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The water/health nexus in disaster medicine: I. Drought versus flood

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Water is a quintessential necessity of life; disasters are an unfortunate fact of life. The nexus of water and human health in Disaster Medicine is an important area of scientific inquiry because the incidence of disasters and their adverse effects on human populations are increasing exponentially worldwide. Whether it is in life-threatening short supply (drought), overabundance (floods, tsunamis and storm surges) or contaminated as a result of a disaster, water can have highly significant health effects on already distressed populations. In this, the first of two articles, the effects of drought and various types of flooding on human health are contrasted. Particularly in developing countries, water security is problematic and international collaboration is required to mitigate water-related adverse health effects.

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Nothing is softer or more flexible than water, yet nothing can resist it.

Lao Tzu

Introduction

Water is a quintessential necessity of life while disasters are an unfortunate fact of life. The nexus of water, health and Disaster Medicine is an important area of research because the global incidence of disasters is increasing [1]. Water-related emergencies are the most common cause of disasters worldwide, accounting for 40–50% of all disasters and disaster-related deaths [2••]. Social determinants of health play a major role in water-related disasters because the poor [3], the uneducated [3], women [4•], the elderly [5,6], the very young [7] and the disabled [8] are more vulnerable.

The World Health Organization (WHO) defines a disaster as ''a serious disruption of the functioning of a community or a society causing widespread human, material, economic or environmental losses which exceed the ability of the affected community or society to cope using its own resources'' [9]. Disasters may be natural, like hurricanes, or related to human activity, like terrorism and industrial accidents. They can also be characterized as sudden onset (e.g. earthquakes, flash floods, and tsunamis) or slower in onset (e.g. drought and riverine floods). The rapid onset disasters usually cause the majority of morbidity and mortality immediately while the slower onset disasters are more likely to cause morbidity and mortality through longer term, secondary effects [10••].

Disaster Medicine is a new medical specialty that not only treats victims in disaster situations but also deals with the medical issues related to emergency preparedness, disaster mitigation and disaster management. The United States formally recognized the new medical specialty by presidential order in 2007 [11]. The American Board of Disaster Medicine is the world's first physician board of certification in the nascent specialty [12]. As Disaster Medicine matures as a discipline, it will be important to develop a coordinated, standardized international approach to disasters, especially in developing countries that struggle with autonomous response to water-related disasters [13].

Whether a disaster involves too little water (e.g. drought), too much water (e.g. floods and tsunamis), or water contamination during or after the event, there is an inextricable connection among disasters, water and human health. This paper examines the most current literature in this subject area and offer perspectives for moving the field forward.

Too little water—drought

Unlike sudden disasters such as earthquakes and tsunamis, drought develops slowly over a period of months to years. Drought is characterized by lower than average precipitation in a given area over an extended timeframe, leading to an inadequate supply of water. As much as 15% of the world's natural disasters are caused by drought and

drought-related deaths account for 59% of the world's extreme weather mortality [14]. Multiple authors have linked climate change to increasing drought severity, although a definitive cause-and-effect relationship remains inconclusive [7,14–17,18]. There are significant public health implications related to drought. Public health workers and other health professionals need evidence-based recommendations for dealing with the consequences of water shortage (see for example, [19••]).

Food production is heavily water dependent. To produce every calorie of plant food at least one liter of water is required, while one calorie of meat or dairy food production can utilize ten liters of water [20]. Thus, drought often leads to decreased food production. Australia, for example, has suffered a significant period of drought over the last 30 years. This has adversely impacted much of the continent, but its effects have been especially problematic in the Murray–Darling Basin, the agricultural heartland of Australia, resulting in significant diminution of its crop and livestock output [20]. Recently, China, too, has been affected by drought in some of its provinces including Yunnan, Sichuan, Guizhou and Chongqing, causing delayed crop planting and livestock failure [21]. Even without drought, China's water resources are scarce. They have only 7% of the world's fresh water but support 20% of the world's population with significant regional disparities in water availability [22].

Severe, prolonged drought can eventually lead to outright famine as has frequently been recorded since the 9th Century in Ethiopia [23•]. It can cause significant population displacement as well [16]. Note that children are particularly at increased risk of adverse health effects, especially when drought results in famine and malnutrition [7]. The elderly, too, are more susceptible to the negative physical health effects of drought [17,18].

In addition to decreased quantity and quality of potable water, drought can cause adverse effects on air quality related to prolonged particulate suspension in the air. Increased airborne particulates aggravate bronchial passages, especially in people with chronic lung diseases like asthma [24]. Wildfires are more common in drought-stricken areas and the smoke from these fires also contribute to deranged lung function [24]. Recreational water activities can become hazardous as a result of increased pollution of depleted surface water [24]. Vector-borne diseases may proliferate. For instance, water shortage leads to mosquitoes breeding in atypical areas nearer to birds and other wildlife; the result can be outbreaks of St. Louis encephalitis, Eastern Equine encephalitis [24] and West Nile virus [25]. There can also be increased incidence of other diseases such as the fungal disease coccidiomycosis, the spores of which are increasingly aerosolized by drought conditions, making them easier to inhale [24].

Drought can also have a significant negative impact on mental health. The main psychosocial effects of droughts include reduced quality of life, significant alteration in lifestyle and conflict over insufficient water resources [26]. Australia's prolonged drought has taken its mental health toll on adolescents [27], the elderly and those living in rural areas, especially farmers [17]. A study in New South Wales demonstrated that over half the population surveyed felt that drought was extremely or very likely to continue. This attitude was especially prevalent among women, those living in rural areas and families with children under 16 years. Interestingly, respondents over 55 years were less likely to feel drought was highly likely to continue, possibly related to their broader life experience and having previously survived 'tough times' [14].

It is obvious from this discussion that lack of water has significant public health implications. The next section will focus on the detrimental impacts on health when there is too much of a good thing (i.e. water).

Too much water—floods, cyclonic storm surges, and tsunamis

Water disasters, whether relatively common (e.g. floods and hurricane storm surges) or rare (e.g. tsunamis), are a major cause of global morbidity and mortality. Floods are the most common type of disaster worldwide. Storm surges are the most dangerous aspect of hurricanes. Tsunamis are one of nature's most awesome spectacles; one may have accounted for Plato's legendary lost city of Atlantis [28]. What these various types of water events have in common is an excess of water; what varies among them is the speed with which that excess occurs.

Floods and storm surges

Floods can occur either by bodies of water overflowing their banks or by water accumulating over low-lying areas [2••]. In the United States, floods account for approximately 90% of natural disaster damage if droughts are excluded; the average annual cost of U.S. floods between 1988 and 1997 amounted to $3.7 billion dollars [28]. In developing countries, the human cost of floods is enormous, especially in countries like Bangladesh that are prone to frequent flooding. In the 2007 Bangladesh flood, for example, over 7.5 million people were affected and more than 250,000 sought refuge in temporary shelters.

Floods can develop slowly, such as in northern latitudes when winter snows melt and ice-choked rivers crest above flood stage over a period of days to weeks (riverine floods). On the contrary, 'flash floods' can develop over a period of just several hours, either from sudden heavy precipitation or dam/reservoir/levee breach as occurred in New Orleans after Hurricane Katrina [2••]. It is flash floods that account for the majority of drowning deaths—often because victims underestimate the power of the current and the

depth of the water. According to the Red Cross, ''six inches of swiftly moving water can sweep you off your feet'' [29]. In developed countries, the majority of flood deaths occur in motor vehicles when drivers inappropriately try to navigate flooded roads and bridges or crash owing to poor driving conditions. In the United States, more than 57% of flood mortality is automobile-related [2••]. The Red Cross notes the following: ''Most cars can be swept away by less than two feet of moving water'' [29]. Fortunately, improved meteorological forecasting has decreased flash flood mortality by >50% [26].

Floods have both direct and indirect health consequences. The most immediate effect is drowning. Those who do not drown may sustain orthopedic and soft tissue injuries from floating debris, electrical injuries from downed power lines, burns and trauma related to gas leaks and ruptured chemical tanks, hypothermia, and loss of health services (e.g. hospitals and clinics) in the flooded area. Secondary health effects of flooding include water contamination (discussed in the second part of this review), carbon monoxide poisoning from inappropriately located gas-powered generators, and increased respiratory illnesses related to mold exposure and microbial growth [2••]. After Hurricanes Katrina and Rita, the burden of fungal spores in flooded houses was significantly elevated with *Aspergillus niger*, *Penicillium* sp., *Trichoderma*, and *Paecilomyces*, all of which can cause either respiratory or dermatological disease, particularly in individuals who are immunocompromised [10••].

Outbreaks of diarrheal illness have occurred after some floods but are not as common as expected. When diarrheal illnesses do occur, they tend to be due to pathogens that already existed in the local environment pre-flood, such as *Shigella* and *Giardia*. For instance, there was a waterborne outbreak of cholera following Cyclone Aila in West Bengal, India in 2009 that lasted from May through August of that year, but cholera is endemic in India. That epidemic was eventually controlled through repairing broken water pipelines, chlorination of household drinking water and public education [30]. In the month of August 2007, Bangladesh's Dhaka Hospital treated 21,401 cases of diarrheal illness as a result of severe flooding, more than three times the amount treated in the same month in 2006 [4•].

Overall, communicable diseases are less common after floods than after other types of disasters. When they do occur, they tend to be related to overcrowded shelters, poor personal hygiene, lack of clean water, poor sanitation, poor nutrition, and increases in disease-carrying vectors like mosquitoes [2••,10••]. For example, Cyclone Sidr hit Bangladesh in 2007 and did significant damage. Once again, authorities feared epidemics of water-borne, respiratory and other diseases, but the dire predictions turned out to be wrong. In fact, a study demonstrated the illness prevalence to be only 3.6% after Cyclone Sidr largely owing to early distribution of food and water, proper medical care and effective public health interventions [3]. Of course, there are exceptions, such as the previously mentioned diarrheal outbreak in Bangladesh's Dhaka Hospital. More discussion about post-disaster water contamination occurs in the second part of this review.

The mental health effects of floods can be significant and long lasting. Flood victims are four times more likely to suffer psychological distress compared with people who have not suffered a flood; they are also 13.8% more likely to commit suicide after flooding compared to pre-flood [2••]. A study of the mental health issues of children who survived Hurricane Katrina in 2005 demonstrated that 29% of pediatric primary care visits between July 2007 and June 2009 involved mental health issues or developmental and learning problems that required significant case intervention. The majority of the children showed disruptive behavior associated with underlying mood or anxiety disorders, but many of them had shown signs of psychological disturbance before the storm [31]. Another study involving youth post-Katrina found similar results. At baseline examination between 18 and 27 months after Katrina, 15.1% of youth showed signs of mental health disorders. On follow-up 12–18 months later (30–45 months after the storm), 11.2% of youth still demonstrated psychiatric problems, compared with only a 4.2% prevalence of psychiatric disturbance before Katrina [32]. In contradistinction, some studies described in a recent review article showed that the elderly might be more psychologically resilient in floods because they had been exposed to similar circumstances before [6].

In the United Kingdom (U.K.), a cross-sectional survey of 444 flood victims found 27.9% suffered from post-traumatic stress disorder (PTSD) symptoms, 24.5% from anxiety and 35.1% from depression, with women showing more symptoms on average than men. Factors associated with greater psychological distress included displacement, poor health and previous flood experiences [33]. This latter finding differed with another U.K. group who found that prior exposure to flooding increased individual preparedness that logically would improve resilience and coping skills [34].

In Bangladesh, a study of flood-related mental health effects found higher household income and better employment translated to better access to food and water resulting in better coping post-flood. Similarly, higher educational level allowed better access to pre-flood warnings that decreased vulnerability and increased coping capacity skills. However, prolonged flooding with higher water levels and household location closer to riverbanks caused increased external stressors and worse coping post-flood [3].

Whereas floods can result from a variety of weather conditions, storm surges are caused by hurricane-force winds and the low-pressure induced vacuum effect of a tropical cyclone. The size of the storm surge depends partly on the shape of the coastline, the slope of the sea floor and the stage of the tidal cycle when the storm hits. The majority of cyclone-associated mortality is caused by the storm surge [10••]. For instance, Hurricane Katrina's storm surge reached 27 feet in parts of Mississippi and leveled the coastline for up to several miles inland [35], while the surge from Hurricane Camille in 1969 reached 25 feet and similarly decimated the Gulf Coast [28]. Although the public had several days warning to evacuate in advance of Katrina, a significant number of residents chose to ''ride it out''. Many of those who remained along the Mississippi coast where the storm surge was the worst were swept away and drowned—a typical ''rapid onset disaster'' despite the advance warning. The post-disaster health effects of storm surge are basically the same as for other floods [10••].

Tsunamis

The Japanese translation of *tsunami* means 'harbor wave'. Tsunamis are caused by underwater earthquakes, volcanoes or landslides that displace huge amounts of seawater, creating waves that can pummel coastal regions; since 1850, more than 400,000 people have been killed by these enormous ''walls of water'' [28].

The March 2011 moment magnitude 9.0 earthquake and resulting tsunami in northeast Japan riveted the world's attention for weeks after the event [36], partly because of the damage sustained at the Fukushima Daiichi nuclear power plant and the release of a significant amount of radiation into the environment [37]. As this analysis is written, there is no end in sight for the worst nuclear power disaster since Chernobyl. The death toll from the earthquake and tsunami currently exceeds 28,000, although an accurate total will probably never be known since thousands of victims were simply washed out to sea [38].

The worst tsunami in recorded history occurred in late December 2004 after a moment magnitude 9.3 earthquake off the island of Sumatra—the Andaman Nicobar earthquake and tsunami. This single catastrophe resulted in >220,000 killed or missing in more than a dozen countries throughout the Indian Ocean region [39••]. The westernmost part of Indonesia, the worst hit area, saw a giant wave of black water 50–80 feet high [40]. Aceh province lost nearly three-quarters of its population and more than half of all survivors were left homeless [39••]. Unlike the extensive tsunami warning system of oceanic monitors in the Pacific Ocean, the Indian Ocean had no such early warning system in 2004, so the coastal areas had no indication of the impending disaster.

A study of the health impacts of the 2004 tsunami in Aceh province examined the incidence of cholera, tetanus, wounds and wound infections, acute respiratory infections, malaria and dengue before and after the event [39••]. There had been widespread speculation that communicable disease outbreaks and epidemics would be problematic in the wake of the disaster, although previous disaster literature did not support such predictions [41]. In fact, the study found no confirmed cholera cases in the four months post-tsunami. The incidence of malaria and dengue, traditionally low compared with the rest of Indonesia, did not increase. Tetanus cases tripled in the weeks after the event with a peak reported January 8–17, 2005. Nonetheless, there was no ''epidemic of tetanus'' [42]. Traumatic injuries, including wounds, fractures and general trauma, were significantly elevated up to eight weeks after the tsunami but reduced to just a few by week 16. Cases of aspiration pneumonia were similarly reported and causal organisms tended to be highly unusual and resistant to common antibiotics [42].

The Andaman Nicobar tsunami significantly impacted international tourist beach areas like Phuket, Thailand. Citizens from multiple countries required emergency evacuation and treatment. A study conducted at three European airport clinics set up to receive tsunami victims (Stockholm, Helsinki and London) demonstrated psychological and physical illnesses, including soft tissue and orthopedic injuries, pneumothoraces, near drowning, and aspiration pneumonias. As was found in the study noted previously [39••], the wound infections and pneumonias were often caused by unusual and highly drug resistant organisms [43].

Like other flood events, tsunamis can have long-term effects on the mental health of survivors. A study of 12,784 victims of the 2004 Andaman Nicobar tsunami [44] compared displaced and non-displaced victims and found a higher prevalence of psychiatric illness in the displaced but an equal distribution of depression and PTSD in both groups. Overall, 37.5% demonstrated adjustment disorder, 21.5% depression, 12% panic, 11.2% PTSD, and 5.5% anxiety. Factors that were found to be psychologically protective included:

- Belonging to a cohesive community.
- Good family system.
- Good social support.
- Altruistic behavior by community leaders.
- Religious faith and spirituality.

Some important lessons were learned from the 2004 tsunami disaster response [45,41,42,46]:

- Tsunamis result in relatively few survivor-casualties—most victims die immediately by drowning. Only 10%

of the wounded (approximately 7200) in Aceh required hospitalization [46].

- Foreign mobile hospitals lacked coordination and many arrived too late to be of much use. By day 20, there were nine foreign mobile hospitals in operation but bed occupancy rates were <50%. The USNS Mercy hospital ship with 12 operating theaters and 1000 beds arrived in Aceh from San Diego five weeks after the tsunami [40,46]. Efficient use of existing local facilities proved more valuable than the foreign mobile facilities [42].
- Prognostication of epidemics was exaggerated.
- Re-establishment of water and sanitation should be the first priority.
- Overly exuberant medical volunteerism actually did more harm than good, as there was no coordination of their activities. Further, volunteer responders were often reluctant to share operational information with one another because of a competitive humanitarian environment.
- Foreign monetary aid was excessive (>$7000 US per affected person) and humanitarian aid groups vied aggressively for these dollars.
- Logistics of sorting through massive amounts of international donations overwhelmed local capacity and most of the perishables were lost. Some of the medical equipment and training offered by international groups was totally inappropriate for the Indonesian reality.

Undoubtedly, many lessons will be learned from the 2011 Japanese tsunami response, but it seems likely that the Japanese will be more self-sufficient than the less developed countries devastated by the 2004 tsunami. It will be interesting to see if this leads to a more streamlined, efficient response.

Conclusions

Whether the problem is a lack of water in drought or an overabundance of water in flood, the public health effects of water on human populations in disasters are significant. This article has delineated the most current literature in this area. Recommendations for improving water safety in disasters are offered in the second article, after discussing the effects of water contamination on human health in disasters.

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