trauma (25%), heart disease (11%). Estimated risk of fatality significantly elevated for those ages 75+ (49% despite this age cohort representing only 6% of this population) and blacks (1.7 to 4 times higher than that among whites for all people aged 18+).
Yeo and Blong, 2010	Fiji Islands, 1931	Descriptive. Mortality data collected post-flood.	225 deaths. Risk of fatality significantly higher for males (MR 9.3 versus females MR 5.4), children, ethnic Indians inhabiting floodplains (MR 9.4 versus Fijian MR 3.7). High death toll attributed to the sudden onset of the floods during night, failed warning system and evacuation constraints (no boats, many could not swim).
Milojevic et al., 2011	England and Wales, 1993-2006	Retrospective longitudinal study. Postcode of residence linked to a national database of flood events.	Analyses suggested a post-flood 'deficit' of deaths, (post/pre flood ratio=0.9, 95% CI: 0.82, 1.00). Possibly because address recorded on mortality data may not be that of permanent residence, and unit of analysis was postcode of residence as opposed to the affected individual.

[1] MR= mortality rate
[2] YPLL= years of potential life lost
[3] RR= relative risk
[4] 95% CI= 95% confidence Interval
[5] SES= socio-economic status

		Injuries	
Schnitzler et al., 2007	Saxony, Germany, 2002	Cross-sectional study. Telephone survey in flood-affected neighbourhoods.	In days following the flood 55 (11.7%) individuals reported injuries, significantly related to skin contact with flood water (OR[6]=17.8, CI: 2.4, 130.5)
Zahran et al., 2008	East Texas, USA, 1997-2011	Analytical study. Analysis of 832 countywide flood events in Texas from 1997–2001	5873 people injured and 49 killed in floods. After adjusting for characteristics of built environment and SES, risk of fatality increases with the level of precipitation on the day of the flood (OR=1.25), flood duration (OR=1.86) property damage caused by the flood (OR=1.73), population density (OR=2.99) and social vulnerability (OR=1.42).
		Toxic Exposure	
Fox et al., 2009	Louisiana, USA, 2005 (Hurricane Katrina)	Cross-sectional analytical study. 4 phases of sediment sampling 1-12 months post-flood in affected areas, combined with collection of target organ and health effects data	Contaminants found to be not specific to New Orleans area or to post-hurricane, but to any industrialized area. 12 (35%) of frequently reported chemicals of concern for health found at concentrations exceeding residential soil or water screening levels.
Cox et al., 2008	Louisiana, USA, 2005 (Hurricane Katrina)	Cohort study. Retrospective analysis of Mississippi Poison Control Centre calls made in the 12 weeks post-flood	Significant increase in calls related to exposures to: lamp oil OR=13.4 (95% CI: 2.8, 63.1), gasoline 7.3 (95% CI: 4.3, 12.4), carbon monoxide 7.8 (95% CI: 2.0, 30.2) and food poisoning 1.7 (95% CI: 0.6, 4.4) as compared to average in years 2002-4.
		Communicable diseases *Water borne disease: gastrointestinal*	
Schwartz et al., 2006	Dhaka, Bangladesh, 3 consecutive floods, 1988, 1998, 2004	Longitudinal study. 15-year surveillance data on children and adults with diarrhoea symptoms. Floods periods compared to seasonally matched control periods.	In all flood-associated diarrheal epidemics (1988-2004) cholera was a predominant cause (IR[7]=2.0, compared to control period) followed by rotavirus. In 1988 floods 35% of all flood-related illness and 27% of deaths attributed to diarrheal disease.
Shimi et al., 2010	Goalanda Upazilla, rural Bangladesh, floods of 1998 and 2004	Qualitative retrospective study with 120 households most affected in previous floods (questionnaires, interviews and focus groups).	In both floods two thirds tube-wells (sources of drinking water) and 97% latrines were inundated. 55% of households reported diarrhoea and 58% reported fever.
Vollaard et al., 2004	Jakarta, Indonesia, 2001-2003	Community-based case-control study. 93 patients presenting with Salmonella-related fever, 289 non-Salmonella fever patient controls and 378 randomly selected community controls.	Flooding of house was significantly associated with increased risk of paratyphoid fever (compared with community controls: OR, 4.52; 95% CI: 1.90, 10.73; compared with fever controls: OR, 3.25; 95% CI: 1.31, 8.02).

[6] OR= odds ratio
[7] IR= incidence rate

Schnitzler et al., 2007	Saxony, Germany, 2002	Cross-sectional. Telephone survey in flood-affected neighbourhoods.	Skin contact with flood water significantly associated with onset of diarrhoea (OR=5.8, 95% CI: 1.3, 25.1). 6.9% of interviewed people reported onset of diarrhoea in days following the flood.
Carroll et al., 2010	Carlisle, England, 2005	Cross-sectional qualitative study. 10-13 month post-flood among flood-affected individuals.	Stomach upsets attributed to the floods.
Yee et al., 2007	Texas, USA, 2005 (Hurricane Katrina)	Cross-sectional study. Surveillance data collected 1-4 weeks post-flood from evacuees residing in a mega shelter.	A 9-day long outbreak of gastroenteritis confirmed with diarrhoea and vomiting attributed to norovirus. IR 4.3 per 1, 000 persons per day (4% of study population fell ill).
		Water borne disease: respiratory and skin infection	
Murray et al., 2009	Texas, USA, 2005 (Hurricane Katrina)	Cross-sectional study. Surveillance data (including specimen collection) collected 1-4 weeks post-flood from evacuees residing in a mega shelter.	29,478 evacuees. Most often reported symptoms likely attributed to exposure to flood water: cough (7.6% out of 487 surveyed), runny nose (9.9% out of 916) (increased over time), rash (3.5% out of 2,665) (in the first days post-flood) and sore throat (3.5% out of 2,165).
Carroll et al., 2010	Carlisle, England, 2005	Cross-sectional qualitative study. 10-13 month post-flood among flood-affected individuals.	Recurring flu-like symptoms, throat and other infections, coughs, general sickness attributed to the floods.
Reacher et al., 2004	Lewes in Southern England, 2000	Historical cohort study. 9 months post-flood telephone interviews with 227 cases (house flooded) and 240 controls (not-flooded households from same postcodes).	Flooding of house associated with increased risk of earache (RR=2.2, p<0.05), gastroenteritis (RR=1.7, p<0.5), respiratory illness in adults with pre-existing asthma (RR=3.1, p<0.05). In adults, the risk estimates for physical illnesses declined after adjustment for psychological distress.
Vachiramon et al., 2008	Thailand, 2006	Descriptive study. 1 month post-flood 38 male and 58 female flood-affected patients complaining of skin problems were clinically evaluated.	Dermatoses (57.9% patients) and infectious skin conditions (39.2% patients) most commonly diagnosed. Two cases of fungal infection.
Noe et al., 2007	Louisiana, USA, 2005 [Hurricanes Katrina and Rita]	Retrospective cohort study. 58 out of 136 (42.6%) workers repairing buildings damaged during hurricane complaining of skin rashes were clinically evaluated.	Sleeping in previously inundated huts significantly associated with rash (OR=20.4, 95% CI: 5.9, 70.2) after adjusting for race/ethnicity and occupation. Rash possibly linked to mite infestation.
		Water borne disease: leptospirosis	
Gaynor et al., 2007	Honolulu, Hawaii 2004	Descriptive study. 1 month post-flood. 271 persons responded to the survey (denominator unknown) + interviews with faculty and staff.	Within 30 days after contact with flood water febrile illness reported by 90 (33%). Fever reported by 32% faculty or staff, 24% students and 69% clean-up crew. 2 cases of leptospirosis confirmed, in both cases due to open wounds exposed to flood water.
Maskey et al., 2006	Mumbai, India, 2005	Cross-sectional study. 1359 serum samples	Eight-fold higher risk of contracting leptospirosis during flood compared to the

		collected from hospitalized patients with clinical symptoms of leptospirosis.	seasonal matched control from four previous years.
Vanasco et al., 2008	Argentina, 1999-2005	Descriptive study. Data from national reference laboratory 1999-2005, where suspected cases of leptospirosis were referred.	Exposure to floodwater a significant risk factor for contracting leptospirosis (OR=4.49, 95% CI: 1.17, 17.25).
Kawaguchi et al., 2008	Khamouane Province, two rural districts, PDR, 2006	Cross-sectional study. 406 randomly sampled residents aged 15+. Leptospirosis endemic in that province (seroprevalance 23.9%).	Flooding of a house a significant risk factor for contracting leptospirosis (OR=2.12, 95% CI: 1.25, 3.58).
		LONG TERM Birth Outcomes	
Xiong et al., 2008	Louisiana, USA, 2005 [Hurricanes Katrina and Rita]	Prospective cohort study. 6-18 months post-disasters. 301 adult women who were pregnant or became pregnant immediate after hurricanes.	Twofold higher risk of preterm birth (OR=2.3, $p<0.05$) and threefold higher risk of low birth weight infant (OR=3.3, $p<0.01$) in women who experienced 3 or more severe hurricane events as opposed to fewer.
Tong et al., 2011	North Dakota, USA, 1997	Historical cohort study. County-level birth files from North Dakota pre-flood (1994–1996) and post-flood (1997–2000) were analysed.	Post-flood higher risk of low birth weight births (OR 1.11, 95% CI: 1.03, 1.21) preterm births (OR 1.09, 95% CI: 1.03, 1.16) and maternal medical risks compared to pre-flood, after adjusting for maternal characteristics and smoking.
		Psychosocial health	
Chae et al., 2005	Korea, 2002	Case-control study. 3-6 months post-flood 339 cases (residents in heavily flooded areas) and 246 controls (residents in non-flooded areas) surveyed, aged14-95.	Exposure to floods associated with higher incidence of: headaches (33.9% cases versus 15.5% controls), sleeping disorders (27.1% cases versus 14.7 % controls); heart palpitations (33.9% cases versus 15.1% controls), post-flood anxiety (21.3% cases versus 1.6% controls), symptoms of PTSD[8] (39.5% cases versus 2.1% controls). 90.1% all respondents reported not suffering from mental health disorders in the past.
Paranjothy et al., 2011	England, 2007	Cross-sectional study. 3-6 months post-flood 2265 individuals surveyed.	Two- to five-fold higher prevalence of mental health symptoms in people whose houses were flooded versus controls. Highest prevalence where water was above floor level (OR=12.8 psychological distress, OR=17.8 anxiety, OR=7.7 depression, OR=11.9 probable PTSD), as compared to below (OR=3.0, 2.1, 2.9 and 2.6, respectively) or outside the house (OR= 1.8, 1.7, 1.1 and 2.6, respectively).
Mason et al., 2010	England, location and year of flood	Cross-sectional study. 6 months post-flood, 440	35.1% of respondents scored over threshold to be classified for depression, followed by

[8] PTSD= post-traumatic stress disorder

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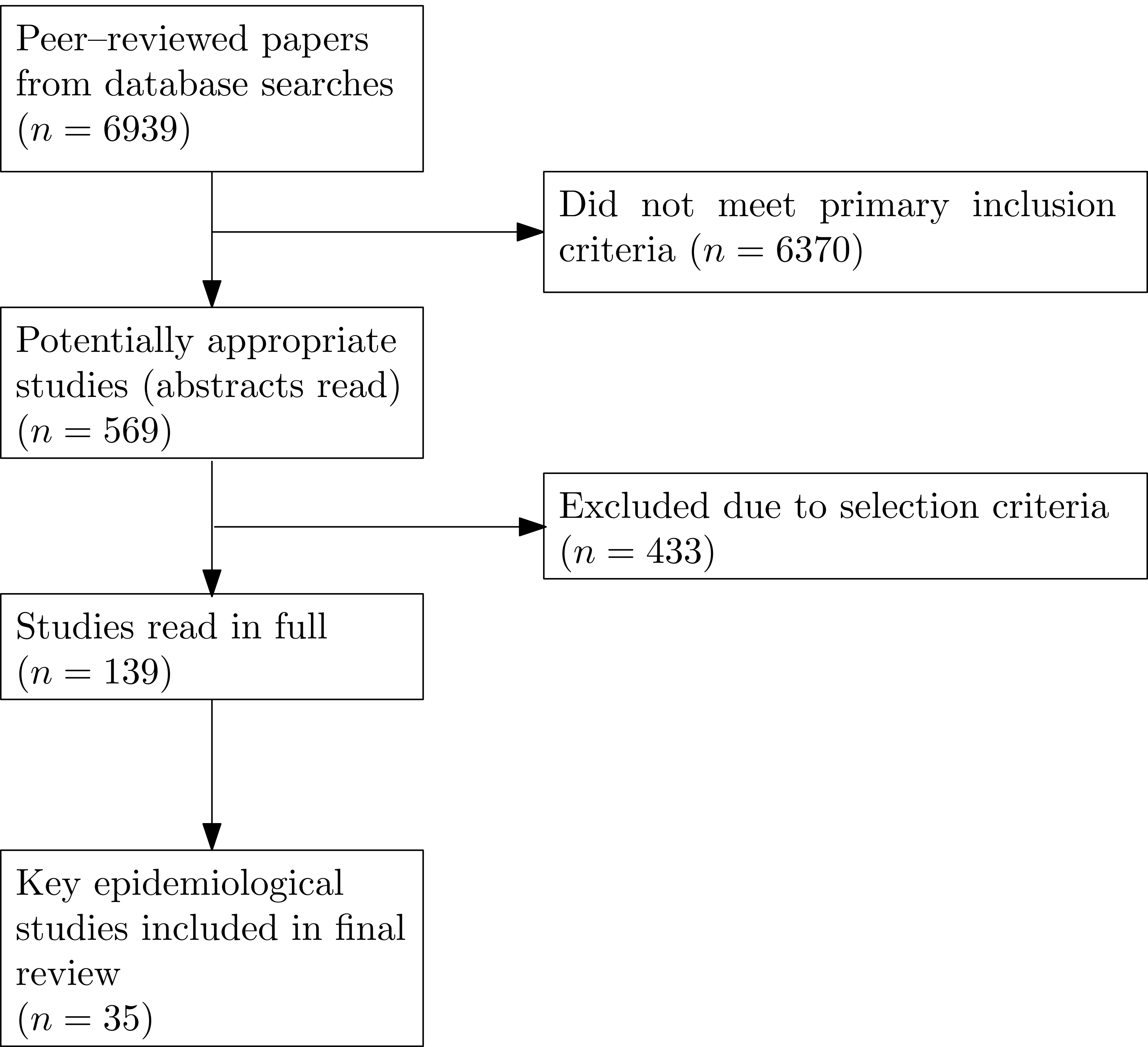
Figure 1



Peer–reviewed papers from database searches ($n = 6939$)
Did not meet primary inclusion criteria ($n = 6370$)
Potentially appropriate studies (abstracts read) ($n = 569$)
Excluded due to selection criteria ($n = 433$)
Studies read in full ($n = 139$)
Key epidemiological studies included in final review ($n = 35$)