

Global Health Impacts of Floods: Epidemiologic Evidence

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Abbreviations: CI, confidence interval; PTSD, posttraumatic stress disorder; RR, relative risk.

INTRODUCTION

Floods are the most common natural disaster in both developed and developing countries, and they are occasionally of devastating impact, as the floods in China in 1959 and Bangladesh in 1974 and the tsunami in Southeast Asia in December 2004 show (1). Their impacts on health vary between populations for reasons relating to population vulnerability and type of flood event (2–5). Under future climate change, altered patterns of precipitation and sea level rise are expected to increase the frequency and intensity of floods in many regions of the world (6). In this paper, we review the epidemiologic evidence of flood-related health impacts. The specific objectives were as follows:

1. to summarize and critically appraise evidence of published studies, covering flood events in all regions of the world, and
2. to identify knowledge gaps relevant to the reduction of public health impacts.

MATERIALS AND METHODS

We developed a search algorithm to identify the published literature concerning the health impacts of flood events. A search was made of the BIDS (Bath Information and Data Services, Bath, United Kingdom), CAB Abstracts (Commonwealth Agricultural Bureau International, Wallingford, Oxfordshire, United Kingdom), PsychInfo (American Psychological Association, Washington, DC), Embase (Elsevier B. V., Amsterdam, the Netherlands), and Medline/PubMed (National Library of Medicine, Bethesda, Maryland) reference databases using combinations of terms for

flooding and selected health outcomes as terms in the title, keywords, or abstract (figure 1). Terms from Medical Subject Headings (MeSH; National Library of Medicine) were used where relevant. We excluded papers that addressed only population displacement, economic losses, and disruption of food supplies. The search found 3,833 references, of which 212 were identified as epidemiologic studies from review of the abstract and/or title. The scientific quality of these papers was assessed on a case-by-case basis. In drawing inferences, we made no exclusions from these 212, but we gave greatest weight to studies based on epidemiologic designs with controlled comparisons. We report and reference the main findings in this review.

Floods are classifiable according to cause (high rainfall, tidal extremes, structural failure) and nature (e.g., regularity, speed of onset, velocity and depth of water, spatial and temporal scale), but in this review we discuss impacts according to health outcome. The influence of flood characteristics on health impacts is discussed where appropriate.

RESULTS

Mortality

Deaths associated with flood disasters are reported in the EM-DAT disaster events database (Centre for Research on the Epidemiology of Disasters, Ecole de Santé Publique, Université Catholique de Louvain, Brussels, Belgium) (1) and also in two reinsurance company databases (www.munichre.com, www.swissre.com). These databases include little epidemiologic information (age, gender, cause), however. Flood-related mortality has been studied in both high- (7–17) and low-income (18–21) countries. The most readily

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<Exposure>

(coastal flood* OR dams OR embankment* OR flash flood* OR flood* OR flood damage* OR flood disaster* OR flood exposure* OR flood risk* OR flood water* OR floodwater* OR hurricane* OR inland flood* OR inundation OR monsoon flood* OR overflow* OR river flood* OR seasonal flood* OR seawater intrusion OR storm surge* OR storm water* OR stormwater* OR tropical storm* OR typhoon* OR water logging OR waterlogging)

AND**<Outcome>**

(accident* OR alcohol* OR allergy OR allergen OR allergies OR anxiet* OR burul* OR campylo* OR cardiac arrest OR cardiovascular OR chemical pollut* OR cholera OR communicable disease* OR conjunctivitis OR contamination OR death* OR dengue OR dermatitis OR diarrhoea* OR diarrhea* OR disease* OR disease outbreak* OR drug suppl* OR drown* OR dysentery OR ear infection* OR electrocution* OR environmental health OR epidemic* OR Escherichia coli OR gastrointestinal OR giardia* OR health OR health care OR health centre* OR health center OR health effect* OR health facilit* OR health infrastructure* OR health impact* OR health post* OR health sector OR health service* OR health system* OR hepatitis A OR hospital* OR hypothermia OR illness OR infectio* OR injur* OR leptospirosis OR malaria OR malnutrition OR medical facilit* OR medicine* OR mental health OR morbidity OR mortality OR mosquito* OR naegi* OR nose infection* OR outbreak* OR pesticide* OR physical health OR poison* OR pollut* OR psychological OR psychosocial OR public health OR respiratory OR risk factor* OR shigella OR shock OR side effect* OR snake bite* OR snakebite* OR stress OR suicid* OR throat infection* OR water OR waterborne OR water-borne OR water related OR water-related OR wound* OR yellow fever)

FIGURE 1. Words used in search strategy (in title, abstract, or keywords). Note: Some search terms have been truncated (e.g., injur*), and this is normal practice when conducting reviews of this sort. In the example shown, the relevant databases will search for all words commencing with these letters and, in this case, would search for “injury,” “injuries,” etc. Nontruncated search terms with “*” (e.g., snakebite*) instruct the database to search for plurals of this term (e.g., snakebites). “OR” instructs the database to search for any of the terms listed and should not be confused with the same abbreviation for “odds ratio.”

identified flood deaths are those that occur acutely from drowning or trauma, such as being hit by objects in fast-flowing waters. The number of such deaths is determined by the characteristics of the flood, including its speed of onset (flash floods are more hazardous than slow-onset ones), depth, and extent (3). Many drownings occur when vehicles are swept away by floodwaters (12, 14, 15, 17). Evidence relating to flash floods in high-income countries suggests that most deaths are due to drowning and, particularly in the United States, are vehicle related (9, 22). Information on risk factors for flood-related death remains limited, but men appear more at risk than women (22). Those drowning in their own homes are largely the elderly.

Although the risk of deaths is most obviously increased during the period of flooding, in a controlled study of the 1969 floods in Bristol, United Kingdom, Bennet (8) reported a 50 percent increase in all-cause deaths in the flooded population in the year after the flood, most pronounced among those aged 45–64 years. Few other studies have examined such a delayed increase in deaths, but it was also reported by Lorraine (11) in relation to the 1953 storm surge flood of Canvey Island, United Kingdom, but not in two Australian studies (7, 10).

Inconclusive evidence for diarrheal deaths has been reported from several studies of floods in low-income countries. Surveillance data showed an apparent increase of mortality from diarrhea following the 1988 floods in Khartoum, Sudan, but a similar rise was also apparent in the same period (May–July) of the preceding year (20). Routine surveillance data and hospital admissions records similarly showed diarrhea to be the most frequent (27 percent) cause

of death following the severe 1988 Bangladesh floods, but again the effect of the flood was not separately quantified from seasonal influences (19). Kunii et al. (21) conducted a cross-sectional survey after the 1998 floods in Bangladesh, and of 3,109 people within flood-affected households, seven (0.23 percent) died during (but not necessarily a consequence of) the flood, two from diarrhea, two from suspected heart attacks, and three from undetermined/unrecorded causes.

Injuries

Flood-related injuries may occur as individuals attempt to remove themselves, their family, or valued possessions from danger. There is also potential for injuries when people return to their homes and businesses and begin the clean-up operation (e.g., from unstable buildings and electrical power cables).

In a community survey (108 of 181 households completed the questionnaire) of the 1988 floods in Nîmes, France, 6 percent of surveyed households reported mild injuries (contusions, cuts, sprains) related to the flood (13). In Missouri after the Midwest floods of 1993, injuries were reported through the routine surveillance system. Between July 16 and September 3, 1993, a total of 524 flood-related conditions were reported, and of these 250 (48 percent) were injuries: sprains/strains (34 percent), lacerations (24 percent), “other injuries” (11 percent), and abrasions/contusions (11 percent) (23). Similar data were also reported from Iowa (24).

Surprisingly little information is available on the frequency of nonfatal flood injuries, as they are mostly not routinely reported or identified as flood related. Although the international EM-DAT database (<http://www.em-dat.net/>) records such injuries, these data are much less robust than are reports of deaths (D. Guha-Sapir, Department of Public Health and Epidemiology, Université Catholique de Louvain, personal communication, 2004).

Fecal-oral disease

In flood conditions, there is potential for increased fecal-oral transmission of disease, especially in areas where the population does not have access to clean water and sanitation. Published studies (case-control studies, cross-sectional surveys, outbreak investigations, analyses of routine data) have reported postflood increases in cholera (25, 26), cryptosporidiosis (27), nonspecific diarrhea (18–21, 28–31), poliomyelitis (32), rotavirus (33), and typhoid and paratyphoid (34) (table 1). Some of the reported relative risks associated with flooding are substantial. In Indonesia, for example, Vollaard et al. (34) found flooding of the home to increase paratyphoid fever, with an odds ratio of 4.52 (95 percent confidence interval (CI): 1.90, 10.73), and Katsumata et al. (27) found it to increase the risk of cryptosporidiosis, with an odds ratio of 3.08 (95 percent CI: 1.9, 4.9).

In high-income countries, the risk of diarrheal illness appears to be low, as shown by studies from the former Czechoslovakia (35), Norway (36), and the United States (23, 24). However, a survey of households affected by Tropical Storm Alison found that diarrhea was significantly associated with residing in a flooded home (odds ratio = 6.2, 95 percent CI: 1.4, 28.0) (37), and Wade et al. (38) also found that flooding of the house or yard was associated with gastrointestinal illness (relative risk (RR) = 2.36, 95 percent CI: 1.37, 4.07). In the United Kingdom, Reacher et al. (39) reported an increase in self-reported gastroenteritis (RR = 1.7, 95 percent CI: 0.9, 3.0) following the Lewes floods of 2001. Another US study (40) investigated an outbreak of oyster-related hepatitis A and, although it was not possible to determine the precise cause of the outbreak, the authors hypothesized that flooding of the Mississippi Valley and discharge of fecal materials in the oyster-growing areas may have been factors.

Vector-borne disease

The relation between flooding and vector-borne disease is complex. Many important infections are transmitted by mosquitoes, which breed in, or close to, stagnant or slow-moving water (puddles, ponds). Floodwaters can wash away breeding sites and, hence, lower mosquito-borne transmission (41). On the other hand, the collection of stagnant water due to the blocking of drains, especially in urban settings, can also be associated with increases in transmission, and there have been numerous such reports from Africa (20, 30, 42, 43), Asia (44, 45), and Latin America (46–50). The 1982 El Niño event, for example, caused extensive flooding in several countries in Latin America and apparently sharp increases in malaria (46, 47).

The Mozambique floods of 2000 also appeared to have increased the number of malaria cases by a factor of 1.5–2 by comparison with 1999 and 2001 (30), although the statistics are difficult to interpret in light of the major population displacement that the flood caused. The reports of flood-related outbreaks in India (44, 45) do not provide particularly strong epidemiologic evidence.

There have also been reported increases in lymphatic filariasis (51) and arbovirus disease in Africa (43), Australia (52, 53), Europe (54–56), and the United States (57–59), although few provide epidemiologic data. Having had a flooded basement has been reported to be a risk factor for West Nile virus among apartment dwellers in Romania (54).

Rodent-borne disease

Diseases transmitted by rodents may also increase during heavy rainfall and flooding because of altered patterns of contact. Examples include Hantavirus Pulmonary Syndrome (60) and leptospirosis. There have been reports of flood-associated outbreaks of leptospirosis from a wide range of countries, including Argentina (61), Brazil (62–65), Cuba (66), India (67–70), Korea (71), Mexico (72), Nicaragua (73–75), Portugal (76), and Puerto Rico (77). In Salvador, Brazil, risk factors for leptospirosis included flooding of open sewers and streets during the rainy season (65). After a series of tropical storms in 1995, two health centers in western Nicaragua reported cases of a fever-like illness and some deaths from hemorrhagic manifestations and shock (73). Dengue and dengue hemorrhagic fever were initially suspected (74), but after a case-control study, Trevejo et al. (73) concluded that the most likely explanation was increased exposure to floodwaters contaminated by urine from animals infected with *Leptospira* species. Although several articles (73–75) implicate contact with floodwaters, specific analyses have not been presented.

Mental health

The World Health Organization recognizes that the mental health consequences of floods “have not been fully addressed by those in the field of disaster preparedness or service delivery,” although it is generally accepted that natural disasters, such as earthquakes, floods, and hurricanes, “take a heavy toll on the mental health of the people involved, most of whom live in developing countries, where [the] capacity to take care of these problems is extremely limited” (78, p. 43). Here, the main evidence relates to common mental disorder, posttraumatic stress syndrome, and suicide.

Common mental disorder (anxiety, depression). Most studies on the effects of flooding on common mental disorders are from high- or middle-income countries, including Australia (7, 79), Poland (80, 81), the United Kingdom (8), and the United States (82–89), but there is also a study from Bangladesh (90).

Bennet’s analysis of the 1968 Bristol floods found a significant increase (18 percent vs. 6 percent; $p < 0.01$)

in the number of new psychiatric symptoms (considered to comprise anxiety, depression, irritability, and sleeplessness) reported by women from flooded compared with nonflooded areas, although there was no significant difference for men. These results broadly agree with the findings for the 1974 Brisbane floods (7), except that in Brisbane men were also affected. Those between 35 and 75 years of age suffered the greatest impacts (79).

Other evidence for impacts on common mental disorder comes from a controlled panel study of adults aged 55–74 years flooded in 1981 and again in 1984 (87, 91). Flood exposure was associated with significant increases in depression ($p < 0.005$) and anxiety ($p < 0.0008$) (and also physical symptoms), especially in those with higher levels of preflood depressive symptoms and in those from lower socioeconomic groups—a finding that Phifer et al. suggest supports Logue et al.'s 1981 assertion that “low-income people are more vulnerable to the adverse effects of a disaster” (91, p. 417).

In a longitudinal study, Ginexi et al. (89) were able to compare symptoms for depression in both the pre- and postflood periods, and they found that, among respondents with a preflood depression diagnosis, the odds of a postflood diagnosis increased significantly (odds ratio = 8.55, 95 percent CI: 5.54, 13.2). A more recent case-control study from the United Kingdom (39) found a fourfold increase in psychological distress among adults whose homes were flooded compared with those whose homes were not (RR = 4.1, 95 percent CI: 2.6, 6.4).

On the other hand, more equivocal evidence comes from two case-control studies of the mental health impacts (82, 83) of Tropical Storm Agnes, which caused extensive flooding in Pennsylvania in 1972. The first study, conducted 3 years postflood, focused on working-class males aged 25–65 years; the second, conducted 5 years after the event, focused on women aged 21 years or more. In both cases, respondents from flooded households reported more mental health symptoms than did nonflooded respondents, but differences were not statistically significant. The authors speculate that “the failure to find a stronger relationship ... may, in part, be the result of the length of time which had elapsed since the disaster impact” (83, p. 239).

Comparatively few studies have examined mental health impacts on children, but an exception is the 1993 study by Durkin et al. (90) that found postflood changes in behavior and bedwetting among children aged 2–9 years. Before the flood, none of the 162 children were reported to be very aggressive; postflood, 16 children were found to be very aggressive toward others. Bedwetting increased from 16.8 percent before the flood to 40.4 percent after it. In the Netherlands, Becht et al. (92) interviewed 64 children and their parents ($n = 30$) 6 months postflood and found 15–20 percent of the children having moderate to severe stress symptoms. Other studies after the 1997 floods in Opole, Poland (81, 93), also suggest long-term negative effects on the well-being of children aged 11–14 years and 11–20 years, with increases in posttraumatic stress disorder (PTSD), depression, and dissatisfaction with life. Six months after Hurricane Floyd, similar findings were found by Russionello et al. (94) for children aged 9–12 years.

Posttraumatic stress disorder. PTSD “arises after a stressful event of an exceptionally threatening or catastrophic nature and is characterised by intrusive memories, avoidance of circumstances associated with the stressor, sleep disturbances, irritability and anger, lack of concentration and excessive vigilance [and the specific diagnosis of PTSD] has been questioned as being culture-specific, and may be overdiagnosed” (78, p. 43). Nonetheless, studies showing increases in PTSD following floods come from Europe (95, 96) and North America (97–99).

McMillen et al. (98), who interviewed those affected by the 1993 Midwest floods, found that 60 subjects (38 percent) met the criteria for postflood psychiatric disorder and 35 (22 percent) met the criteria for flood-related PTSD. However, the limitations, recognized by the authors, included retrospective data collection, self-selection of interviewees, self-reporting, and the absence of a control group. Similar limitations applied only to a study of 1997 flood victims in the Central Valley of northern California (99): 19 percent (24) of the 128 participants who completed the acute stress disorder questionnaire met the criteria for the disorder's diagnosis, and of the 73 participants who completed the 1-year follow-up, seven (10 percent) met the criteria for full PTSD. Studies of the 1996 flooding in the Saguenay/Lac St. Jean region of Quebec, Canada, also suggest substantial increases in emotional distress and PTSD among flooded respondents (97). Evidence from Puerto Rico and from work by Norris et al. (95) suggests that PTSD symptoms are influenced by the extent of flooding, culture, and age. The difficulties of interpretation are demonstrated in a study by Verger et al. (100), who examined the mental health impacts 5 years after the 1992 floods in Vacluse, France. They concluded that the subjects' reports of their disaster-related experiences (significantly worse for women and subjects older than 35 years) “are by nature subjective ... and not entirely reliable” (100, p. 440).

Suicide. Evidence about suicides in relation to flooding is very limited. One US analysis that was initially interpreted as showing evidence for increased suicides in the 4 years after natural disasters (101) was subsequently retracted, with the conclusion that “the new results ... do not support the hypothesis that suicide rates increase” (102, p. 148). A paper from China (103) reports that suicide rates in the Yangtze Basin, an area affected by periodic flooding, are 40 percent higher than in the rest of the country, but there is no direct epidemiologic evidence to suggest that the difference is attributable to flooding.

Other health outcomes

In addition to the health outcomes detailed above, our review identified reports of other flood-related health impacts, including *Acanthamoeba* keratitis (104), epilepsy (105), leukemia, lymphoma, spontaneous abortion (106), melioidosis (107), effects of chemical contamination (108, 109), infection from soil helminths (110), and schistosomiasis (111–113). Most were isolated reports or provided only weak evidence of a possible flood link.

TABLE 1. Key studies that assess the relation between flooding and health

Authors, year (reference no.)	Location and year of flood*	Design	Main results
<i>Studies of multiple health outcomes</i>			
Reacher et al., 2004 (39)	Lewes, United Kingdom, 2000†	Telephone interviews of 227 cases (house flooded) and 240 controls (nonmatched), 9 months postflood	Fourfold higher risk of psychological distress in flooded group ($RR_{\ddagger} = 4.1$, 95% CI \ddagger : 2.6, 6.4); flood also associated with earache in all age groups ($RR = 2.2$, 95% CI: 1.1, 4.1); association for gastroenteritis less marked ($RR = 1.7$, 95% CI: 0.9, 3.0)
Kondo et al., 2002 (30)	Mozambique, 2000§	Collection of emergency clinic data and interviews of 62 randomly selected families; no details on how families were selected	Incidence of malaria reported as increasing by a factor of 1.5–2.0 and diarrhea by a factor of 2.0–4.0
Kunii et al., 2002 (21)	Bangladesh, 1998§	517 persons (nonrandomized selection) interviewed 2 months after start of flood	Fever accounted for 42.8% of health problems among 3,109 family members; diarrhea, 26.6%; respiratory problems, 13.9%
Biswas et al., 1999 (28)	West Bengal, India, 1993§	Survey conducted before, during, and after flood in four villages; no further details on sample	Attack rate for diarrhea increased from 4.5% pre-flood to 17.6% postflood ($p < 0.01$); rates for respiratory infections were 2.8% and 9.6%, respectively ($p < 0.01$)
Duclos et al., 1991 (13)	Nîmes, France, 1988§,¶	108 questionnaire interviews 1–2 months postflood; review of medical care delivery data for Nîmes area; active surveillance in GP \ddagger clinics instigated 1 week after flood	Nine flood-related drownings, but death certificates did not reveal increased mortality; 6% of interviewees reported mild injuries, but no specific increase in infectious disease observed
Woodruff et al., 1990 (20)	Khartoum, Sudan, 1988§,¶	Review of admissions data; 12 sentinel disease surveillance sites established postflood	Diarrheal disease most reported cause of nonfatal illness among all age groups; population-based mortality rates could not be calculated
Dietz et al., 1990 (15)	Puerto Rico, 1985¶	Routine death certificate data from 12 most flood-affected municipalities	180 disaster-related deaths; data for 95 recovered bodies with 22% (21/95) drowned; no significant change in communicable disease postflood
Handmer and Smith, 1983 (10)	Lismore, Australia, 1974¶	Comparison of patients from flooded and nonflooded areas	No flood-related increase in hospital admissions, and this holds for all classes of flood severity; no significant overall change in total number of deaths
Price, 1978 (79)	Brisbane, Australia, 1974†	695 cases and 507 controls (no details of selection procedure)	Percentage claiming worsened health rose with age in flooded group ($r = 0.9104$); between-groups analysis saw general tendency for difference to increase with age, although those >75 years were least affected
Abrahams et al., 1976 (7)	Brisbane, Australia, 1974†	738 cases and 581 controls interviewed; no details on how sample was selected	No differences in mortality between control and flooded groups; flooded males more likely to visit GP than nonflooded males ($p < 0.01$); psychological disturbances more prominent than physical ones in both sexes
Bennet, 1970 (8)	Bristol, United Kingdom, 1968†	Survey comparison of 316 flooded and 454 nonflooded homes	76% rise in flooded males visiting GP more than three times ($\chi^2 = 10.6$, $p < 0.01$); hospital referrals among the flooded more than doubled in the year after the floods ($p < 0.01$); increased self-reporting of physical and psychiatric complaints; 50% increase in number of deaths among the flooded; most pronounced rise in the group aged 45–64 years with increases predominantly in those aged >65 years
<i>Mortality</i>			
Staes et al., 1994 (17)	Puerto Rico, 1992†	23 flood-related deaths (cases) and 108 controls (randomly selected from those seeking disaster relief)	Estimated risk of mortality significantly elevated ($OR_{\ddagger} = 15.9$, 95% CI: 3.5, 44) for those who occupied a vehicle, and the risk remained significantly elevated after controlling for age and sex

Table continues

TABLE 1. Continued

Authors, year (reference no.)	Location and year of flood*	Design	Main results
Siddique et al., 1991 (19)	Bangladesh, 1988¶	154 flood-related deaths; comparison of health center and district level records	Children aged <5 years accounted for 38% of all deaths, and those aged between 5 and 9 years accounted for 12%; diarrheal disease was the most frequent (27%) cause of death among all ages; respiratory tract infections accounted for 13% (20/154) of deaths
<i>Fecal-oral disease</i>			
Wade et al., 2004 (38)	Mississippi River, United States, 2001§,#	1,110 persons from intervention study cohort provided flood survey health data	Flooding of house or yard significantly associated with gastrointestinal illness for all subjects (IRR‡ = 2.36, 95% CI: 1.37, 4.07) and children aged ≤12 years (IRR = 2.42, 95% CI: 1.22, 4.82)
Vollaard et al., 2004 (34)	Jakarta, Indonesia†	93 (69 typhoid and 24 paratyphoid) enteric fever cases compared with 289 non-enteric fever patient controls and 378 randomly selected community controls	Flooding of house a significant risk factor for paratyphoid fever; when paratyphoid group was compared with community control, OR = 4.52, 95% CI: 1.90, 10.73; when compared with fever controls, OR = 3.25, 95% CI: 1.31, 8.02
Heller et al., 2003 (31)	Betim, Brazil†	997 cases (children aged <5 years with diagnosis of diarrhea) and 999 controls	Flooding of family compound significantly associated with diarrhea (RR = 1.39, 95% CI: 1.09, 1.76)
Prado et al., 2003 (115)	Salvador, Brazil§	694 children aged 2–45 months from 30 clusters throughout the city	Susceptibility to flooding studied as potential risk factor for <i>Giardia duodenalis</i> , but no statistically significant result was found
Mondal et al., 2001 (29)	West Bengal, India, 1998†	Comparison of flooded and nonflooded areas; two villages in each area selected by systematic random sampling	Frequency distribution of diarrheal disease significantly higher in flooded area ($p < 0.001$)
Sur et al., 2000 (26)	West Bengal, India, 1998**	Mortality and morbidity data collected from district hospital and four primary health centers	In 3-month period after flood, 16,590 cases were reported, with 276 deaths (attack rate of 1.1% and case-fatality rate of 1.7%); laboratory results suggested that <i>Vibrio cholerae</i> was primary causative agent
Korthuis et al., 1998 (25)	Irian Jaya, Indonesia**	Cases of diarrhea identified from community health clinic records	Epidemic curve inconclusive as to the source of the outbreak, and no <i>V. cholerae</i> species isolated from water sources
Katsumata et al., 1998 (27)	Surbaya, Indonesia†,§	917 hospital patients with acute diarrhea (cases) and 1,043 inpatients without gastrointestinal problems (controls), plus community-based study during rainy and dry seasons	Flooding independently associated with an increased risk of <i>Cryptosporidium</i> infection (OR = 3.083, 95% CI: 1.935, 4.912)
van Middelkoop et al., 1992 (32)	Kwazulu Natal, South Africa**	Cases of poliomyelitis identified from hospital records	Strong correlation (Spearman's $r = 0.56$, $p < 0.01$) between flood-related mortality rates in each district used as an indicator of the severity of the floods and of poliomyelitis attack rates
Fun et al., 1991 (33)	Bangladesh¶	Data for patients seeking treatment for acute diarrhea between June 1987 and May 1989	Major peak for RV‡ recorded in September 1988, coinciding with major flood; occurrence of RV diarrhea declined immediately after the flood, but nonrotavirus diarrhea remained high
<i>Vector-borne disease</i>			
Han et al., 1999 (54)	Bucharest, Romania†	Compared asymptotically infected persons ($n = 38$) with uninfected persons ($n = 50$) identified in serosurvey	Among apartment dwellers, 63% (15/24) of infected persons had flooded basements; 30% (11/37) for uninfected persons (OR = 3.94, 95% CI: 1.16, 13.7; $p < 0.01$)
<i>Rodent-borne disease</i>			
Leal-Castellanos et al., 2003 (72)	Chiapas, Mexico§	1,169 persons aged 15–86 years randomly selected for interview who provided blood sample	Contact with water in puddles or from flooding was a risk factor related to <i>Leptospira</i> infection
Sarkar et al., 2002 (65)	Salvador, Brazil†	66 randomly selected hospitalized cases and 132 controls matched on age and sex and from the same neighborhood as the cases	Incidence of severe leptospirosis for the city was 6.8/100,000; exposure to flooded open sewers (OR = 4.21, 95% CI: 1.51, 12.83) and flooded street (OR = 2.54, 95% CI: 1.08, 6.17)

Table continues

TABLE 1. Continued

Authors, year (reference no.)	Location and year of flood*	Design	Main results
Sanders et al., 1999 (77)	Puerto Rico, 1996¶	All patients who had negative results in an antidengue test were assigned to a pre- and posthurricane period by the date of onset of illness	24% (17/70) were laboratory confirmed in posthurricane period, compared with 6% (4/72) in prehurricane period (RR = 4.4, 95% CI: 1.6, 12.4)
Trevejo et al., 1998 (73)	Achuapa and El Sauce, Nicaragua, 1995†	61 cases identified from health center records and 51 controls randomly selected from the same area and matched by age group	Age-specific incidence significantly higher ($p < 0.05$) among those aged 1–14 years compared with other age groups
<i>Mental health</i>			
Ginexi et al., 2000 (89)	Iowa	Nonrandomized quasiexperimental longitudinal interview survey, pre- and postflood	1,735 participated in interviews 60–90 days postflood; ages ranged from 18 to 90 years (mean = 50.9 (SD‡ = 16.5) years); among respondents with a predisaster depression diagnosis, the odds of a postflood diagnosis were increased by a factor of 8.5 (95% CI: 5.54, 13.21)
Durkin et al., 1993 (90)	Bangladesh§	Prospective cross-sectional study of children aged 2–9 years ($n = 162$)	Postflood, 16 children were reported to have “very aggressive” behavior (preflood = 0), and this represented a significant increase ($p < 0.0001$); preflood, 16% of the children wet the bed; postflood, 40.4% wet the bed ($p < 0.0001$)
Canino et al., 1990 (116)	Puerto Rico, 1985†	321 exposed and 591 unexposed to flood	The higher the level of exposure to the disaster, the greater the number of new depression and PTSD‡ symptoms in retrospective sample; increased depressive and somatic symptoms in prospective sample; after control for demographic variables, the magnitude of effect was not more than 0.2
Phifer et al., 1988 (87); Phifer, 1990 (91)	Southeastern Kentucky, 1981 and 1984††	Stratified three-stage area probability design; 198 adults aged 55–74 years with six waves of interviews	Flood exposure was associated with increases in depression ($p < 0.005$) and anxiety ($p < 0.0008$); flood exposure also associated with reports of increased physical symptoms ($p < 0.003$)
Ollendick and Hoffmann, 1982 (85)	Rochester, New York, 1978§	Personal interview (8 months postflood) of 124 adults and 54 children whose homes were flooded	Significant difference between pre- and postflood scores for depression and stress in both groups; however, preflood data collected postevent
Powell and Penick, 1983 (86)	Mississippi, 1973#	Personal interview of 98 flooded individuals 2 and 15 months postflood	Significant increase in short- and long-term emotional distress ($p < 0.001$), but preflood data collected retrospectively
Logue et al., 1981 (83)	Pennsylvania, 1972†	Postal questionnaire survey (5 years postdisaster) of 396 flooded and 166 nonflooded females (>21 years of age)	Flooded respondents had longer periods of ill health, and a statistical trend ($p < 0.10$) was noted for anxiety
Melick, 1978 (82)	Pennsylvania, 1972†	Personal interview survey (3 years postdisaster) of 43 flooded and 48 nonflooded, working-class males (aged 25–65 years)	Those who were flooded had longer periods of ill health but no significant differences in the number and nature of illnesses experienced by flooded and nonflooded respondents

* Where date is provided, study refers to a specific flood event.

† Case-control study design.

‡ RR, relative risk; CI, confidence interval; GP, general practitioner; OR, odds ratio; IRR, incidence rate ratio; RV, rotavirus; SD, standard deviation; PTSD, posttraumatic stress disorder.

§ Cross-sectional study design.

¶ Outbreak investigation.

Cohort study design.

** Panel study.

†† Routine data (e.g., disease surveillance, hospital admissions, clinic attendance).

DISCUSSION

There is a surprisingly limited evidence base about the health effects of floods, particularly in relation to morbidity. This may in part be due to the difficulty of carrying out rigorous controlled epidemiologic studies of floods, especially in low-income countries. Evidence on public health interventions (e.g., the need for measures to reduce the spread of infectious disease, dealing with mental health impacts, targeting of vulnerable groups) appears particularly limited. We found no studies on the effectiveness of public health measures, including early warning systems. Nonetheless, the wide range of risks to health and well-being, both physical and mental, is understood, though there remains scientific uncertainty about the strength of association and public health burden for specific health effects. The immediate risks of trauma and death are generally clear, but it seems that longer-term impacts, specifically on mental well-being, are often underestimated and probably receive too little attention from public health authorities. These and the location-specific infectious disease risks require further study.

In terms of public health responses, some caution is required in drawing general lessons from a global literature, because floods vary greatly in their character and in the size and vulnerability of the populations they affect. The evidence is also dominated by studies of slow-onset floods in high-income countries that may have little relevance to flash floods and floods in low-income settings. Some floods are catastrophic and affect thousands of people who may have little capacity to protect themselves, as was the case in Mozambique in 2000 and Bangladesh in 2004. At the other end of the spectrum is the small-scale flood in a high-income country where emergency and support services are better able to cope with the immediate and longer-term effects.

Comparison of different flood events suggests that the risk of death is influenced by both the characteristics of the flood (e.g., its scale and duration, the suddenness of onset, the velocity and depth of water, the lack of warning) and of the population that it affects. Floods with the largest mortality impacts have occurred where infrastructure is poor and the population at risk has limited economic resources.

The formulation of policies to protect against flood-related health risks is limited by the paucity of evidence on epidemiologic risk factors and public health interventions. We identified the following knowledge gaps:

- the mental health impacts of flooding, especially the long-term impacts, and their principal causes, which have been inadequately researched even in high-income settings;
- the nature and magnitude of mortality risks in the period after flooding;
- quantification of the risks of infectious and vector-borne diseases following floods;
- the effectiveness of warning systems and public health measures in reducing flood-related health burdens;
- the health-related costs of flooding that are often given little weight in decisions about specific interventions; and
- quantification of the degree to which climate and land-use change will contribute to flood risk and associated health burdens in different settings.

Epidemiologic study of these questions presents particular challenges because of the unpredictability of the timing and location of floods; the necessity for retrospective designs, therefore, which may suffer from recall bias; and the difficulty of obtaining appropriate comparison groups. The availability of geographically coded routine data in some countries may offer opportunities for future research.

There is much that can be done to reduce health and other impacts through public education, emergency service planning, and the implementation of early warning systems (114). On the other hand, there are clear research needs to improve understanding of the health risks in different settings and of the social and cultural modifiers of those risks. Some of the deficiencies in evidence are apparent from the summary we provide in this report. There is also more to understand about the long-term consequences of flooding on health and about the mechanisms by which such consequences can best be prevented or alleviated.

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