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Outbreaks Following Natural Disasters: A Review of the Literature

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Abstract

Understanding the relationship between infectious disease outbreaks and natural disasters is important in developing response and disaster risk reduction strategies. The aim of this study was to identify outbreaks associated with natural disasters during the past 20 y, and outline risk factors and mechanisms for postdisaster outbreaks. Review of the international disaster database (EM-DAT) and systematic review of the literature were conducted. The records of disaster events in EM-DAT during the past 20 y were screened. A literature search was carried out in the databases PubMed and Embase. Articles in English language published between 2000 and 2020 were searched. Data were extracted from articles and Narrative synthesis was used to summarize the findings. We found 108 events associated with epidemics, the majority being floods. We found 36 articles, most of them focused on outbreaks after floods. Risk factors and mechanisms that contributed to the outbreaks were mainly related to the consequences of disaster and its impact on the environment and living conditions of population. Infrastructure readiness and postdisaster measures play important roles in controlling the spread of epidemics after natural disasters. More evidence and research are required for better understanding of the association between natural disasters and infectious diseases outbreaks.

Disasters occur when the hazards affect societies and people's lives and cause harm to people, their properties and livelihood sources. Natural hazard is defined by The United Nations Office for Disaster Risk Reduction as "a natural process or phenomenon that may cause loss of life, injury or other health impacts, property damage, loss of livelihoods and services, social and economic disruption, or environmental damage."[1] The impact of disasters manifests in different forms. It can be limited to a specific place and period, but it may extend to include a larger geographical area and last for a long period of time. Socio-economic situation and demographic change resulting from increased population density in small areas in many countries may increase the impact of a natural hazard.[2] The interest in climate-related disasters is increasing worldwide. The rise in the intensity and frequency can be observed in different types of natural disasters such as floods, storms, droughts, and heatwaves.

Natural disasters have significant impact on public health. These effects appear through various mechanisms. One of the important aspects of natural disasters that appears after the initial response to the direct consequences of the event are epidemics.

An epidemic occurs when there is an increase in the incidence of disease infections among the population over a period in a specific geographical area.[3] Many factors are considered to determine whether the spread of a disease could be considered as an epidemic, including the location of the occurrence of the disease, the timing of the spread of the disease and the history of the disease in the area.[3] Epidemics may occur as a consequence of natural disasters.[4] The risk of epidemics and disease outbreaks is assumed to increase after disaster events due to consequences of the disaster event. The displacement and living in a crowded shelter result in an increased risk of exposure to pathogens and disease transition.[5] During disaster situations, malnutrition increases vulnerability as well to communicable diseases.[6] The interaction of various factors resulting from the catastrophic situation, whether environmental or population-related, is likely to contribute to the increase in epidemics[7].

Understanding the association between infectious disease outbreaks and natural disasters is essential to mitigate the public health consequences of natural disasters[8,9]. This can provide a solid evidence-base for disaster preparedness and response interventions. In this study, we identify outbreaks associated with natural disaster events reported in EM-DAT during the past 20 y and in the scientific literature, and outline risk factors and mechanisms for post-disaster infectious diseases.

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Table 1. Terms and queries used in the search in PubMed and Embase databases

	Concept	Mesh	Key words	Query
PubMed	Outbreak	Disease Outbreaks	outbreak, infectious disease, epidemic	#1: “Disease Outbreaks“[Mesh] OR outbreak*[tw] OR “infectious disease*“[tw] OR epidemic*[tw]
	Natural disasters	Natural Disasters	cyclone, storm, drought, earthquake, flood, landslide, tidal wave, tsunami, tornado, hurricane, avalanches, and wildfire.	#2: “Natural Disasters“[Mesh] OR “natural disaster*“[tw] OR cyclone*[tw] OR storm*[tw] OR drought*[tw] OR earthquake*[tw] OR flood*[tw] OR landslide*[tw] OR “tidal wave*“[tw] OR tsunami*[tw] OR tornado*[tw] OR hurricane*[tw] OR avalanches*[tw] OR wildfire*[tw]
	#1 AND #2: (“Disease Outbreaks“[Mesh] OR outbreak*[tw] OR “infectious disease*“[tw] OR epidemic*[tw]) AND (“Natural Disasters“[Mesh] OR “natural disaster*“[tw] OR cyclone*[tw] OR storm*[tw] OR drought*[tw] OR earthquake*[tw] OR flood*[tw] OR landslide*[tw] OR “tidal wave*“[tw] OR tsunami*[tw] OR tornado*[tw] OR hurricane*[tw] OR avalanches*[tw] OR wildfire*[tw])			
Embase	(‘Disease Outbreaks’ OR outbreak OR ‘infectious disease’ OR epidemic) AND (‘Natural Disasters’ OR ‘natural disaster’ OR cyclone OR storm OR drought OR earthquake OR flood OR landslide ‘tidal wave’ OR tsunami OR tornado OR hurricane OR avalanches OR wildfire)			

Methods

This research has 2 components: an extensive review of the international disaster database (EM-DAT), and a systematic review of the literature.

Associated Outbreaks and Disaster Events in EM-DAT

EM-DAT is a global database on natural and technological disasters, containing essential core data on the occurrence and effects of more than 24,000 disasters in the world, from 1900 to present. EM-DAT is maintained by the Centre for Research on the Epidemiology of Disasters (CRED) at the Institute of Health and Society of the Université catholique de Louvain located in Brussels, Belgium. EM-DAT includes all disasters from 1900 until the present, conforming to at least 1 of the following criteria: (a) 10 or more people dead; (b) 100 or more people affected; (c) the declaration of a state of emergency; and (d) a call for international assistance[10].

The search was done in a raw dataset which is not the same as the publicly available on EM-DAT website. In this data set, each event can have multiple entries according to the number of sources, and each entry has a “comment” column with free text which includes more information about the event.

The first step was to extract all outbreak events recorded in the database, and the second step was to identify the events during the past 20 y in which an outbreak was associated with a natural disaster[11-14]. Data of both epidemic event and natural disaster were separated.

For epidemic events[15-18], we searched for terms related to natural disasters to identify any kind of association. The opposite was done for natural disasters.

The records were screened searching for relevant terms based on the type of disaster recorded.

1. In events recorded as epidemics, the search included natural disasters, flood, earthquake, landslide, tsunami, storm, extreme temperature, drought, wildfire, typhoon, and cyclone.
2. In all other natural disasters, the search included whether there were any associated outbreak using the following terms: infect, epidemic, outbreak, cholera, diarrhea, and respiratory disease.

Based on the search in EM-DAT, the entries that had at least 1 of the defined words in the comments were selected and the disaster events associated with these comments were identified. Then all comments related to these events were screened, meaning we assessed all entries related to 1 event. The identified events were divided into 2 categories. The first category was the outbreaks reported in the database which were identified to be following natural disaster events[19], and the second category was natural disaster events identified that it was followed by an outbreak[20,21]. We then conducted a descriptive analysis of the data.

Systematic Literature Review

We followed PRISMA Guidelines.[22] The methodological approach was determined through discussion with the research team. The steps followed were to start with formulating the research question and objectives, developing search strategy and relevant terms, determining the approach for screening results, identifying relevant studies to be included in the analysis, extracting data, and synthesizing the information.

Search strategy

A literature search was carried out in 2 scientific databases. The first search was conducted in PubMed (National Center of Biotechnology Information, Bethesda, USA), and included the combination of 2 concepts, outbreak and natural disasters. The key words searched included disease outbreaks, outbreak, infectious disease, epidemic, natural disasters, cyclone, storm, drought, earthquake, flood, landslide, tidal wave, tsunami, tornado, hurricane, avalanches, and wildfire. The terms used in the search including the MESH terms and the key words and the detailed query are described in Table 1.

The inclusion criteria of the search done was the availability of full text, articles in English, articles published from 2000-2020. The search was carried out as well using the same keywords and terms in Embase. This search included looking for the terms in “all fields”, and the date of the publish was selected to be from the year 2000 to 2020 (Table 1).

Eligibility criteria

Inclusion criteria. Any peer-reviewed paper published between 2000 and 2020, establishing an association between a natural disaster and the occurrence (or aggravation of the occurrence) of an infectious disease of any type. Papers mentioning risk factors associated with the outbreaks. Papers discussing the mechanisms which led to the spread of infectious diseases.

Exclusion criteria. Outbreaks not related to natural disasters. Outbreaks associated with events that occurred before 2000.

Table 2. Number of natural disaster events that has been associated with outbreaks (EM-DAT)

Natural disaster type	No. of events identified by screening data of natural disaster events	No. of events identified by screening data of epidemic events
Flood	**44** Angola(n = 2), Argentina(n = 1), Benin(n = 2), Brazil(n = 1), Burundi(n = 1), Chad(n = 1), Colombia(n = 2), Ethiopia(n = 1), Ghana(n = 1), Guatemala(n = 1), Guyana(n = 1), India(n = 2), Haiti(n = 1), Indonesia(n = 3), Korea (the Democratic People's Republic of)(n = 1), Madagascar(n = 1), Malawi(n = 1), Mozambique(n = 2), Nepal(n = 2), Nicaragua(n = 1), Niger(n = 2), Pakistan(n = 1), Sierra Leone(n = 1), Somalia(n = 1), Sudan(n = 3), Suriname(n = 1), Thailand(n = 3), Uganda(n = 1), Ukraine(n = 1), Zambia(n = 1), Zimbabwe(n = 1)	**33** Angola(n = 2), Bangladesh(n = 3), Benin(n = 2), Bolivia (Pluractional State of)(n = 1), Cambodia(n = 1), Chad(n = 2), Guinea(n = 1), India(n = 4), Indonesia(n = 2), Madagascar(n = 1), Mali(n = 1), Malawi(n = 2), Mexico(n = 1), Mozambique(n = 5), Nepal(n = 1), Nicaragua(n = 1), Sierra Leone(n = 1), Sudan(n = 1), Zambia(n = 1)
Extreme temperature	**11** Afghanistan(n = 1), Bolivia(n = 1), Chile(n = 1), India(n = 1), Nepal(n = 1), Peru(n = 5), Spain(n = 1)	**0**
Storm	**4** Madagascar(n = 1), Syrian Arab Republic(n = 1), Vietnam(n = 1), Zimbabwe(n = 1)	**1** Mozambique(n = 1)
Volcanic activity	**3** Ecuador(n = 1), Indonesia(n = 1), Vanuatu(n = 1)	**0**
Earthquake	**2** Haiti(n = 1), Indonesia(n = 1)	**1** Pakistan(n = 1)
Wildfire	**2** Indonesia(n = 1), United States of America (n = 1)	**0**
Draught	**1** Sri Lanka(n = 1)	**6** Afghanistan(n = 2), Ethiopia(n = 1), Kenya(n = 1), Somalia(n = 1), Zimbabwe(n = 1),
Total	**67**	**41**

Papers not in English. Outbreak not documented, verified artificial increase of cases (due to increased surveillance), etc.

Study selection

The process of selection of the papers was done in 3 steps. First, the titles of the studies were screened, and relevant studies were selected. Second, the abstracts of the selected papers were read, and papers that did not match the inclusion criteria were excluded. Finally, the full text of the papers was read and papers discussing the potential risk factors, or the mechanisms were included for the review. There was no double check of the selection process and only the lead investigator carried out the selection process.

The data extracted from the studies included author's name, titles of the papers, year of publication, aim of the papers, natural disaster event type, type of disease associated with, geographical location, the year of the event, and main findings. The findings regarding risk factors and mechanisms were identified. Narrative synthesis was used to summarize the findings from different studies.

Results

EMDAT Overview

The results from reviewing the data of both natural disasters and epidemics recorded in EM-DAT database indicated that, during the past 20 y, there was an association between natural disasters and infectious diseases in 108 events.

In 67 natural disaster events reported in EM-DAT, the comments mentioned the occurrence of outbreaks of disease. The natural disasters identified included earthquakes, droughts, extreme temperature, floods, insect infestation, landslides, storms, volcanic activity, and wildfires. The main disaster events identified were floods ($n = 44$).

The records of epidemic data were screened to identify any potential relation to a natural disaster. In total, 41 epidemic events mentioned association with a natural disaster, the majority of which were floods ($n = 33$). The number of different events identified, and its geographic areas are described in Table 2.

Various diseases were identified by screening the data (Table 3). The spread of many diseases was often mentioned following the occurrence of natural disasters. Water-borne diseases and diarrheal diseases were the most common, with cholera specifically mentioned in 17 events, diarrheal diseases in 14 other cases, and water-borne diseases in 6 other cases. The respiratory diseases were reported in 18 events. The respiratory diseases were reported in 21 events. other diseases were mentioned as well such as skin diseases, malaria and vector borne diseases.

Among the diseases highlighted by reviewing the data of epidemic disasters, cholera was the most common which was reported in 17 of 41 events. Diarrhea was reported in 4 events, dengue fever in 4 events, and the other diseases mentioned included influenza A H3N2, respiratory diseases, measles, tetanus, and meningitis.

Disaster events identified occurred in different geographic areas. Out of the 108 events, 48 occurred in Africa in 19 countries, 35 events occurred in Asia in 12 countries, 16 events occurred in South America in 10 countries, 6 events occurred in North America in 4 countries, 2 in Europe and 1 in Oceania. Mozambique and Indonesia had the highest number of events globally where 8 events were identified in each country.

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Table 3. Diseases identified by screening EM-DAT data

Diseases	No. of events identified by screening data natural disasters events	No. of events identified by screening data epidemic events
Cholera	17	17
Respiratory diseases	21	1
Diarrhea	14	4
Water-borne diseases	6	2
Dengue	0	4
Pneumonia	2	0
Malaria	2	0
Vector-borne diseases	1	0
Skin diseases	4	0
Digestive diseases	1	0
Influenza A H3N2	0	1
Measles	0	1
Meningitis	0	1
Tetanus	0	1
Enteric diseases	0	1
Leptospirosis	1	0
Conjunctivitis and fungal foot infections	1	0
Unspecified diseases	5	8
Unspecified Outbreak	5	0

The number of events identified during the past 20 y varied from 0 to 18. Generally, the number of events during the past 10 y was lower than in the period form 2000 to 2009. The year in which the highest number of events was identified was 2007, with possible association between the natural disaster and epidemics in 18 events and 15 of it were due to floods (Figure 1).

Literature Review

The results after the initial search in PubMed and Embase yielded 4458 results after removal of duplications. The next step was screening the titles of papers and 639 relevant papers were included. After reading the abstract of the papers 106 papers left, and finally the full text of the results was read, and 36 papers were included in the review (Figure 2).

Of the included studies, 19 focused on floods, 5 articles studied earthquakes, 3 studied typhoons, 3 studied hurricanes, 2 studied cyclones, 2 studied tsunamis, and 2 studied droughts.

The natural disaster events occurred between 2000 and 2019. The articles were studying events occurring in different geographic areas, 19 articles studied events in Asia, 6 in North America, 5 in Europe, 3 in Africa, 2 studies in South America, and 1 in Oceania.

The data analysis revealed various risk factors and mechanisms that led to different infectious diseases after various natural disaster types. Table 4 describes the risk factors and mechanisms.

Discussion

The results of the review of the literatures and data from EM-DAT indicated that floods were the most common cause of the spread of infectious diseases. This may be attributed to the fact that floods are the most common type of natural disasters globally.[59] Many factors lead to floods such as heavy rainfalls, floods of dams and waterways, tsunami, and storms. Many health consequences result from flood including direct physical impact by causing injuries and drowning,[60] contamination of water resources and groundwater,[61] and lack of access to basic needs. It can lead to many outbreaks and infectious diseases through different mechanisms including the direct contact and consumption of water contaminated by pathogens or creating suitable environmental conditions that lead to increase in vector-borne diseases such as the increase that may occur in the number of mosquitoes.[12]

Floods contributed to the spread of various disease outbreaks during the past 20 y. Examples include the Leptospirosis outbreak in Kelantan, Malaysia[26]; malaria in Anhui Province, 2007 China[37]; gastroenteritis illness and respiratory infections in Netherlands 2015[32]; bacillary dysentery in Hunan China 2012[35]; scabies in East Badewacho District, Southern Ethiopia, in 2016[38]; and other various infectious diseases.[36,40,41] Additionally, in 2 other studies assessing the impact of a tsunami and a cyclone, the contamination of flooded water was the direct mechanism that led to the spread of diseases.[43,56]

The environmental changes that occur in the post-flood period are providing suitable condition for pathogens to multiply in flooded areas.[62] In addition to the increased pathogens concentration, there is higher chance of mobilization and transmission of the pathogens during floods. During heavy rainfalls, pathogens transport to the surface water and groundwater.[63] In the cohort study conducted in Denmark in 2010 after flood, there was an increase in gastrointestinal cases among contacts with contaminated water after the urban heavy rainfall.[31] Another example is the cross-contamination between the water supply system and sewage system in Dalian City, China, which led to the increase of bacillary dysentery.[34]

The spread of infectious diseases was related to the consequences of flood event, the contamination of water, the overcrowding and displacement and impact on the environmental conditions. The events took place in different countries around the world. However, developing countries are more vulnerable and have less capacity of coping with the disaster situations. Many of these risks can be prevented through appropriate interventions and protective measures. Appropriate water treatment during emergencies,[64] sheltering with appropriate infection prevention and control measures,[65] and vector control measures[66] will help for better control of the spread of diseases.

Different clusters of mechanisms and risk factors have been reported in various natural events. The most frequent risk factors reported in the studies reviewed were the factors associated with the consequences of disasters event on water and sanitation, factors associated with displacement and crowding, behavioral risk factors during and after the disaster period, factors related to socioeconomic status, factors related to occupations, and in some cases, factors related to age and gender were reported.

One of the most highlighted mechanisms for the spread of diseases, especially those transmitted by water and food, was the contamination of water systems. Contamination often occurred when sewage networks mix with water supply system and with water bodies that people contacted with. Contamination and the risk factors resulted from it were reported in more than half of the diseases reported, and it occurred mainly during hydrological and metrological events. The risk increased when other risk factors were present, such as overcrowding, displacement, and low level of personal hygiene. The use of untreated water was the cause of many

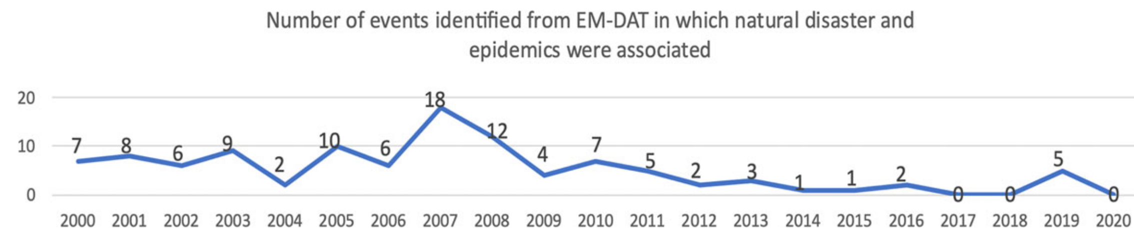

Figure 1. Number of events identified from EM_DAT in which natural disasters and epidemics were associated.

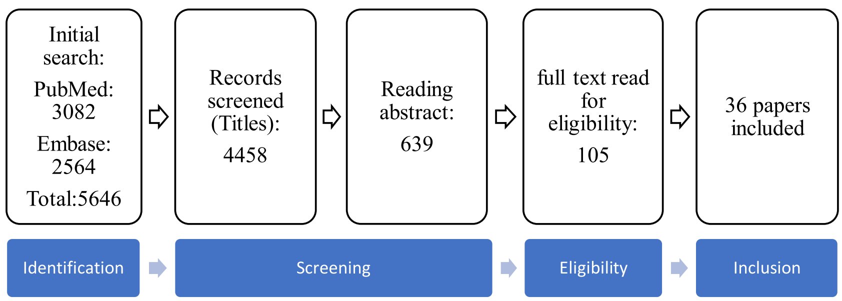

Figure 2. Article screening flowchart for the selection of the final papers.

outbreaks reported like diarrheal, gastrointestinal diseases, and cholera. After the cyclone in 2012, Cholera cases were reported in 2 areas in Pondicherry, India. Evidence suggested that the outbreak was due to the ingesting contaminated water by drainage.[43] After the typhoon Haiyan in the Philippines, an increased number of gastroenteritis was reported. The study conducted to identify the source of infection suggested that the cause was *Aeromonas hydrophile* transmitted through the consumption of untreated water.[53] The risk arising from water contamination includes respiratory diseases as well. In a study conducted after urban pluvial flooding in Netherlands in 2015, respiratory pathogens were isolated in polluted water. Many children and adults who have been in contact with water contaminated with flood water have developed acute respiratory infections.[32]

The above emphasizes the importance of having an adequate water, sanitation, and hygiene (WASH) system during natural disasters, especially in developing countries, where they suffer from the consequences of the insufficient WASH system on public health in normal times as well. The increase in the incidence of infectious diseases may be attributed to the natural disaster, but the main problem lies in the lack of an adequate sewage system that can resist the effects of the natural disaster and reduce contamination and exposure of the population to pathogens.

Contamination is caused by various pathogens and the characteristics and survival time varies with different environmental conditions and the intervention plans varies from 1 event to another. Therefore, taking the necessary steps for the development of WASH systems is 1 of the main aspects in the development of disaster risk reduction policies and is 1 of the main measures in limiting the spread of diseases. During disasters situations, it is important to establish a proper excreta disposal and solid waste management system, and to ensure that the population has access to adequate supplies of water, hygiene products, and water sanitizers in cases where there are no potable water sources.

Environmental risk factors play a role in increasing the likelihood of disease outbreaks. The characteristics of some geographical areas may help in the transmission of pathogens in different mechanisms. The heavy rainfall and warmer temperatures contributed to the leptospirosis outbreak after the 2014 Major Flooding Event in Kelantan, Malaysia.[26] The damp and hot living conditions assist the growth and reproductive of pathogens and led to the increase of malaria cases after Huai River flood in Anhui Province, 2007 China.[37] The tsunami in South Andaman, Andaman, and Nicobar Islands in India resulted in changing the environment in the area, and the paddy fields and fallow lands become suitable site for breeding due to saline water. The land subsidence and continued flooding increases the vector abundance and malaria transmission and people living close to the folded paddy fields become in higher risk for malaria infection. The high prevalence of leptospirosis in rodents and the simultaneous presence of risk factors like the wet climate increased the number of cases following a flood in the Veneto area, north-east Italy 2012.[25]

Awareness of the role of environmental factors in the spread of diseases is essential in response plans to natural disasters, especially in cases of displacement, where the movement of a population to the new environment can lead to an increase in exposure to pathogens. Regular monitoring of environmental characteristics and vector surveillance are important for early detection of increased risk and proper response plans.

Socio-economic factors are believed to play a role in the emergence of epidemics in general.[67] In the studies reviewed, during disasters situations, many of socio-economic factors contributed to the increase of infectious disease incidences such as high poverty rate,[24] low economic status,[28] and educational level and literacy rate.[47] According to the study conducted in Fiji after the floods in 2012, the leptospirosis diseases was associated with poverty, and communities with high poverty rate had approximately twice the incidence rate than people from other communities.[24] The infectious diarrhea in Hunan province during flood season from 2004 to 2011 in China was higher in regions with low economic level.[28]

In addition, many other factors highlighted in the studies might be driven by socio-economic status, such as malnutrition,[58] and lack of access to clean water.[24] People in lower socioeconomic groups may live in areas more prone to natural disasters and have less capability to access to protective shelters during disaster

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Table 4. Mechanisms and risk factors contributed to the spread of infectious diseases following natural disasters

Disaster type	Disease	Mechanisms	Risk Factors
Flood	- **Leptospirosis:** - Increase in cases in Santa Catrina in Brazil from 2000 to 2006[23]. - Infections in Fiji 2016[24]. - Cases following a flood in the Veneto area, North-east Italy 2012[25]. - Outbreak After the 2014 Major Flooding Event in Kelantan, Malaysia[26]. - Outbreak after flood in the Philippines, 2009[27].	- Exposure to the flood water[23 24]. - Multiple animal reservoirs[24] and the prevalence of leptospirosis in rodents[25]. - The high prevalence of leptospirosis in rodents with the simultaneous presence of risk factors[25]. - Warmer temperature: with every increase of 1C in minimum temperature, 1 mm of rainfall and 1 m of river water level, the incidence risk ratio of leptospirosis increases by 1.14, 1.01 and 1.04 respectively[26].	- Men[23]. - Living in urban areas[23]. - Risky occupational activities[23]. - Lack of treated water at home[24]. - Working outdoors[24]. - Living in rural areas[24]. - High poverty rate[24]. - Living <100m from a major river[24]. - The presence of pigs in the community and high cattle density in the district[24]. - Socio-economic problems[25]. - Mild/wet climate[25]. - Street flooding[25], Garbage accumulation[25]. - Living close to water bodies[26]. Risk factors associated with fatal infection: older age, haemoptysis, anuria, jaundice, and delayed treatment with antimicrobial drugs[27].
Flood	**Diarrhoea:** - In Hunan, China 2004-2011[28]. - In Guangxi, China from 2005 to 2012[29]. - In Botswana 2011- 2017[30].	- Compromised water treatment due to hydrological variability and rapid water quality shifts in surface waters[30]. - Contamination of flood water after displacement of domesticated animals and the increase of amplification of rodent population due to the garbage scattering and food[29].	- Geographic locations (RR = 1.72, 95% CI: 1.22, 2.41)[28]. - Low economic levels (RR = 1.54, 95% CI: 1.13, 2.09)[28].
Flood	**Gastrointestinal Illness:** - In areas affected by heavy rainfall, Denmark, 2010-2011[31]. - After urban pluvial flooding in Netherlands 2015[32]. - Increase of the cases in Massachusetts, USA during 2003-2007[33].	- Swimmers ingesting flood water after rainfall in urban areas[31]. - Contact with floodwater[32]. - Swimming in contaminated seawater[32].	- Swallowed contaminated water (Risk ratio RR 2.5; 95% and confidence interval (CI): 1.8-3.4); and the risk increased with the number of mouthfuls of water swallowed[31 33]. - Skin contacts with floodwater (Adjusted Odds Ratio a OR 4.0, 95%CI 1.8-9.0)[32]. - Performing post-flooding cleaning operations (a OR 8.6, 95%CI 3.5-20.9)[32]. - Cycling through floodwater a OR 2.3, 95%CI 1.0-5.0)[32]. - Severity of the flood[33]. - Compromised hygiene[33].
Flood	**Respiratory infections**: - After urban pluvial flooding in Netherlands 2015[32].	- Contact with floodwater[32]. - Swimming in contaminated seawater[32].	- Skin contact with floodwater (OR 3.6, 95%CI 1.9-6.9)[32]. - Performing post-flooding cleaning operations (OR 5.5, 95%CI 3.0-10.3)[32].
Flood	**Bacillary Dysentery** - In Dalian City, China, From 2004 to 2010[34]. - In Hunan China 2012[35].	- The change in the environment lead to more reproduction of pathogens and its mobilization and transport into rivers, coastal waters, and wells[34]. - Cross-contamination between sewage and drinking-water pipes or by passing into local water- ways[34]. - A sudden and severe flooding with a shorter duration may cause more burdens of bacillary dysentery than a persistent and moderate flooding[35].	The RR of flood impact on bacillary dysentery was 1.17 (95% CI: 1.03-1.33)[34]. floods were significantly associated with an increased risk of the number of cases of bacillary dysentery (OR = 3.270, 95% CI: 1.299–8.228 in Jishou; OR = 2.212, 95% CI: 1.052–4.650 in Huaihua)[35].
Flood	**Malaria:** - Mengcheng China after flooding during 2005-2010[36]. - Huai River flood in Anhui Province, 2007 China[37].	- Flooding and waterlogging lead to increased risk of malaria[36]. - The damp and hot living condition assist the growth and reproduction of pathogens[37]. - Disruption of water purification and sewage disposal systems[37]. - Direct exposure to floodwater[37]. - Living in flood-hit houses[37].	

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Table 4. (*Continued*)

Flood	**Scabies:** - In East Badewacho District, Southern Ethiopia in 2016[38].	- Displacement of population, overcrowding, and lack of personal hygiene increased disease transmission[38]. - Contact with flood water[38].	- Age less than 15 years (a OR = 2.62, 95% CI: 1.31–5.22).[38] - Family size greater than 5 members (a OR = 2.63, 95% CI: 1.10–6.27)[38]. - Bed sharing with scabies cases (a OR = 12.47, 95% CI: 3.05–50.94)[38]. - Home being affected by flooding (a OR = 22.32, 95% CI: 8.46–58.90)[38].
Flood	**Cryptosporidium hominis**: - Increase number of cases in Halle (Saale), Germany, August 2013[39].	- Children performing activities in the dried-out floodplain led to infections[39].	- Visits to previously flooded areas (OR: 4.9; 95%-CI: 1.4-18)[39]. - Visits to the zoo (OR: 2.6; 95%-CI: 0.9-7.6)[39].
Flood	**Various Infectious Diseases:** - Increase in prevalence after Floods in Iran 2019[40]. - Infectious diseases - After 2018 Flood in Kerala, South India[41]. - Infectious diseases in urban floods 2011-2012 Netherlands[42]	- Overcrowding and disruption of sewage disposal system[41]. - Human contact among refugees[41]. - Devastating flood influenced the bacterial composition in watershed areas[41]. - Faecal contamination in the flood sites[41]. - Contamination of combined sweres with waterborne pathogens[42]	- Poor standards of hygiene[40]. - Poor nutrition[40] - Negligible sanitation[40] - The mean risk of infection per event for children, who were exposed to floodwater originating from combined sewers, storm sewers and rainfall generated surface runoff was 33%, 23% and 3.5%, respectively, and for adults it was 3.9%, 0.58% and 0.039%. - The concentration of pathogens[42] - Exposure volumes[42] - dose response parameters.[42]
Cyclone	**Cholera:** - Outbreak following Cyclone Aila in Sundarban area of West Bengal, India, 2012[43].	- Contamination of water distribuation system[43].	- Consumption of water from the public distribution system (Matched-Odds Ratio MOR=37, 95% CI 4.9-285, PAF: 97%)[43]. - Drinking untreated water (MOR=35, 95% CI 4.5-269, Population Attributable Fractions (PAF): 97%)[43]. - Common latrines used by two or more households (MOR=2.7, 95% CI 1.3-5.6)[43].
Earthquake	**Cholera:** - After 2010 earthquake in Haiti[44 45].	- Consumption of contaminated water[44]. - Close contact with cholera patients (sharing latrines, visiting cholera patients, helping someone with diarrhoea[45]. - Eating food from street vendors and washing dishes with untreated water[45].	Habitual water treatment and handwashing[44]. In Gonaive, eating meals outside the home [adjusted OR (a OR) 35·9], owning pigs (a OR 10·3) and sharing latrines (a OR 3·5)[45]. In Carrefour. The aORs were 3·2 for sharing a latrine, 3·7 for visiting a cholera patient, and 3·8 for caring for someone suffering from diarrhoea or cholera. Using untreated water for washing dishes (a OR 3·2)[45].
Earthquake	**Acute respiratory infection:** - In Eastern Japan 2015[46].	- Displacement and living in Crowded shelters[46].	- Crowded shelters[46]. - Cases of near-drowning[46].
Earthquake	**Zika**: - Increase in number of cases in Ecuador 2016[47].	- Spending more time outdoors in the camps of displaced population increases the chance of exposure to mosquito bites[47]. - Lack of sanitation and public utilities in the camps[47].	- Synthetic pyrethroid alphacypermethrin exposure[47]. - School years and literacy rate[47]. - Poverty rate[47]. - Persons per household[47].
Earthquake	**Cutaneous leishmaniasis:** - Outbreak in Iran Bam 2003[48].	- The arrival on non-immune population and the suitable environmental conditions increased the number of incidences[48].	- Poor hygienic conditions[48]. - Individual and behavioural changes[48].
Hurricanes	**Cholera:** - Haiti following Hurricane Matthew 2016[49].	- Heavy precipitation and high winds of the hurricane damaged an already insufficient WASH infrastructure. - Initial contact with contaminated water followed by secondary transmission routs[49].	- Habitual water treatment and hygiene practices (handwashing[49].
Hurricanes	**Food and Waterborne Diseases**: - After Hurricane Sandy in 2012[50].	- Direct contamination of food and water with the pathogens[50]. - Indirect contamination after refrigeration compromising power outages and disrupted food distribution networks[50].	- Residence in storm area - Age 65 and older (RR = 2.16, 95% CI: 1.11-4.19)[50].
Hurricanes	**Polymicrobial fungal:** - Outbreak in USA after Hurricanes Sandy 2012[51].	- Mould growth inside the hospital due to flooding and water permeation[51].	- Air and water permutations in the hospital facility[51]. - leaky or open windows[51]. - water leaks in ceilings[51]. - perforated ceilings[51]. - lack of positive pressure[51]. - Dust.[51].

(*Continued*)

Table 4. (*Continued*)

Disaster type	Disease	Mechanisms	Risk Factors
Typhoon	**Waterborne and Foodborne diseases:** - Increase in prevalence in South Korea during 2001-2009[52].	- Increase in pathogens concentration[52]. - Destroying public health infrastructure systems[52]. - Displacement of population[52].	
Typhoon	**Gastroenteritis:** - Outbreak in Haiyan, Leyte, Philippines, 2013[53,54].	- Contamination of water system pipes by pathogens due to the typhoon[53,54]).	- Consumption of untreated drinking water (adjusted odds ratio: 18.2)[54].
Tsunami	**Malaria:** - Outbreak in South Andaman, Andaman and Nicobar Islands, India in 2004[55].	- Environmental damage[55]. - Increase in breeding of local malaria vector due to the salinity level of the fallow land and low-lying paddy fields[55].	
Tsunami	**Hepatitis A:** - outbreak of hepatitis A virus among children in a flood rescue camp India 2013[56].	- Faecal contamination of common water sources[56].	- Poor hygienic conditions[56]. - Consumption of contaminated water[56].
Drought	**Diarrheal Diseases:** - Seasonal incidences in Southeast Asia dry season 2016[57].		- Hygiene practices[57]. - More densely populated areas[57]. - 0–4 age group[57]. - Gender: Male[57].
Drought	**Scabies:** - Outbreak in Drought-Affected Areas in Ethiopia 2015[58].	- Poor personal hygiene due to limited access to water especially for people living in rural areas[58].	- Age under 18 were 2.5 times more at risk of scabies. - High level of Malnutrition[58].

events. Therefore, strengthening the capacity and resilience for people with low-economic status to cope with disaster situation is essential for any disaster risk reduction policy.

Displacement is common especially after extreme natural disaster events in which buildings and infrastructure are destroyed.[12] Displacement may be necessary in cases of major disasters, as the protection of the population from environmental conditions and the provision of basic services are essential elements in any response to emergency conditions. However, displacement, and the crowding that often accompanies it, may have negative consequences. The risks arising from displacement are due to many factors. The poor overall physical and mental health state and lack of access to adequate basic health services increases vulnerability especially in overcrowded shelters where there is lack of hygiene and sanitation measures. Overcrowding in shelters leads to increased exposure to pathogens and increases the spread of diseases.[68]

Many examples within the review indicated how overcrowding in shelters caused an increase in disease transmission such as the increase in various infectious diseases after the floods in Iran in 2019,[40] and the increase in acute respiratory infections among a displaced population after the 2014 earthquake in eastern Japan.[46] During displacement situations, consideration must be given to the size and characteristics of the displaced population as well as the health and immune status and vaccination level, especially for children. Rapid response with vaccination campaigns and identifying and treating the cases, may contribute significantly to preventing the spread of infection.

The result of the review highlights the importance of the behavioral factors that lead to the increase of infections. In many of the studies reviewed, daily health habit and the lack of an adequate level of hygiene and awareness greatly increased the possibility of disease outbreaks. In the study assessing the increase in prevalence of various infectious diseases after floods in Iran 2019,[40] poor hygiene standards, negligible sanitation, and human contact among refugees increased the vulnerability of people to infectious diseases and caused outbreaks.

Awareness of behaviors that reduce contact with sources of infection is a key factor in limiting the spread of pathogens. This includes human contact and the contact with contaminated water.

The lack of awareness of the importance of isolating patients in many transmissible diseases emerged in many cases as a reason for the increase in disease cases. For example, in the investigation conducted after the flood in 2016 in East Badewacho district, Southern Ethiopia, bed sharing with scabies patients especially among children was a major risk factor for the outbreak.[58] The contact with patients, habitual water treatment, hand washing, and other hygiene practices were the main factors influencing the spread of cholera during 2010 earthquake in Haiti.[44,45]

The impact of behavioral factors on the spread of diseases indicates the importance of health promotion strategies in the recovery period from natural disasters. Changes in behavior and bad health practices as well as the awareness of the risks are playing important roles in mitigating health consequences of these practices. There is strong evidence of the value of health promotion interventions during the response and recovery stages after natural disasters, and this could be done through awareness raising, education, community engagement, and capacity building of the population.[69]

Taking the necessary measures during evacuation and rescue operations is necessary to protect rescue workers from the risk of exposure to infectious diseases. Many diseases including a cluster

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of infectious skin diseases were reported among the rescue workers during the evacuation operations after hurricanes Catrina in 2005 in the United States.[70] Performing postflooding cleaning operations after urban pluvial flooding in Netherlands in 2015 was identified as a risk factor for respiratory infections.[32] Working outdoors was identified as 1 of the risk factors for leptospirosis infections in Fiji after severe flooding in 2012.[24] Protective measures and personal protective equipment especially for rescue workers are important to decrease their exposure to infections.

Limitations

There are some limitations in this review. Only peer-reviewed scientific papers published during 2000-2020 were included, and gray literatures were not included in the review. The search was carried out only in 2 databases (PubMed and Embase). This, in addition to including only papers in English, might have decrease the comprehensiveness of the review, and more evidence for the actual association between natural disasters and disease outbreaks could have been captured.

The literature search and studies selection were carried out by 1 person, and there was no double check of the process. This bias was minimized by the participation of all authors in the rest of the research process (terms and query selection, results analysis, and discussion).

Conclusions

Many of the risk factors and mechanisms that caused the occurrence of epidemics after disasters are mainly related to the consequences of the disaster event. The readiness of infrastructure, the availability of infectious diseases surveillance systems and implementing appropriate emergency plans play important role in mitigating the disaster's impact on the spread of infectious diseases. Health promotion and awareness raising are important aspects of strengthening population's ability to protect themselves against infectious diseases during disaster events. More studies and further evidence are needed to understand the relationship between the spread of diseases and natural disasters.

Data availability statement. The datasets used and/or analyzed during the current study are available from the corresponding author on reasonable request.

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