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EXPERT REVIEWS

Infectious diseases following natural disasters: prevention and control measures

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Natural disasters may lead to infectious disease outbreaks when they result in substantial population displacement and exacerbate synergic risk factors (change in the environment, in human conditions and in the vulnerability to existing pathogens) for disease transmission. We reviewed risk factors and potential infectious diseases resulting from prolonged secondary effects of major natural disasters that occurred from 2000 to 2011. Natural disasters including floods, tsunamis, earthquakes, tropical cyclones (e.g., hurricanes and typhoons) and tornadoes have been secondarily described with the following infectious diseases including diarrheal diseases, acute respiratory infections, malaria, leptospirosis, measles, dengue fever, viral hepatitis, typhoid fever, meningitis, as well as tetanus and cutaneous mucormycosis. Risk assessment is essential in post-disaster situations and the rapid implementation of control measures through re-establishment and improvement of primary healthcare delivery should be given high priority, especially in the absence of pre-disaster surveillance data.

Keywords: communicable diseases • control • epidemic • infectious diseases • natural disasters • outbreak • prevention • surveillance

Global population growth, poverty, land shortage and the urbanization in many countries have increased the number of people living in areas prone to natural disasters and multiplied their public health impacts [101]. In recent decades, the incidence and magnitude of natural disasters has grown resulting in substantial economic damages, affecting and killing millions of people. The consequences of devastating disasters such as Hurricane Katrina in the USA (2005) and the Great Eastern Japan Earthquake and tsunami (2011) have shown that even the most developed countries are vulnerable to natural disasters. Natural disasters are defined as disruptions of the ecological system that exceed the community's capacity to adjust, thereby necessitating external assistance [1]. They can globally be classified in three main groups:

- Hydro-meteorological disasters (e.g., floods, wave surges, storms, typhoons, hurricanes and tornadoes);
- Geo-morphological disasters (e.g., landslides and avalanches);
- Geophysical disasters (e.g., earthquakes, tsunamis and volcanic eruptions).

The risk of infectious disease outbreaks in the aftermath of natural disasters has usually been overemphasized by health officials and the media leading to panic, confusion and sometimes to unnecessary public health activities [2]. Injuries and deaths during or shortly after natural disasters are directly associated with fractures, lacerations, blunt trauma, crush injuries, projectile injuries, burn injuries and drowning [3]. Most people believe that there is a high risk of infectious diseases transmission and outbreaks shortly after a natural disaster. However there is no scientific evidence supporting that belief, especially when the disaster has not resulted in substantial population displacement [3]. There is also no evidence that corpses pose a significant risk for infectious diseases transmission and outbreaks, especially when they are directly due to the natural disasters. Therefore, the source of acute infections is more likely to be from the survivors rather than from the resulting corpses [4]. The prolonged health impact of natural disasters on a community may see the collapse of health facilities and healthcare systems, disruption of surveillance and health programs (immunization and vector control programs), limitation or destruction of farming activities (scarcity of

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food/food insecurity), interruption of ongoing treatments and use of un-prescribed medications. Increases in infectious disease transmission and outbreaks following natural disasters are associated with prolonged after-effects of the disaster. These after-effects include displaced populations (internally displaced persons and refugees), environmental changes, increasing vector breeding sites, high exposure to and proliferation of disease vectors (rodents, mosquitoes), unplanned and overcrowded shelters, poor water and sanitation conditions, poor nutritional status and poor personal hygiene, low levels of immunity to vaccine-preventable diseases or insufficient vaccination coverage, and limited access to healthcare services. These changes in human conditions, in the ecosystem of pathogens and in the environment facilitate the occurrence and transmission of infectious diseases (epidemiologic triad). The goal of an emergency health response system is to prevent and control epidemics as well as to improve deteriorating health conditions among disaster victims. Although there is a growing interest in disaster studies, few have provided a clear understanding of the concept of infectious disease occurrence following disasters. This comprehensive review aims at describing potential infectious diseases after natural disasters. In addition, we summarize prevention and control measures to be considered by public health and humanitarian professionals in addressing disaster and public health challenges.

Materials & methods

Comprehensive literature review

Original articles, reports and documents were screened during the period from 14 June 2010 to 4 April 2011, using the following available sources: PubMed, Centre for Research on the Epidemiology of Disaster (Emergency Disaster Database [102]); WHO websites (Diseases Outbreaks News) [103]; Pan American Health Organization [104]; and the CDC [105]. Several keywords were used, including 'natural disasters', 'infectious diseases', 'communicable diseases', 'outbreak', 'epidemic', 'surveillance', 'prevention' and 'control'.

Selection criteria

Only articles, reports and documents that specifically described "disasters and infectious diseases outbreaks from 2000 to 2011" were included in our study. Those describing disasters alone (not followed by disease epidemics) as well as those that occurred before the year 2000 were excluded.

Findings

Although we collected 142 articles and reports, only 21 were included in our study. The documented disaster events and following disease outbreaks occurred over a period of 12 years (2000–2011). The following classification describes three clinical phases of natural disasters which summarize the chronological public health effects on injured people and survivors in light of infectious diseases consideration [5]. Phase 1, the impact phase (lasting 0–4 days), is the period usually when victims are extricated and initial treatment of disaster-related injuries are provided. Phase 2, the postimpact phase (4 days to 4 weeks), is the period when the first waves of infectious diseases (air-borne, food-borne and/or water-borne infections) might emerge. Phase 3, recovery phase (after 4 weeks), is the period when symptoms of victims who have contracted infections with long incubation periods or those with latent-type infections may become clinically apparent. During this period, infectious diseases that are already endemic in the area as well as newly imported ones among the affected community may result in an epidemic. The increased infectious diseases transmission and outbreaks recorded have been documented in a context of substantial population displacement and basic public health breakdown following disasters (Table 1).

Natural disasters & public health

Hydro-meteorological disasters

Flood disasters are the most common (40%) natural disasters worldwide [6] and have been more widely documented than any other natural disaster. They occur globally and are weather and climate change related events. Immediate injuries and deaths that result from flood disasters are caused by drowning and blunt trauma [3]. The public health consequences of flooding include disease outbreak resulting from the displacement of people into overcrowded camps and cross contamination of water sources with fecal material and toxic chemicals. Flooding is also usually followed by the proliferation of mosquitoes resulting in an upsurge of mosquito-borne diseases such as malaria [6]. The public health after-effects of tropical cyclones (hurricanes and typhoons) disasters and tornadoes, especially infectious diseases outbreaks, have been less documented compared with flood disasters.

Geophysical disasters

Earthquake disasters are found to be the second most reported natural disaster (after floods) and the first among the geophysical disasters. They are specifically reported in regions with high seismic activity such as in America (central and south) and Asia (southeast and central Asia). The impact of the earthquake may vary according to the power, intensity, geographical localization (high density population) and level of development of the affected country. The direct cause of death in the aftermath of an earthquake is primarily seen as a result of building collapse and traumatic injuries. Outbreaks of infectious diseases may be reported when the earthquake disasters result in substantial population displacement into unplanned and overcrowded shelters, with limited access to food and safe water. Disease outbreaks may also result from the destruction of water/sanitation systems and the degradation of sanitary conditions directly caused by the earthquake. Tsunamis are commonly associated with earthquakes but can also be caused by powerful volcanic eruptions, or underwater landslides [106]. Although classified as geophysical disasters, they have a similar clinical and threat profile (water-related consequences) to that of a tropical cyclones (e.g., typhoon or hurricane) with resultant flooding. No documentation on geomorphologic disaster (e.g., avalanche and landslide) associated with infectious disease transmissions and outbreaks was found.

Potential infectious diseases & outbreaks following natural disasters

As stated earlier, epidemics are not directly linked to natural disasters. Several synergic factors including massive population displacement, and changes to the environment, to the conditions of the affected population, as well as the vulnerability to existing pathogens need to be in place and exacerbated as a result of the after-effects of the disaster. Infectious diseases epidemics/outbreaks are quite inexistent in the impact phase of a disaster. They may occur several days, weeks or months in the postimpact or recovery phases after major disasters strike (Table 2). However, it is common to see the international community, NGOs, volunteers, experts and the media leaving a disaster-affected zone usually within 3 months, when in reality basic sanitation facilities and access to basic hygiene may still be unavailable or worsen due to the economic burden of the disasters [1]. Compared to complex emergencies, most natural disasters are not associated with diseases outbreaks, especially when they do not result in massive population displacement. Although it is not possible to predict with accuracy which diseases will occur following certain types of disasters, outlined below are examples of disease outbreaks documented after natural disasters (Table 1).

Table 1. Breakdown of natural disasters recorded from 2000 to 2011 and potential secondarily-associated infectious diseases†.

Country	Disaster event	Year(s)	Infectious disease outbreak following natural disaster	Ref.
USA	Tornado	2011	Cutaneous mucormycosis	[25]
Japan	Earthquake	2011	Diarrhea (norovirus), influenza	[109]
Haiti	Earthquake	2010	Cholera	[108]
Cote d'Ivoire	Flood	2010	Dengue	[113]
Brazil	Flood	2008	Dengue	[112]
USA	Hurricane (Katrina)	2005	Diarrhea, TB	[18,24]
Pakistan	Earthquake	2005	Diarrhea, hepatitis E, ARI, measles, meningitis, tetanus	[11,21]
Dominican Republic	Flood	2004	Malaria	[110]
Bangladesh	Flood	2004	Diarrhea	[8]
Indonesia	Tsunami	2004	Diarrhea, hepatitis A and E, ARI, measles, meningitis, tetanus	[13,22]
Thailand	Tsunami	2004	Diarrhea	[14]
Iran	Earthquake (Bam)	2003	Diarrhea, ARI	[12]
Indonesia	Flood	2001–2003	Diarrhea	[9]
USA	Hurricane (Allison)	2001	Diarrhea	[17]
Taiwan	Typhoon (Nali)	2001	Leptospirosis	[20]
China	Typhoon (Nali)	2001	Leptospirosis	[20]
El Salvador	Earthquake	2001	Diarrhea, ARI	[15]
Thailand	Flood	2000	Leptospirosis	[110]
Mozambique	Flood	2000	Diarrhea	[10]
India (Mumbai)	Flood	2000	Leptospirosis	[19]

†Summarizes natural disasters that had resulted first in substantial population displacement and then exacerbated risk factors for disease transmission and outbreaks.
ARI: Acute respiratory infection.

Risk of water- & food-borne diseases & infections from compromised personal hygiene

Diarrheal diseases are a leading cause of death (40%) in disaster and camp settings [7,107]. Epidemics among victims are commonly related to polluted water source (fecal contamination), and contamination of water during transportation and storage. Outbreaks have also been related to shared water containers and cooking pots, scarcity of soap and contaminated food.

Natural disasters do not import diseases, including diarrheal diseases. It is not possible for diseases that are not endemic or imported in the disaster affected areas to occur naturally. Diarrheal disease epidemics (more than 17,000 cases) have been reported after population displacement by flooding in Bangladesh in 2004 [8]. An investigation conducted after floods in Indonesia between 2001 and 2003 revealed that diarrheal case-patients with *Salmonella enterica* serotype paratyphi A were four times more likely to have been exposed to the disaster [9]. Floods are recurrent disasters in many African countries. In 2000 in Mozambique, flooding resulted in a significant increase in incidences of diarrheal diseases [10]. Following the 2005 earthquake in Pakistan, an estimated 42% increase in diarrheal infections was reported in an unplanned and poorly equipped refugee camp [11]. In Iran, 1.6% of the 75,586 persons displaced by the Bam earthquake in 2003 were infected with diarrheal diseases. This was due to poor hygiene, crowding, lack of potable water and ineffective sanitation [12]. A rapid assessment conducted in Indonesia after the 2004 tsunami showed that 85% of the survivors in the town of Calang experienced diarrheal illness after drinking from contaminated wells [13]. In Thailand, the 2004 Indian tsunami has also contributed to a significant increase in diarrheal disease incidence [14]. An investigation conducted in 100 households after the 2001 earthquake in El Salvador showed that 137 persons out of 594 (22%) experienced diarrheal infections [15]. An evolving cholera epidemic was described with a high case–fatality rate (CFR:

Table 2. Risk factors and onset of communicable diseases following natural disasters†.

Major risk factors following natural disasters	Water-borne diseases			Air-borne/droplet diseases				Vector-borne diseases		Contamination from wounded injuries		Clinical phase of natural disasters		
	Diarrhea (cholera; dysentery)	*Leptospirosis*	*Hepatitis*	*ARI (pneumonia/ influenza)*	*Measles*	*Meningococcal meningitis*	*TB*	*Malaria*	*Dengue fever*	*Tetanus*	*Cutaneous mucormycosis*	*Impact phase (0–4 days)*	*Postimpact phase (4 days- 4 weeks)*	*Recovery phase (>4 weeks)*
Population displacement from nonendemic to endemic areas								✓	✓					✓
Overcrowding (close and multiple contacts)	✓			✓	✓	✓	✓						✓	
Stagnant water after flood and heavy rains	✓	✓						✓	✓					✓
Insufficient/contaminated water and poor sanitation conditions	✓		✓										✓	
High exposure and proliferation to disease vectors		✓						✓	✓					
Insufficient nutrient intake/ malnutrition	✓			✓	✓		✓							✓
Low vaccination coverage					✓									
Injuries										✓	✓		✓	✓

†Disasters do not carry diseases/epidemics. Disease risk factors need to be in place and exacerbated as a result of the after effects of the disaster.
ARI: Acute respiratory infection.

6.4%; 303 out of 4722), 9 months after the earthquake in Haiti struck [108]. The existing poor sanitary and living conditions were exacerbated by the earthquake and furthermore by a hurricane, contributing to the rapid spread of imported *Vibrio cholerae* in an immunologically naive and highly susceptible population [16].

Diarrheal epidemics are frequently reported following natural disasters in developing countries. Major disasters can exacerbate the risk factors for infectious diseases transmission by affecting pre-existing poor water, sanitation and sewage systems. In these countries where *V. cholerae* is highly endemic and microbiological laboratories are often absent or limited, many severe gastroenteritis cases detected after flood disasters have been reported as cholera outbreaks. No significant outbreaks of infectious diseases were reported following the devastating Great Eastern Japanese Earthquake and associated tsunami. Only a small cluster of norovirus cases was reported in evacuation centers [109] some weeks after the disasters. Various pathogens including norovirus, and toxigenic and non-toxigenic *V. cholerae* were confirmed among the populations displaced by Hurricanes Allison (2001) [17] and Katrina (2005) [18] in the USA.

Leptospirosis can be transmitted through contact with contaminated water, food and soil containing contaminated urine (leptospires) from infected animals (e.g., rodents). Contamination occurs through contact of broken skin and mucous membranes with water, damp soil or mud contaminated with rodent urine. Floods facilitate the proliferation of rodents and the spread of leptospires in a human community. The disease is usually reported following flooding in developing countries (Table 1). Investigations conducted in populations affected by flood disasters in 2000 in India [19] and Thailand [110] reported Leptospirosis epidemics to be associated with contact, bathing and drinking of contaminated water. Increased risk factors and outbreaks were also reported after Typhoon Nali [20] in China and Taiwan in 2001.

Viral hepatitis A and E are common in countries or areas where existing sewage disposal and sanitation system are inadequate. Following the 2005 earthquake in Pakistan, more than 1200 cases were reported among the displaced population in areas where access to safe water was limited [20]. Clusters of hepatitis A and E cases were also described among a susceptible community in Banda Aceh (Indonesia) following the 2004 tsunami disaster [21].

Risk of acute respiratory infections or diseases associated with overcrowding

Acute respiratory infections (ARIs) account for 20% of all death in children less than 5 years of age, with the majority of deaths resulting from pneumonia [111]. The risk of ARIs may be increased due to overcrowding, poor ventilation and poor nutrition, and in crowded shelters specifically in cold weather [110]. A study conducted after the 2001 El Salvador earthquake showed that 30% of

594 affected people experienced upper respiratory tract infection [15]. In Iran, respiratory tract infections were also found among 14% of the 75,586 population displaced by the Bam earthquake in 2003 [12] associated with inadequate protection during freezing winter nights. Increases in acute respiratory infection incidence was also documented after the 2005 Pakistan earthquake [21], while in Aceh province (Indonesia) morbidity and mortality due to ARIs were the highest among the tsunami victims in 2004 [22].

Measles transmission and outbreaks in disaster settings depends on the baseline immunization coverage among the affected populations, especially in crowded camps or shelters. While epidemics are an expected threat in complex emergencies, few outbreaks have been associated with acute natural disasters. Clusters of more than 400 measles cases were found following the earthquake in Pakistan in 2005, mostly in communities living in crowded shelters with existing low vaccination coverage conditions [21]. Clusters of measles cases were also reported in a susceptible community living in unplanned and crowded camps following the 2004 tsunami disaster in Banda Aceh [22].

Meningitis caused by *Neisseria meningitidis* (meningococcal) is a major cause of morbidity and mortality in childhood especially in Africa and Asia [23]. The disease is easily transmitted from person to person, particularly in situations of crowding [3]. Meningitis outbreaks have been documented after only a few natural disasters including the 2005 Pakistan earthquake [21] and the 2004 Indonesian Tsunami [22]. Crowded camps, poor hygiene, limited access to medical care as well as living in close quarters with infected persons are major risk factors associated to the spread of the disease.

TB is a growing concern in refugee settings, especially in post-conflict situation. Factors such as population displacement, poor access to healthcare services and interruption of on-going treatment or control programs may increase the disease burden. Thus, after Hurricane Katrina in the USA (2005), TB control efforts were given priority with regard to both detecting new cases and continuing treatment for known cases [24].

Influenza infection is a rapidly evolving disease with widespread morbidity as observed during the pandemic of the novel influenza A H1N1 in 2009. Epidemics of influenza infection following natural disasters are less documented, however, cases were reported in some evacuation centers a few weeks after the Great Eastern Japan Earthquake in 2011[109].

Risk of vector-borne diseases or diseases related to the change in the environment

Malaria epidemics after flooding are a well-known phenomenon in malaria-endemic areas. Standing water caused by floods creates a breeding site for mosquitoes. Overcrowded conditions and temporary shelter may increase mosquito bite frequencies and promote the transmission cycle. Dramatic increases in malaria cases were observed following floods in the Dominican Republic [110] associated with the disruption of sanitary services, in addition to the crowded environments in camps.

Dengue fever is transmitted to humans via the bite of infected mosquitoes of the Aedes genus. *Aedes aegypti* can adapt well to urban environments by breeding in clean or stagnant water in a wide variety of containers that collect rainwater such as tires, tin cans, pots and buckets. Following the flood disaster in Brazil (2008), 57,010 dengue cases including 67 deaths were reported among victims [112]. This epidemic was associated with the disruption of basic water supply and solid waste management services. Other risk factors included changes in human behavior (e.g., sleeping outside and movement from nonendemic to endemic areas) and changes in habitat that promote mosquito breeding. In 2010, cases and deaths due to dengue fever were reported in Cote d'Ivoire following periods of heavy rain [113].

Risk of infections resulting from wounds & injuries

Tetanus was a serious public health problem among those with wound infections and unvaccinated populations during the 2004 tsunami in Indonesia [22]. The disease is often associated with crush injuries and contaminated wounds. The tetanus CFR rose up to 18% (CFR: 20 out of 106) in Banda Aceh province. Cases were also recorded during the 2005 Pakistan earthquake [21].

An unusual cutaneous mucormycosis or fatal necrotizing fungal soft-tissue infection due to Mucormycete *Apophysomyces trapeziformis* was observed (after 12 days) among wound-injured victims from the tornado that struck Joplin, Missouri (USA) on 22 May 2011 [25]. The disease is caused by fungi of the order Mucorales, which are typically found in soil and decaying wood. The disease has a high fatality rate (29–83%) and is often associated with immunocompetant hosts after traumatic penetration of fungal spores [26].

Myth of infectious disease transmission from corpses

Despite the vast number of deaths resulting from major disasters such as the earthquakes in Haiti, the Great Eastern Japan Earthquake and tsunami, no outbreaks resulting from corpses has been documented. That corpses pose a significant risk for infectious diseases transmission and outbreaks still involves controversy and is frequently overstated after natural disasters. Corpses do not pose a public health risk for disease outbreaks because the environment in which pathogens live can no longer sustain them, and microorganisms involved in putrefaction (decay processing) are not pathogenic [24,27,28]. However, since this does not happen immediately after death, some pathogens, including blood-borne viruses (e.g., Ebola virus, Lassa virus, Marburg virus, Crimean-Congo hemorrhagic fever virus) and enteric pathogens (e.g., *V. cholerae*) may remain alive for some time in the dead body [29]. In these cases, the risk of transmission of infectious agents from corpses is possible and requires specific precautions [30]. Therefore, families should not be deprived of appropriate identification and burial ceremonies for their dead relatives after a disaster has occurred (**Box 1**). Indeed, survivors from disasters present a more important reservoir for potential infectious diseases.

Prevention & control measures

A rapid diseases risk assessment should be conducted by public health responders within the first week of the disaster in order to identify disaster impacts and health needs. The summarized

Box 1. Precautions for handling corpses†.

- Burial is preferable to cremation in mass casualty situations.
- Every effort should be made to identify the bodies. Mass burial should be avoided if at all possible.
- Families should have the opportunity (and access to materials) to conduct culturally appropriate funerals and burials according to social custom.
- Where existing facilities such as graveyards or crematoria are inadequate, alternative locations or facilities should be provided.
- For workers routinely handling bodies, ensure:
  - Use and correct disposal of gloves
  - Use of body bags if available
  - Hand-washing with soap after handling bodies and before eating
  - Disinfection of vehicles and equipment
  - Bodies do not need disinfection before disposal (except in cases of cholera, shigellosis or hemorrhagic fever)
  - Bottom of any grave is ≥1.5 m above the water table, with a 0.7-m unsaturated zone

†Mass management of corpses is often based on the false belief that they represent an epidemic hazard if not buried or burned immediately.

checklist in Table 2 needs to be considered for the early warning system as well as when doing post-disaster risk assessment. Prompt and adequate prevention and control measures, and appropriate case management and surveillance systems are essential for minimizing infectious disease burdens. The summarized checklist in Table 3 for prevention and control of recorded diseases may also help operators in the field of public health response as described in the following sections.

Site planning

Site planning must ensure the most rational organization of space, shelters and facilities required for the provision of essential goods and services. It should be implemented according to the existing international guidelines [31]. Some typical requirements include providing 3.5 m^2 of shelter space per person, building one latrine for every 20 persons and locating the latrines at 30 m distance from shelters and 100 m distance from water supplies [32]. Practically, it must provide adequate solutions to water and sanitation needs and meet the minimum space requirement per person to prevent water-borne and air-borne diseases.

Box 2. Circumstances when hand washing is critical†.

- Before eating food
- After handling uncooked foods, particularly raw meat, poultry or fish†
- After going to the bathroom
- After changing a diaper or cleaning up a child who has gone to the bathroom
- Before and after tending to someone who is sick
- Before and after treating a cut or wound
- After blowing your nose, coughing or sneezing
- After handling an animal or animal waste
- After handling garbage

†Food handlers should wash hands with soap and water before beginning work, and before returning to work from any toilet visit or break. Alcohol hand gel should not be substituted for handwashing in food handlers.

Food, water supply & sanitation

Adequate supplies of water per person (minimum agreed standard of 20 l per person per day) for drinking, bathing, washing and for excreta disposal, as well as management of solid wastes, are essential in preventing outbreaks of diarrheal diseases and other vector-borne diseases. Appropriate and sufficient water containers, cooking pots and fuel (firewood) should also be provided. People should ensure that water storage containers are well protected and that the food is well cooked. It is necessary to provide sufficient amounts of soap (minimum of 250 g per person per month) and to educate the community on personal hygiene and circumstances in which hand washing is important (Box 2) [114]. Relief programs should not only construct latrines but most importantly should educate the community in the use of these latrines since personal fecal practices are resistant to a rapid change. Chlorine remains the most easily and widely used disinfectant for drinking water and also the most affordable one. It is highly effective against nearly all water-borne pathogens and is essential where no alternative supply of safe water exists [33]. Provision of adequate general rations (2100 kcal and 46 g of protein) is important specifically for underweight and malnourished children through selective feedings programs.

Vector-borne disease control

Vector control is the primary public health intervention for reducing transmission at the community level [115]. For malaria vector control, insecticide-treated mosquito nets, specifically long-lasting insecticide-impregnated nets, are the preferred form of insecticide-treated mosquito nets in public health distribution programs. Indoor residual spraying with insecticides is appropriate for populations living in permanent housing structures with vectors residing indoors [32]. For dengue vector control, proper solid waste disposal, improved water storage practices, including covering containers to prevent access to egg-laying female mosquitoes, are among the methods encouraged through community-based programs.

Vaccination

Measles immunization has been documented as one of the most cost-effective public health interventions in disaster and refugee settings [34]. Vaccination measures for sheltered populations after natural disaster can supplement normal public health vaccination programs. Measles vaccinations should be conducted as soon as people start gathering in camps. Immunization should be done preferably using the combined measles–mumps–rubella vaccine especially in case of limited or inexistent laboratory facilities [34]. The target age groups for vaccination should be guided by surveillance data. Measles vaccination campaigns together with vitamin A supplementation are a protective measure against ARIs as well as measles [35]. Vaccination campaigns

Table 3. Prevention and control checklist of recorded infectious diseases following natural disasters.

Prevention and control of infectious diseases following natural disasters	Water-borne diseases			Air-borne/droplet diseases				Vector-borne diseases		Contamination from injury/wound	
	Diarrhea (cholera; dysentery; others)	*Leptospirosis*	*Hepatitis*	*ARI/pneumonial/ influenza*	*Measles*	*Meningococcal meningitis*	*TB*	*Malaria*	*Dengue fever*	*Tetanus*	*Cutaneous mucormycosis*
Site planning	✓			✓	✓	✓					
Clean water	✓										
Good sanitation (e.g., excreta disposal)	✓		✓								
Solid waste management								✓	✓		
Water and food hygiene	✓		✓								
Nutrition and supplements				✓	✓		✓				
Vaccination					✓						
Vector control								✓	✓		
Personal hygiene (e.g., hand washing)	✓		✓	✓			✓				
Personal protection		✓		✓				✓	✓		
Insecticide-treated nets								✓			
Isolation of the sick				✓			✓				
Prophylactic treatment								✓			
Wound/injury care										✓	✓
Health education	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Disease management/treatment and or supportive care (follow national guidelines)	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓

Specific communicable diseases applicable to the preventive and control measure given.
ARI: Acute respiratory infection.

for other diseases such as cholera, hepatitis and tetanus have not been documented.

Disease management

Prevention and clinical management should be implemented immediately to control infectious disease outbreaks. Several management protocols are available, but those in accordance with the national guidelines (as mentioned in Table 3) must be used to ensure appropriate treatment at every contact point between patients and healthcare services. Regarding diarrheal diseases (the most reported diseases in post-disaster settings), it is important to emphasize that rehydration therapy remains the same for any etiology of acute gastroenteritis and should start as soon as possible before the results of other investigations are obtained.

We recommend re-establishing and improving the delivery of primary healthcare through restoration of affected health services. Besides a sufficient level of sanitation, medical supplies should be provided and training of healthcare workers and medical personnel on appropriate case management should be conducted. Outreach health workers and volunteers can play an important role by informing people about the risk of the on-going outbreaks. They can encourage early referral of patients as well as advise on preventive measures to be taken. Community leaders should contribute to mobilizing resources, and improving surveillance and vaccination activities [34].

Every country should have emergency and preparedness plans in place but in developing countries, surveillance systems and even basic facilities (clinical and laboratory) are not functioning and an epidemic may go unnoticed. Moreover, such countries still live in very dynamic and unstable situations with a shortage of skills and resources, which make it difficult to set-up and/or maintain a proper health information system for appropriate emergency and preparedness plans.

Most of the publications on disasters and communicable diseases are limited to morbidity and mortality studies. Therefore, we suggest further study in areas such as the socioeconomic burden

of disasters and subsequent infectious diseases, and the potential of information communication technology (e.g., mobile health and e-learning) in disaster management and disease prevention in developing countries.

Conclusion

Natural disasters and infectious diseases outbreaks represent global challenges towards the achievement of the Millennium Development Goals. Our study described risk factors and potential infectious diseases following major natural disasters recorded from 2000 to 2011. Therefore it is important for the public, policy makers and health officials to understand the concepts that disasters do not transmit infectious diseases; the primary cause of death in the aftermath of a disaster is noninfectious; corpses (from disasters) are not a source of epidemic; and that infectious diseases outbreaks result secondarily from exacerbation of disease risk factors. Rapid implementation of control measures should be a priority in communities displaced by disasters, especially in the absence of pre-disaster surveillance data. Surveillance in areas affected by disaster, in camps, health facilities (hospitals and clinics) and other points where victims are treated, is fundamental. It is also important to consider stepping-up the existing system (e.g., national surveillance of reportable diseases). Management protocols should preferably be provided in accordance with the national guidelines.

Expert commentary

Natural disasters are continuously occurring globally, sometimes leading to substantial population displacement, and to the exacerbation of factors that enhance infectious disease transmission. Surveillance and early warning systems should include diseases that are already endemic as well as unusual events that could occur since new pathogens can be imported or can emerge and re-emerge in the disaster affected region. In order to increase the ability to control infectious diseases and prevent epidemics following disasters, it is vital that preparedness measures be taken before disasters occur. These efforts will minimize disease transmission and importation. It is important to consider the clinical phase of natural disasters and local disease (endemic) patterns for better resource allocations and an efficient response.

Five-year view

Recent disasters have shown that even the most developed countries are vulnerable to natural disasters. Natural disasters and infectious diseases will continue to be a threat to our global community and impact on country development. Every country should take preparedness measures by implementing a national preparedness and response plan, by empowering the local community in rescue activities, by training the health and outreach health staff in the identification and management of particular diseases, and by creating a stockpile of supplies and equipment for diagnosis, treatment and sanitation. National surveillance systems and the establishment of protocols for health information management have to be strengthened. In disaster situations, education on hygiene and hand washing, provision of adequate quantities of safe water, sanitation facilities and appropriate shelter are very important for the prevention of infectious diseases. Assessment and response activities described in this review should be remarkably coordinated.

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Key issues

- A natural disaster is a catastrophic event defined as a disruption of human ecology that exceeds the community's capacity to adjust, so that the outside assistance is needed.
- The overwhelming number of deaths immediately after a natural disaster are directly associated with blunt trauma, crush-related injuries and burn injuries.
- No certain risk of an infectious disease epidemic occurring in the short-term period after a disaster has been well documented.
- There is no proven evidence that corpses resulting from natural disasters increase the risk of infectious disease transmission.
- Infectious diseases transmission or outbreaks may be seen days, weeks or even months after the onset of the disaster and is due to massive population displacement and exacerbation of risk factors for disease transmission, such as the increasing size and characteristics of the displaced population within the local disease ecology, unplanned and overcrowded shelters or camps, lack of food, safe water and functioning latrines, poor personal hygiene and nutritional status, and low level of immunity to vaccine-preventable diseases.
- The potential infectious diseases resulting from natural disasters in our study included diarrheal diseases, leptospirosis, hepatitis fever, typhoid fever, acute respiratory infection, measles, meningitis, TB, malaria, dengue fever, tetanus and cutaneous mucormycosis.
- Epidemiological assessment for public health planning and resource allocation (e.g., drugs and water purification tablets) is essential in emergency assistance situations.
- Flooding is the most common natural disaster described with an increase in cases or outbreaks of infectious diseases including diarrhea, malaria and leptospirosis.
- Ideal prevention and control measures should include a strong disaster preparedness plan; surveillance systems for early case detection and treatment; adequate site planning following international guidelines; appropriate management of water and sanitation systems; adequate food supplies and storage; and a strong vector control and vaccination programs.
- Several management protocols are available, but those in accordance with the national guidelines must be used.
- The recommended control approach remains re-establishng and improving the delivery of primary healthcare through the restoration of affected health services.

information on disaster response and volunteer activities as well as infectious diseases (e.g., norovirus and influenza clusters in evacuation centers) during their field investigation in Sendai (June 2011) after the Great Eastern Japan Earthquake–Tsunami. The authors also acknowledge Ahmed Amara for his contribution in the group discussion for the validation and categorization of infectious diseases risk factors in **Table 2** *and infectious diseases prevention measures and control measures in* **Table 3**.

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