Health Impacts of Floods

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Abstract

Introduction: Floods are the most common hazard to cause disasters and have led to extensive morbidity and mortality throughout the world. The impact of floods on the human community is related directly to the location and topography of the area, as well as human demographics and characteristics of the built environment.

Objectives: The aim of this study is to identify the health impacts of disasters and the underlying causes of health impacts associated with floods. A conceptual framework is developed that may assist with the development of a rational and comprehensive approach to prevention, mitigation, and management.

Methods: This study involved an extensive literature review that located >500 references, which were analyzed to identify common themes, findings, and expert views. The findings then were distilled into common themes.

Results: The health impacts of floods are wide ranging, and depend on a number of factors. However, the health impacts of a particular flood are specific to the particular context. The immediate health impacts of floods include drowning, injuries, hypothermia, and animal bites. Health risks also are associated with the evacuation of patients, loss of health workers, and loss of health infrastructure including essential drugs and supplies. In the medium-term, infected wounds, complications of injury, poisoning, poor mental health, communicable diseases, and starvation are indirect effects of flooding. In the long-term, chronic disease, disability, poor mental health, and poverty-related diseases including malnutrition are the potential legacy.

Conclusions: This article proposes a structured approach to the classification of the health impacts of floods and a conceptual framework that demonstrates the relationships between floods and the direct and indirect health consequences.

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Introduction

Despite the media attention given to catastrophic disasters such as those resulting from tsunamis and earthquakes, floods responsible for the most common disasters due to natural and/or technological hazards—they account for 40–50% of all disasters and disaster-related deaths worldwide.[1–3] According to the EM-DAT database, floods (excluding tsunamis) accounted for 38.7% of all incidents, 6.2% of the deaths, and 43.0% of the population affected by all disasters caused by natural hazards in the world during the period of 2000–2009.[4] The speed of onset of the flood is the main factor determining the number of flood-related deaths. However, floods often are long-term events that may last days, weeks, or longer.[5]

Floods are defined as "the condition that occurs when water overflows the natural or artificial confines of a stream, river, or other body of water, or accumulates by drainage over low-lying areas."[6] Floods are caused by rainfall, melting snow or ice, or by structural failure of water containing structures, including subterranean structures. The nature and extent of the flood is determined by the physical location and topography, and by the built environment. Floods

impact the human community either directly through contact with the water or indirectly through the damage the water does to the natural and human-built environment. Even relatively small, localized floods may have a significant impact on people's physical and mental health.[7] One study found a four-fold increase in illnesses among people whose homes had been flooded compared with those whose homes were not flooded.[8] Not only is the incidence of floods increasing, but rapid urbanization is resulting in the exposure of more people to floods. In addition, it is projected that global warming will have an impact on the frequency of floods worldwide.[9]

Management of the health impacts of floods is dependent upon an extensive knowledge and understanding of the health risks and on the capacity of the health system to mitigate or manage those consequences. All floods are unique in that the regions affected have different social, demographic, economic, and population health characteristics. Yet, many similarities exist, and knowledge of the causes of death and types of injuries and illnesses from floods is essential to help to ensure that health and emergency medical relief is well-managed.[10]

The aim of this review is to identify the impacts of floods on the health of the human community and to propose a renewed framework for future analysis and evaluation. The specific research objectives are: (1) to describe causes of floods and their characteristic impacts on health outcomes; (2) to describe the factors that influence human health as a result of floods; (3) to describe the health impacts of floods; and (4) to develop a conceptual framework to aid in the management and evaluation of flood health management.

Methods

This study is an analysis of the literature and published reports. A search was conducted of health databases (Medline/PubMed, ScienceDirect, Academic Search Elite, Web of Science, Environmental Science and Pollution Management Collection on CSA Illumina, and Biological Abstracts®) as well as industry-based websites, and Google Scholar and published texts utilizing keywords "flood" and "health". Tsunamis and cyclones were not included in the search terms, as the focus of this study is on floods alone. While a tsunami can cause flooding, they are rare but catastrophic events that are not representative of floods. Similarly, cyclones/hurricanes can cause floods, but also are associated with death and health outcomes from factors other than flooding. The search was restricted to the English language. The research mainly focused on data published after 1998, though some important works before 1998 are included.

The search found 570 references, of which 197 were identified as relevant and significant in that they contributed to the understanding of the health impacts of floods. Distillation of the themes by the research team resulted in conceptual frameworks to aid further analysis and evaluation.

Causes and Types of Floods

The nature and consequences of floods vary according to the cause of the flood and the nature of the natural and human environment. Floods may be caused by a range of factors or combinations of those factors. A summary classification of the causes of floods is provided in Table 1. Different types of floods have different impacts on the human community, and therefore, different health effects.

Precipitation

Precipitation, including rain, snow, hail, etc. can have both immediate and longer-term effects. Heavy rainfall can cause localized flash flooding or down stream (riverine) inundation. Snow falls cause immediate effects associated with hypothermia, ice-associated injuries, and infrastructure or building failures. Delayed floods may result from the melting of snow and ice. Hail can cause immediate injury to people and block drainage systems precipitating building inundation. Global warming increases the overall temperature of the oceans, which in turn increases torrential downpours, tropical storms, and hurricanes/cyclones.[3]

Rising Water Levels

Rising water levels, both fresh water and sea water, may occur suddenly or gradually. Sudden rises of sea water are caused by tsunamis, storm surges, or by breaches in sea defenses. Longer-term increases in sea levels are anticipated with global warming, melting of polar ice caps, and thermal expansion of sea masses.[9]

Rising fresh water may occur as a result of planned or unplanned damming of water drainage or by release of subterranean water sources to the surface. One extreme case of the latter was the mud volcano in East Java where steam, water, and mud erupted from underground resulting in inundation of land and villages.[11]

Release of Stored Water

Floods may be caused by release of stored water associated with failure of retaining walls or structures or by the displacement of stored water as may occur with landslides into the water. For example, the landslide in the Vajont Dam in 1963, during which rocks, mud, earth, and uprooted trees tumbled into the lake resulting in the overflow of the dam, thus flooding nearby villages.[12]

Failure of Natural Drainage

Floods also may be caused or exacerbated by failure of natural drainage. Reduced absorption of water occurs when the natural landscape is replaced with non-absorbent infrastructure, e.g., urban expansion or the replacement of wetlands. Impaired drainage may be associated with poorly planned or inadequate drainage systems in new constructions or drainage systems which become blocked with debris or trash.[13]

The timing of the flood also may affect its impact. Heavy rain in coastal areas at high tide may have a greater impact because of the difficulty for the water to clear to sea.

Factors Affecting the Health Outcome

Apart from the quantity of water, there are many other factors that affect the severity and scale of floods, and thus, their impacts on human health.

Causes	Sub-category	Comments and Examples
Precipitation	Rain	Impact is dependent on the size and rapidity of the rain
	Snow	Immediate impact from the snow and its impact and delayed impact from melting of snow and ice
Rising water level	Sea water	Sudden rises associate with tidal waves, tsunami and storm surge
		Long terms rises due to global warming
	Fresh water	Rising levels associated with planned or unplanned damming of waterways, e.g., the dams caused by landslides in the Sichuan Earthquake, China (2008)
		Rising subterranean water, e.g., the mud flow in Indonesia (2007)
Structural failure	Failure of the dam	Collapse of water retaining structures with sudden release of stored water
	Relocation of the stored water	Landslide into a reservoir displacing large quantities of water
	Breaching of sea defenses	Breaching of dykes in New Orleans
Reduced natural drainage	Prevention of natural absorption	Development of wetlands, which reduces absorption of rainfall
	Blocked drainage	Poor planning of water drainage infrastructure or through blocked drainage due to debris or trash.

Table 1—Causes of floods

Flood Type

The type of flood is directly relevant to the health consequences. The term "flash flood" implies sudden onset and may be associated with tsunamis, sudden downpour, or breach of reservoirs. The sudden onset may entrap people, resulting in drowning. In addition, the forces associated with the hydrological pressure may carry debris along with the water and cause damage to buildings and other infrastructure such as bridges. This debris can result in injuries to people. On the other hand, gradual inundation is more predictable and less likely to cause drowning and injury.

Geography

The geography of the area flooded has a significant impact on the nature of the flood and the health consequences. An area close to the sea is more likely to be affected by tidal waves and storm surge. Areas in a valley are more likely to be inundated during flash floods that often are debris laden. Low lying areas are more likely to be affected by riverine flood and gradual inundation. There is a significant increase in mortality when flooding occurs within mountainous and narrow river valley areas.[14] However, communities at greatest risk of flood are those in low-lying areas, near water, and/or located downstream from a dam.[15,16]

Demography

The human health impact of floods also is dependent on the demographics of the population affected by the flood. This includes the size and density of the population as well as the level of awareness and education of the community and their capacity to escape. Several groups within the community are at particular risk and include older people, children, people with disabilities and/or illness, and people confined in the prisons. Children and older individuals are more likely to suffer adverse physical consequences during floods.[17,18] Women are more affected psychologically than men.[18–21] Children and adolescents with chronic conditions are at increased risk of adverse outcomes.[22] The poor are particularly vulnerable to floods, and isolation and lack of participation in decision-making intensify their vulnerability.[23]

Community Infrastructure

The capacity of the community to respond and their attitude to disaster preparedness and prevention is related to the culture and education of the population. The extent of community infrastructure will affect the health and other consequences of the flood. Construction standards will affect the likelihood of building collapse. Well-designed and maintained drainage systems limit the accumulation of water. Appropriate design of community infrastructure such as dams, will limit the likelihood of structural failure. The availability of well-constructed places of refuge and safety may limit the injury and death created by floods. Proper design and safe location of health infrastructure is essential to the ongoing provision of health services in the event of a flood.

Disaster Management System
The effectiveness of the disaster management system may influence the health impacts of a flood. A well-organized system is more likely to carry out flood preparations and respond more efficiently than are other systems. Evacuation routes should be planned and practiced. The usual routes of access to and from the hospitals and health services may be flooded; therefore, alternative routes should be planned in advance. Effective community communication of risks to the community is essential those at risk to limit the health risk and health consequences both in the short- and long-term.

Health Consequences of Floods

The health consequences of floods may be categorized broadly as direct or indirect. *Direct* consequences are those resulting from direct exposure to the water and the flooded environment, and include drowning, injuries from debris, chemical contamination, and hypothermia. *Indirect* consequences are those associated with risks associated with the damage done by the water to the natural and built environment and include infectious diseases, malnutrition, poverty-related diseases, and diseases associated with displaced populations.[24]

The health consequences of flooding may be described in terms of time as immediate, medium-term, and long-term. There is no clear definition of these terms; indeed, in many respects, these periods overlap. However, this classification is useful to aid with planning and the development of management strategies. For the purposes of this study, *immediate* is considered as the period when the flood is present, *medium* is the immediate recovery phase (days to weeks), and *long-term* is the reconstruction phase (months to years) after the flood.

Immediate Health Effects

Drowning
The leading cause of death from floods is drowning, and most of these deaths are due to flash flooding rather than the slower riverine flooding.[25] Drowning often occurs as a result of individuals under-estimating the power of the current or depth of the water during late evacuation, attempted salvage, or inappropriate conduct. Many flood deaths can be attributed to motor vehicles and are caused by driving on flooded roads or causeways, or from the trauma associated with crashes occurring on wet roadways. More than 57% of all flood fatalities in the United States are associated with motor vehicles.[14,26] Drowning also occurs when people are swept away from their home or campsite while attempting to cross a bridge, rafting or sailing in storm water drains, or during evacuation or rescue. The number of such deaths is determined by the characteristics of the flood.

Approximately 0.2% to 2% of flood survivors will require urgent medical care.[27]

Injuries
Flood-related injuries may occur as individuals attempt to escape from danger or as a result of the collapse of buildings or other structures. Orthopedic injuries and lacerations may be caused by fast moving water containing debris.[27–29] Injuries also occur when people return to their flooded homes and businesses and begin to clean up (e.g., from unstable buildings and electrical power cables). Falls from ladders, sprains, strains, and wounds may occur as individuals repair homes or use chainsaws to clean up fallen trees and other debris.[30]

Electrical Injuries
Electrical injuries may occur with flooding. Standing water anywhere close to electrical lines, circuits, or equipment represents a potential electrical hazard. Additionally, rescue boats may come into contact with overhead power lines.

Burns and Explosions
Burns and explosions may be caused as floodwaters disrupt propane and natural gas lines, tanks, power lines, and chemical storage tanks. Oil and other flammable, non-polar, low density liquids may allow fires to spread along the surface of floodwaters.[25]

Hypothermia
Hypothermia with or without submersion occurs in some floods and may occur in any season.[13] Ice dam breakage elevates the risk, but water does not have to be ice cold for hypothermia to occur. Most flood water is well below human core body temperature.

Disruption of Health Services
Floods can have a significant impact on the provision of health services. Potential damage to health facilities from the flood may require displacement of patients and staff. Flooding may impair access to health resources or the ability of health personnel to provide their services. A flood can limit access to primary health care, and result in changes in the demand for services (as evidenced by the frequency and type of patient visits).[31,32] During Hurricane Katrina, the Louisiana Department of Health and Hospitals (LDHH) was extensively damaged, thus limiting the surveillance for illnesses, injuries, and toxic exposures.[33] Flooding also can cause the loss of medical records and disrupt the provision of health resources, consumables, and the infrastructure required to maintain services. Patients also may suffer from loss of medication or medical devices, and find difficulty accessing health services resulting in an exacerbation of health problems among families affected by the flood.[34]

Secondary Health Effects

Water Contamination
Contact with floodwaters without drowning, by itself, does not pose a serious health risk.[35] However, floodwaters may contaminate the local water and food supply and damage the sewage system resulting in contamination and increase the potential for communicable diseases.[27,36] Contaminated water sources result in waterborne disease transmission, including *Escherichia coli*, *Shigella*, *Salmonella*, and hepatitis A virus. Fecal contamination of livestock and crops also may lead to the spread of infectious diseases.[37] The flood or irrigation with contaminated water represents a risk to farm and other outdoor workers.[38]

Chemical Contamination
Flooding can cause nutrient runoff from agriculture, and thus, cause algal blooms, which alter the coastal ecosystems

and threaten human health.[39] Floodwaters may result in the spread of chemicals. Industrial sites may become flooded, unleashing chemicals and other contaminants into the floodwaters. Floods also can lead to release of hazardous materials causing fires and/or explosions, toxic gas emissions, spills, damage to equipment, damage to pipes and connections, short circuits and/or power failures, punctured tanks and vessels, and structural damage to buildings and facilities in refineries, etc.[40]

Carbon Monoxide Poisoning

Carbon monoxide poisoning is a relatively common risk during the event and recovery phases of floods.[13] Unventilated gas-powered electrical generators, gas-powered pressure washers, unventilated cooking tanks, and house fires started by candles are common culprits.[41,42]

Communicable Diseases

In one study, fever accounted for 42.5% of health problems following a flood.[43] Communicable diseases are a concern during any disaster, though it is less commonly observed with flooding.[2,44] There are several reasons for increased risk of communicable diseases during flooding:

1. Temporary shelters to house those displaced by flooding may result in crowded and unsanitary living conditions and may increase the incidence of infectious illnesses.[27] Flooding also leads to decreased basic hygiene if toilets become inaccessible and clean water is not available for washing;
2. Lack of clean water, overcrowding, insufficient understanding of personal and domestic hygiene, nutritional deficiency, and overall poor sanitation are the major contributing factors for the spread of diarrheal diseases;[45] and
3. Vector-borne diseases may increase during periods of flooding. Stagnant water provides a breeding ground for many vectors, such as mosquitoes, resulting in diseases such as malaria and dengue.

Respiratory Illness

Respiratory problems account for a significant proportion of morbidity associated with floods.[43,46] Mold is a particular hazard for persons with impaired host defenses or mold allergies.[47] Microbial growth can cause potentially harmful inhalation exposures for persons entering or cleaning affected structures.[48–50]

Animal Displacement

Animal displacement commonly occurs during periods of flooding. Displaced domesticated animals, rats, insects, snakes, and reptiles often result in an increased incidence of bites.[51,52] Diseases transmitted by rodents also may increase during heavy rainfall and flooding because of altered patterns of contact.[53] Finally, diseases among sick animals may spread to the human population, such as rabies, tuberculosis, and avian influenza.

Longer-Term Health Consequences

Disability

In the longer term, disability from trauma incurred during the flood is a common cause of morbidity particularly if exacerbated by complications such as infection. Disability may be associated with the exacerbation of chronic diseases such as asthma or ear, nose, or throat conditions.[54]

Mental Health Problems

Mental health problems are a common sequelae of floods. Major life stressors, such as disasters, increase susceptibility not only to physical illness, but also to poor mental health.[55–59] People who have experienced a flood have been shown to have a fourfold higher risk of psychological distress than do those not exposed to flood,[54] and a suicide rate 13.8% higher than pre-disaster rates.[60]

Mental health problems may derive from physical health problems or from personal losses, social disruption, and economic hardship.[24] Management of the mental health consequences of exposure to disasters "have not been fully addressed by those in the field of disaster preparedness or service delivery".[61] In developing communities, young people, especially girls, have been shown to be particularly vulnerable.[62,63] Disaster mental health teams should be sensitive to the socio-economic status, local culture, tradition, language, and local livelihood patterns.[19]

Social Disruption and Related Health Issues

Floods may be associated with extensive economic disruption which has significant health consequences. Antisocial/violent behavior, such as assaults, gunshot wounds, and rapes have been reported following floods.[36] Destruction of health infrastructure including public health structures, such as clean water and proper waste disposal, contribute to social disruption. Access to medical services can be affected by both personal and community economic factors.[64,65]

Poor nutrition may follow floods as food supplies are destroyed and disruption of livelihood also may affect household incomes and their capacity to purchase food (especially in low-income countries).[66] The nutritional status of children in households that were more severely exposed to the flood was seen to deteriorate, and children exposed to the flood were adversely affected.[67]

Discussion

The health consequences of floods depend upon the vulnerability of the environment and the local population. Improved disaster management, including mitigation and preparation has contributed to a reduction in flood-related deaths. Fewer people die from drowning, the majority of which are due to the misuse of motor vehicles or engaging in risky behavior such as swimming in flooded drains.

The provision of clean food and water as well as the safe disposal of waste has reduced the incidence of communicable disease outbreaks following floods. Improved risk management of chemicals and other contaminants also has reduced the risks associated with disruption during major floods. Long-term mental health problems have been identified more clearly as a problem and responses must be more coordinated. Ultimately, it is the responsibility of the

	Immediate		Mid-Term		Long-Term	
	Health Impacts	Strategies	Health Impacts	Strategies	Health Impacts	Strategies
Direct	Drowning	Public awareness Rescue	Complications of injury	Early medical care	Mental health (Loss and grief)	Support and counseling
	Injury - Trauma Injury—debris, collapsed building, car crash, etc. - Electrical Injury - Burns and Explosions Injury	Building construction standards Evacuation Public awareness	Infection—skin and eye infections, fecal-oral injections	Early medical care	Chronic diseases	Effective health care
	Hypothermia	Rescue Awareness	Poisoning—Chemical contamination	Risk management Decontamination	Disability	Early intervention Rehabilitation
	Animal Bites	Rescue	Mental health—shock	Support and counseling		
Indirect	Health risks associated with the displacement of patients, disabled persons, seniors, children, etc. (e.g., heart attack, illness, deterioration)	Rescue Safe health services	Communicable diseases— - Overcrowding - Vector - Exposure to infectious diseases - Animal bites	Clean food and water Safe waste disposal Refugee care Immunization program	Malnutrition—poverty, damage of property	Economic recovery Aid and assistance programs

Table 2—Immediate, mid-term, and long-term direct and indirect health consequences of floods

disaster management system to continue to upgrade the recovery phase and part of this is the long-term coordination of the mental health aspects. The solution is organizational and community-specific, but often not well managed.

The destruction of health service infrastructure can be avoided by improved design, location, and construction to appropriate standards. Both domestic and international collaboration may contribute to a rapid replacement of damaged health infrastructure in both the short- and longer-term.

Adverse health outcomes associated with floods may be direct or indirect as well as immediate-, medium-, and long-term effects. The relationship between these perspectives and the specific prevention and mitigation strategies required to address each of the aspects is presented in Table 2.

The relationships between causes and health consequences are complex. The relationship between the flood and the health consequences often is indirect, and management of the health consequences often are focused on the intermediary elements. A conceptual map may assist health planners and emergency managers to ensure a comprehensive and rational approach in planning for and responding to the health consequences of floods.

Floods vary greatly in their character and their impact, as does the vulnerability of the populations they affect. Areas at greatest risk are low-lying, near water, and located downstream from a dam. The health impacts of floods depend upon various factors, including the characteristics of the flood hazard, patterns of exposure, and underlying vulnerability of the population. The health impacts of a particular flood event are context specific, and are very different between developed and developing countries. The current review may be biased towards developed countries as the US and Western countries have published more than have other countries. Variations in population, density, resources, and building codes between developed and developing countries will alter the health impact. Disruptions to food supply are more likely in developing

countries while motor vehicle-related injuries are more predominant in developed countries.

The range of risks to health and well-being, both physical and mental, is understood, though there remains uncertainty about the strength of association and the public health burden for specific health effects. Overall, it is difficult to assess the duration of symptoms and disease, and the attribution of cause, and there is a relatively weak scientific evidence base to assess the health impacts of flooding. Most flood-related morbidity and mortality are preventable through education, good floodplain management, and prediction-warning systems.

This study sought to identify and categorize the health consequences of floods in a way that may aid the development of prevention, mitigation, and response strategies. It provides a conceptual framework that may assist health disaster managers with planning, preparation, and response.

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