REVIEWS

Outbreaks of Vector-borne Infectious Disease Following a Natural Disaster

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Introduction

Over the past century, global disaster deaths have averaged approximately 45,000 people annually. Vector-borne pathogens are susceptible to climatic conditions influencing vector survival, gonotrophic cycle, and transmission efficiency in human hosts. However, the literature has not collectively analyzed the relationship between natural disasters and vector-borne disease (VBD) outbreaks over decades.

Objective

This literature review identifies and examines published papers documenting VBD outbreaks associated with natural disasters. Additionally, information was gathered about the kinds of natural disasters commonly associated with VBD outbreaks and which diseases typically occur post- disasters.

Methods

A literature review was performed using two search strategies with terms for natural disasters and vector-borne infectious diseases as identified in the title, keywords, or abstract. Observational studies and systematic review papers were screened on the occurrence of a VBD post-disaster.

Results

A total of 30 studies were captured. Eight disaster types were captured: flood, hurricane, tropical cyclone, typhoon, tsunami, drought, monsoon, and earthquake. Floods (n=21), hurricanes (n=20), tsunamis (n=8), and drought (n=8) account for the top four disaster events commonly associated with VBDs. Of the VBDs identified, malaria outbreaks were identified in 16 papers, while dengue outbreaks were captured in 11.

Conclusion

The literature reveals a predominance of floods, malaria and dengue. While there is increasing acknowledgment that disasters can lead to outbreaks of VBDs, there is limited research and consistent data available. Future research should rely on well-defined, consistent case detection and enrollment procedures, preferably at various lag periods following a disaster event.

Introduction

Natural disasters, particularly rapid-onset disasters, pose various risks to public health, including emerging and reemerging infectious diseases. More than 700 000 deaths in the acute phase of the post-disaster period are caused by infectious diseases.[1] Approximately 80% of the world's human population is at risk of 1 or more vector-borne diseases (VBDs) exclusively transmitted by mosquitoes.[2] The risk for outbreaks is often presumed to be very high following a natural disaster event due to population displacement, unsafe water, sanitation facilities, overcrowding, and limited health care services. The implications of natural disasters and infectious diseases often affect populations with limited resources for disease surveillance, limited public health infrastructure, and inadequate emergency response capability. Approximately 20% of the global tropical infectious disease burden is vector-borne and responsible for 1 million human deaths annually.[1]

While there is increasing acknowledgment that disasters can lead to outbreaks of VBDs, the risk of disease transmission after a natural disaster has not been collectively analyzed across decades. There are well-established theoretical pathways for such outbreaks, but how these events influence the distribution and propagation of VBD has not been consistently evaluated and potentially differs by disease type, location, and social or temporal contexts.[3]

Natural disasters can vary in frequency and magnitude. For this review, we define *natural disaster* as the abnormal intensity of severe weather, including flooding, hurricanes, tropical cyclones, tsunamis, monsoons, earthquakes, or any combination thereof.[4] Hurricanes, typhoons, and tropical cyclones are all the same meteorological phenomenon, but the terms are applied differently depending on the region around the world (hurricane = is used in the Atlantic Ocean,; typhoon = Pacific Ocean; tropical cyclone = Indian Ocean). Therefore, we categorized all three disasters and referred to them as hurricanes in this review. Monsoon-induced disasters are common geological hazards triggered by torrential rainfalls during the rainy season. This is not per se a natural disaster, except when it causes flooding or landslides. Natural disasters can occur seasonally and without warning and pose a significant threat to human health, safety, property, critical infrastructure, and security. Nearly 40% of all natural disasters are floods. Floods are increasing in almost every region of the world.[5] These events can spur outbreaks. For instance, a resurgence of West Nile neuroinvasive disease cases was reported within 4 weeks following Hurricane Katrina in areas directly impacted by floods in Louisiana and Mississippi.[6] As the number of natural disasters continues to rise,[7] so have the niches that harbor pathogens, increasing their chances of coming in contact with humans.

Natural disasters kill an average of 45 000 people per year,[8] accounting for approximately 0.1% of total deaths worldwide. While most deaths are caused by trauma-related fatalities and injuries from structural collapse, other causes can include disturbances in medical care and infections from contaminated food and water sources.[9] The US, China, and India are the top 3 countries that have experienced the highest global occurrences of natural disasters from 1900 to 2020.[8]

Nearly 145 million people in the Americas live in areas at risk for dengue, yellow fever, malaria, chikungunya, and Zika virus disease.[10] In addition, the Southeast Asia Region has become hyperendemic with regular reporting of dengue cases since 2000. Additional outbreaks have included malaria, chikungunya, Japanese encephalitis, and lymphatic filariasis.[11] The degree of influence of natural disasters on VBD transmission depends on multiple factors, including (1) the lifecycle of the vector; (2) development of the infectious agent within the vector; (3) environmental requirements for nonhuman hosts; (4) environmental determinants of vector-human interaction; and (5) host susceptibility.[5] Perturbations caused by natural disasters can lead to alterations in the environment, affecting vector populations in ways that further intensify transmission rates in humans. What is most concerning is that the emergence or resurgence of viruses may compound with extreme weather events in the coming decades.

This literature review aims to identify published articles that document VBD outbreaks associated with natural disasters. It demonstrates which kinds of natural disasters appear to be most commonly associated with VBD outbreaks and which VBDs are most common after natural disasters. This information may guide future analyses of the relationship between disasters and VBDs and help inform risk reduction strategies. Further in-depth research to understand the dynamics that compound the types of VBDs and natural disasters will be necessary to develop more effective vector reduction strategies in disaster response processes. Through education and science, such advances provide evidence for revised health policies and improved disaster health readiness.

Methods

A literature review was conducted to identify published articles that observed VBD after a natural disaster event. Two search strategies were developed using a combination of terms for natural disasters and vector-borne infectious diseases and selected outcomes as identified in the title, keywords, or abstract. First, PubMed was searched using the terms: (*Communicable Diseases" [OR "Disease Outbreaks" OR disease-outbreak* OR infection-outbreak* OR communicable-disease* OR infectious-disease* OR infection-control AND "Disasters" OR disaster* OR earthquake* OR wildfire* OR tsunami* OR hurricane* OR typhoon* AND English[lang AND vector/insect vector).* This search resulted in 593 articles.

A second search included a refined list of terms with *time* as a factor to capture articles that assessed post-disaster outbreak timeframes, using the following search strategy: *("Natural Disasters"[mh] OR natural-disaster*) AND vector* AND disease* AND (time[tiab] OR change*[tiab] OR "Time Factors"[mh]).* This method captured 18 articles.

Because most of the literature generated from initial and second searches identified outbreaks mainly among Asian and African countries, a hand-search method was used to find articles not found through traditional searches and identify further relevant studies focused on the Americas. Google Scholar, Web of Science, and Embase databases were selected using a combination of the following terms: *natural disaster(s)*, *disease carrier*, *disease(s)*, *vector*, *vector-*

borne, *South and Central America*, *Zika*, *yellow fever*, *dengue*, *malaria*. This method captured 6 articles. While these were articles outside of the search strategy, they were deemed quality articles useful for the research.

Original and systematic review studies in English published in any year on the occurrence of a VBD after a natural disaster event were included. First, articles were screened by title and abstract. The full text of these articles were then reviewed. At all stages of review, the following types of articles were excluded: articles describing a natural disaster event alone (ie, those with no mention of vectors); articles, theses, proceeding papers, and dissertations about irrelevant types of disasters; articles about VBDs unrelated to a natural disaster event; articles that did not provide information on the occurrence or outbreak of a VBD; and articles the author was unable to access.

Publications that presented evidence of a temporal association between VBD outbreaks and natural disasters were selected for final inclusion, totaling 30 articles (18 from the first PubMed search, 6 from the second PubMed search, and 6 from the hand-search method).

Results

The 30 studies were collated and chronologically listed (Table 1). They captured natural disaster events and associated VBD outbreaks from 1963 to 2020 in countries and regions across the globe. Some of the articles analyzed multiple occurrences for the same natural disaster event; therefore, the same event appears more than once in Table 1. In addition, these natural disasters varied in their geographical location, spanning regions in Asia, Africa, and the Americas (43%, 60%, and 43%, respectively).

Eight types of natural disaster events were captured. Because typhoons and tropical cyclones are types of hurricanes, they were all categorized as hurricanes. Thus, the data in this review present 6 disaster types: 4 are hydrological (floods, hurricanes [ie, typhoons, tropical cyclones], monsoons, and droughts) and 2 are considered geophysical disasters (earthquakes and tsunamis). Fourteen infectious disease outbreaks were documented.

There was wide variation in the timing of post-disaster VBD outbreaks, from as early as 2 weeks and as late as 2 years. Depending on the type of study, not all articles published case counts. Those that did quantify case counts observed anywhere from 116 to 75 000 cases of malaria, 29 to 57 010 cases of dengue, and 12 cases of St Louis encephalitis after a flood-related event. Other studies noted that West Nile virus, Zika virus, Rift Valley fever, Ross River virus, and Japanese encephalitis were evident after a flood. Moreover, three articles collected pupae samples to understand whether the increased mosquito abundance following a disaster was associated with increased arbovirus transmission. For instance, after hurricanes Irma and Maria, 441 *Aedes aegypti*

Table 1. Studies identifying the outbreaks of vector-borne disease(s) post natural disaster

Year	Type of disaster	Location	Identified VBD	*Number of cases	*Timeline of disease outbreak	Reference
[c]1954-2020	Flood, Hurricane and Tropical Cyclones	Dengue and malaria studies predominantly used data from Asian countries,with a considerable number of malaria studies also reporting data from African countries.	45 studies reported on DENV, 61 reported on malaria, and 49 reported on other VBD ,primarily RVF, WNV, JE,and Murray Valley encephalitis (MVE)	A study from Indonesia found that the prevalence of dengue hemorrhagic fever was statistically significantly higher (p<0:05)1 month after a major flood at 0.7% in comparison with a "preflood" prevalence of 0.2% 5 publications reported a statistically significant increase in malaria incidence in the subacute or medium term after singular flooding events: significant increase after lags of 5 and 6 months.	Not specified	3(p3)
1963	Hurricane	Haiti	Malaria	~ 75,000	6 weeks after the hurricane	12
1963, 2000	Hurricane, Flood	Haiti, Mozambique	Malaria	Haiti: 75,000 + cases Mozambique: 4 to 5 fold increase	Not specified	13
1975	Flood	USA	WEE, SLE	55 WEE, 12 SLE	2-3 months	14
1991	Earthquake & Flood	Costa Rica	Malaria	3,597 cases	up to 12 months	15
1991-2013	Flood	South eastern Australia	RRV	Outbreak events occurred most frequently for the North west Slopes (n = 15), Central-west Slopes (n = 15), North Riverina (n= 15) and North-west Plains (n = 16).	1-3 months	16
2000	Flood	Mozambique	Malaria	~ 1,827 patients	Not specified	17

				evaluated were diagnosed as having malaria, and 5% of the deaths were related to malaria.		
2004	Tsunami	Nancowry Islands	Malaria, JEE	Not specified	2- weeks	18
2004	Hurricane	Haiti	Malaria, DENV, WNV	A total of 116 acutely febrile patients for a mosquito-borne disease	Not specified	19
2004	Tsunami	Sri Lanka	Malaria	less than 4,000 cases were reported over the year 2004, and 1,628 cases over 2005	Not specified	20
2004, 2008, 2010	Flood	Dominican Republic, Brazil, Cote d'Ivoire	Malaria, DENV	Following the flood disaster in Brazil (2008), 57,010 dengue cases including 67 deaths were reported among victims. In 2010, cases and deaths due to dengue fever were reported in Cote d'Ivoire following periods of heavy rain	Not specified	12
[a]2004	Tsunami	Indonesia	Malaria, DENV	**Malaria:** 987 confirmed cases in Aceh Province were reported. **Dengue:** ~29 Dengue cases were reported	4 months	21,22
[a]2004	Tsunami	Indonesia	Malaria	57% of the 252 cases were infected with *P. falciparum* (n = 144, 95% CI 51.0%-63.3%), and 40.1% were infected with *P. vivax* (n = 101, 95% CI 34.0%-46.1%), with 0.03% (n = 7, 95% CI	~ 2 years	22

				0.8%-4.8%) being mixed infections.		
[a]2005	Hurricane	USA	WNND	Louisiana increased an average annual number of 30 cases in 2002-2005 to 45 cases in 2006. Mississippi cases increased from 23 cases in 2002-2005 to 55 cases in 2006.	3 weeks	6
[a]2005	Hurricane	USA	WNND, SLE	WNND: 117 cases SLE: 11	14-36 days	23
2005-2011	Hurricane (Tropical Cyclone)	China	Malaria, DENV	Malaria: 18.2 cases in Cyclone period/ per day Dengue: 5.6 cases in Cyclone period/ per day	Not specified	24
[c]2005-2007	Drought	East Africa & Western Indian Ocean Islands	CHIKV		Not specified	25
[c]2006	Drought	East Africa	RVF	Not specified	Not specified	25
2008	Flood	Brazil	DENV	57,010 dengue cases including 67 deaths were reported among victims	Not specified	25
2008	Earthquake & Tsunami	Nicobar Islands	Malaria	75 per cent (163/217) of the migrant laborers and 20 per cent (165/823) aborigines reported having suffered fever.	Not specified	26
[b] 2008 -2014	Natural disasters & flood	79 countries	Malaria	1% increase in the number of people affected by total disaster and flood increase the cases by 0.150% and 0.161%		27
2009	Drought	Australia	DENV	Not specified	Not specified	24

2011	Monsoon	Pakistan	Malaria	883 patients presented with symptoms of malaria. Overall, 71.6% of the respondents had positive *P. vivax* and 28.4% were *P. falciparum* positive.	Not specified	28
2012	Drought	Portugal	DENV	2000 cases	Not specified	24(pp11-12)
2013	Flood	Western Uganda	Malaria	increase of 30% in the risk of an individual having a positive malaria diagnostic test result in the post flood period in villages bordering a flood-affected river, compared with villages farther from a river.	Up to 12 months	29
2013-2014	Hurricane (Typhoon)	Philippines	DENV	5,264 cases	10 days	30
2016	Earthquake	Ecuador	ZIKV	89 in the pre-earthquake period to 2,103 during the post-earthquake period;	Not specified	31
2017	Hurricane	Puerto Rico	DENV, CHIKV, and ZIKV	Not specified	5 weeks	32
2017	Drought	Peru	ZIKV, CHIKV, DENV	1,838 cumulative cases of the diseases transmitted	3 weeks	33
2017-2018	Monsoon	Islands of Lakshadweep	Malaria, JEE, Bancroftian filariasis, Brugian filariasis, DENV, CHIKV	Not specified	Not specified	34
[c] Not available	Flood	Asia, Africa, North America	RVF, WNV, ZIKV, encephalitis, malaria	131 studies focused on malaria, 54 studies looked at dengue	Dengue: disease incidence may decrease in the first month after a flood only	35

					to increase over the next 3 months	
[c] Not available	Flood, Tsunami, Hurricane,Earthquake, Drought	India, Costa Rica, USA, Eastern Africa, Southeast Asia, Australia	Malaria, JEE, Chagas, SLE, WNV, DENV	Not specified	Malaria: 6-8 weeks post-flooding. Increased 5-6 fold over a 3 month period following the tsunami. 16-47 fold increase following an earthquake & flooding.	5

pupae were found in 35 of 395 buildings in metropolitan San Juan, Puerto Rico, before the hurricanes compared with 1962 pupae in 140 of 677 buildings after the hurricanes.

The panels in the Figure represent the VBDs associated with each natural disaster event. Floods (n = 21), hurricanes (n = 20), tsunamis (n = 8), and drought (n = 8) are predominantly associated with a VBD in the literature.

The 2 notable VBDs in this literature review were malaria and dengue virus. Malaria outbreaks were reported in 16 articles, while dengue virus was documented in 11 articles. In some instances, both diseases were co-circulating with autochthonous transmission, and reports were confirmed in or beyond subtropical and tropical regions of the globe. All but 1 natural disaster event (drought) was associated with at least 1 malaria occurrence, and all but 1 natural disaster event (earthquake) was associated with at least 1 dengue virus occurrence.

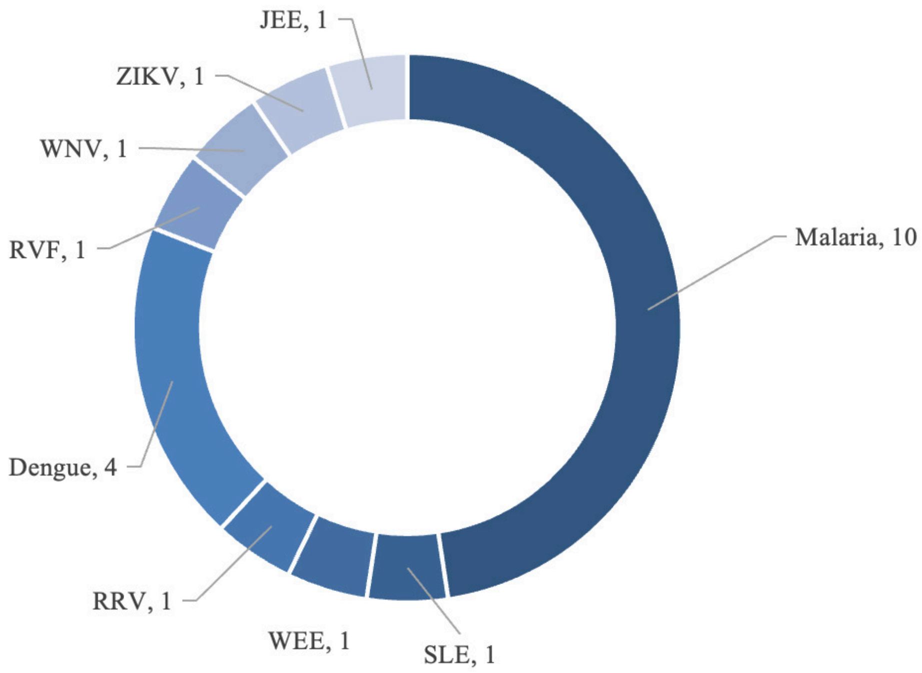

Figure 1a. Number of papers describing vector-borne outbreaks associated with floods (n=21)

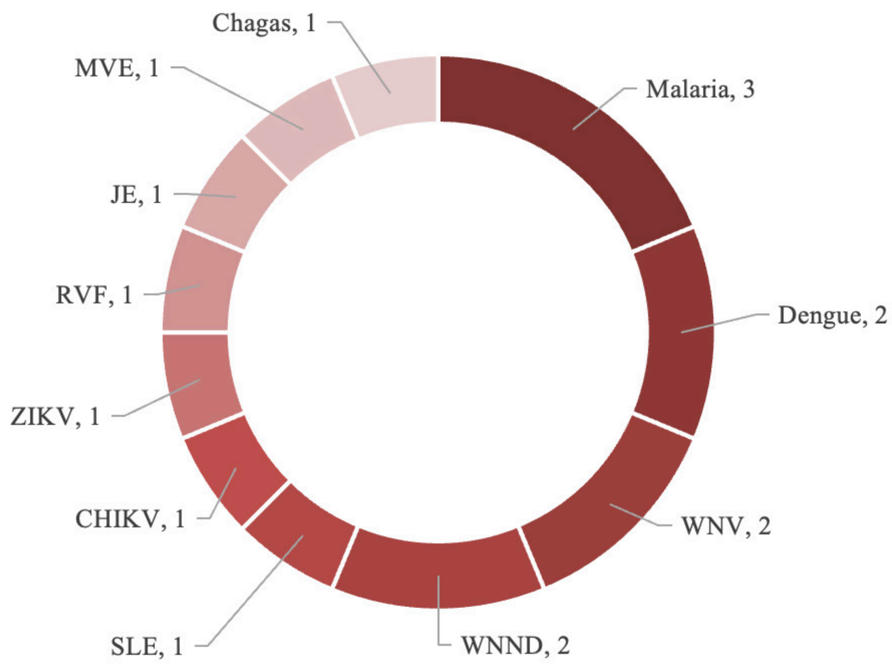

Figure 1b. Number of papers describing vector-borne outbreaks associated with hurricanes (n=20)

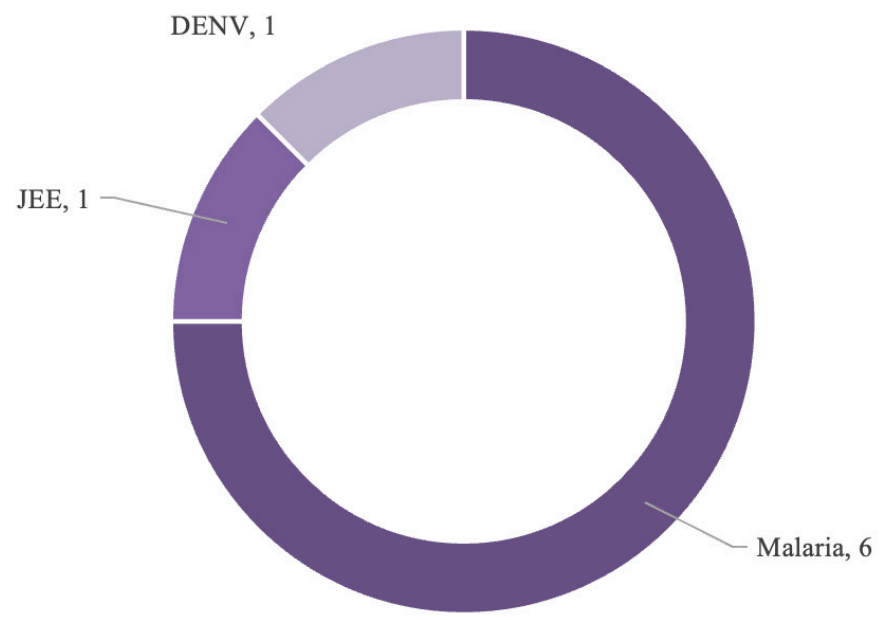

Figure 1c. Number of papers describing vector-borne outbreaks associated with tsunamis (n=8)

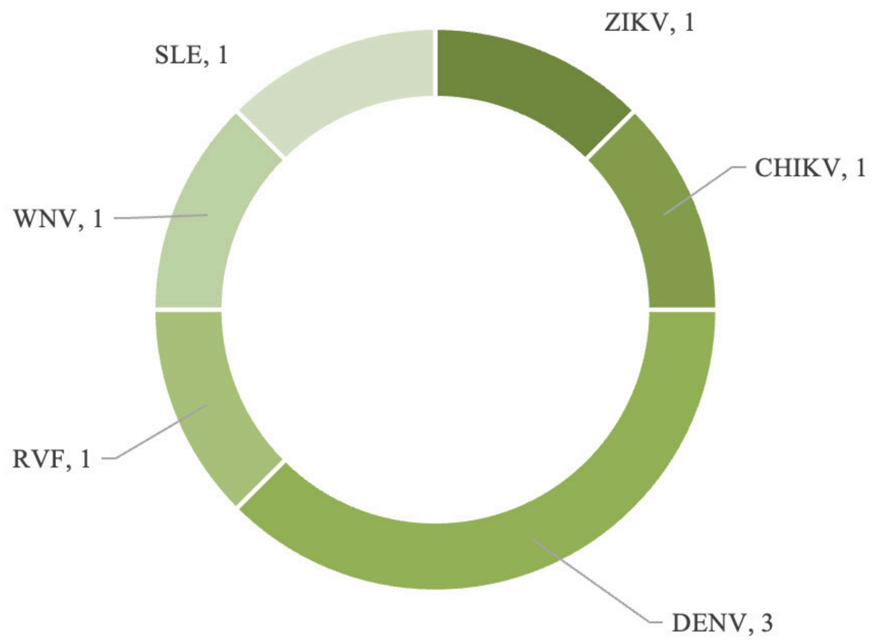

Figure 1d. Number of papers describing vector-borne outbreaks associated with droughts (n=8)

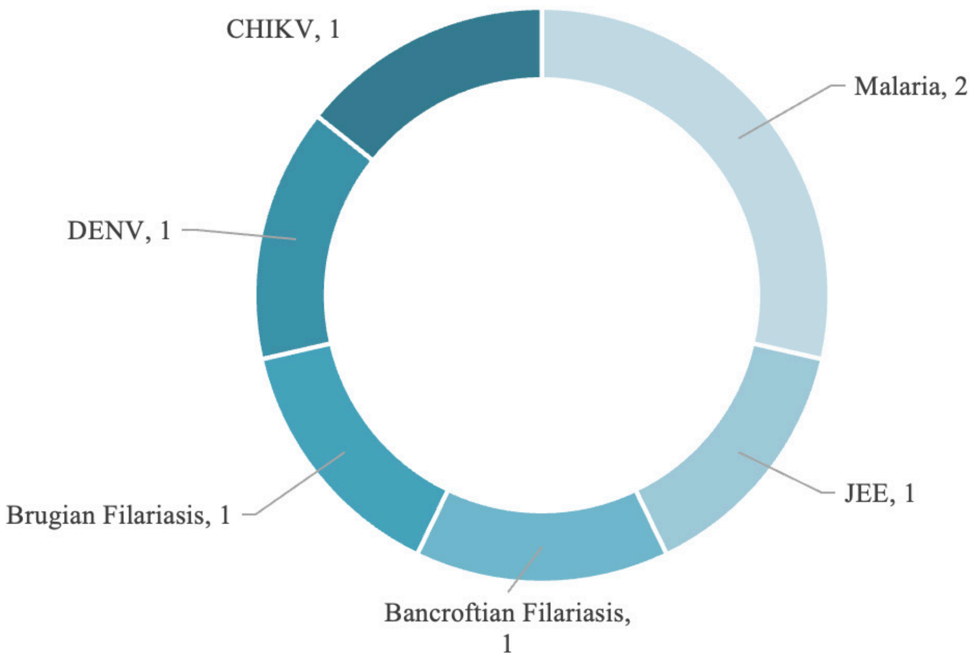

Figure 1e. Number of papers describing vector-borne outbreaks associated with monsoons (n=7)

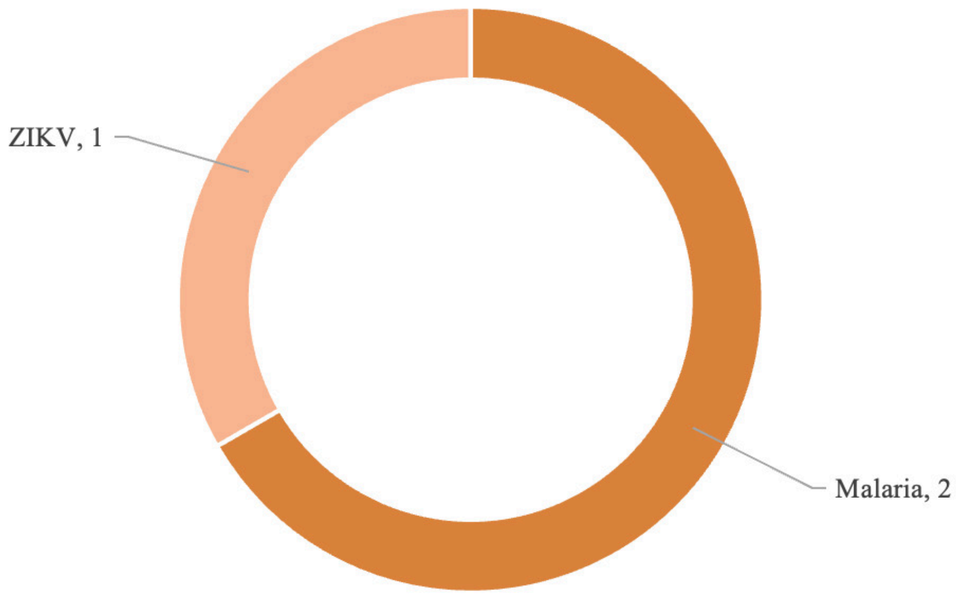

Figure 1f. Number of papers describing vector-borne outbreaks associated with earthquakes (n=3)

The pie charts are stratified according to the most common type of natural disaster found in the literature. The number associated with each disease represents the number of papers where the disease was reportedly found and not the number of outbreaks. Figure 2b. Includes data on hurricanes, typhoons and tropical cyclones.

Twelve articles examined the proliferation of flooding-related VBDs. Approximately 1827 patients receiving medical care during the 9 days post flood in Mozambique were diagnosed as having malaria, and 5% of the deaths were related to malaria. Another article found that the prevalence of dengue virus was statistically significantly higher ($P < .05$) 1 month after major flooding at 0.7% compared with a pre-flood prevalence of 0.2%. Following the earthquake and subsequent flooding disaster incident that struck Costa Rica in 1991 and 1992, some of the cantons in the region experienced increases in the incidence of malaria as high as 1600% and 4700% above the average monthly rate for the pre-earthquake period, respectively ($P < .01$).

Hurricane disasters were the second most reported natural disaster and were associated with 8 VBDs. After the 1963 hurricane in Haiti, the proportion of malaria cases with high parasite density (more than 1000 parasites per cubic millimeter in the blood) increased from 56% in October 1963 to 77% in November 1963, dropped to 64% in March 1964, and increased to 84% in June 1964. Following the effects of Hurricane Katrina, 117 cases of West Nile neuroinvasive disease and 11 cases of St Louis encephalitis were observed in some regions.

Tsunamis and drought tied at 6 articles for the third most reported natural disaster associated with VBDs. About 57% of the 252 cases associated with tsunami were infected with *Plasmodium falciparum*, and 40.1% were infected with *P vivax*. Following the Chikungunya virus epidemics in East Africa and the western Indian Ocean areas (2005-2007), a traveler returning from India imported the mutated virus into Italy. As a result, more than 200 locally acquired cases of Chikungunya virus were transmitted by Italian populations of *A albopictus.* Later in 2012, an outbreak of dengue virus in Madeira, Portugal, involved more than 2000 cases following a period of drought. Australia, Brazil, East Africa, Peru, the United States, western Indian Ocean islands, and Yemen provide examples of areas that experienced increased transmission following drought events.

Discussion

The evidence presented in this review aligns with existing literature suggesting that natural disasters may lead to infectious disease outbreaks when they result in substantial population displacement and exacerbate synergic risk factors for disease transmission. This was especially evident during more severe disaster events, such as the 1963 hurricane in Haiti, the 2004 Indian Ocean earthquake and tsunami, and Hurricane Katrina in 2005.

The risk of VBDs increasing can be due to several factors. Natural disasters can amplify human host interactions; for instance, increases due to high temperatures and humidity follow flooding events, creating further opportunities for host-vector interaction. Furthermore, human behavior, such as movement from nonendemic to endemic areas, limited or no access to vector control programs, and overcrowding, can proliferate vector breeding areas. If coupled with minor temperature changes, mosquito populations can thrive past the incubation period and alter species composition towards or away from more competent vector species.Generally, there is a brief window of opportunity before relief efforts are deployed wherein vector populations develop, feed, and replicate within the vector.

In the wake of a natural disaster, displacement and overcrowding can facilitate the transmission of VBDs, especially in endemic regions. This was the case during an earthquake in Ecuador,[30] and a tsunami in Southeast Asia.[36,37] The main vector control effort has been the distribution of bed nets. However, interruptions of ongoing control programs, such as bed nets or insecticides, increase vector population and the potential for disease transmission. Nevertheless, a notable example of a rapid control strategy was observed in India after a tsunami in 2004. A series of antivector measures were implemented to strengthen vector control in displacement camps, including distributing family-size insecticide-impregnated bed nets to mitigate dengue transmission. The World Health Organization (WHO) also assisted in clearing stagnant water sites to prevent the formation of breeding and malaria sites.[28]

The dynamic between natural disasters and VBDs is frequently misconstrued. The risk for outbreaks is often presumed to be very high post natural disasters, a fear likely derived from a perceived association between dead bodies and epidemics; however, natural disasters and VBDs compound one another. This review supports previous evidence that floods and hurricanes can increase VBDs, but the dearth of high-quality evidence undermines the strength of the conclusions. Event-to-transmission timing has differed among disease systems. About 215 million people per year are affected by floods worldwide.[29,37] While hydrological disasters have various origins and result in immediate damage, stagnant water or flooding may coincide with the origin of most outbreaks. *Anopheles vagus* is likely to breed prolifically in muddy rain-fed pools and is largely responsible for a malaria outbreak in southern Sri Lanka.[38,39] *A culicifacies* type E is the primary vector of malaria in Sri Lanka, breeds mainly in pools formed in rivers and stream beds, and is primarily dependent on temporal and spatial variations in rainfall and river flow. Boyce et al[29]noted that most of the residents exposed to malaria resided in villages containing a flood-affected river. Overall, there was a 30% increase in the risk of an individual having a positive malaria diagnostic test in the post-flood period in villages bordering a flood-affected river compared with villages farther from a river. The study also identified several geographical factors associated with post-flood malaria outbreaks. During periods of increased rainfall or severe drought, the risk of transmission may be exacerbated by the availability of vector breeding sites allowing them to flourish in containers, such as drums, discarded tires, and leaf axils, that are naturally filled with rainwater.

The studies identified many potential solutions. While current climate change models help steer intervention efforts, scientists and engineers can better incorporate arboviral traits into these models that are important for transmission linked to natural disasters. Tall and Gatton[16] provides insight for future research studies and the importance of understanding the interaction between flooding and arboviral disease to help minimize disease risk and ensure better use of the limited resources. Better prediction models for the location and timing of disease activity could improve public health outcomes by prompting more timely health alerts and more targeted mosquito spraying programs. Most importantly, such models could inform how these studies can incorporate data over a longer period instead of days or weeks. To inform future modeling studies, the research by Tall and Gatton suggests that studies looking at vector abundance for Ross River virus outbreaks after floods should incorporate the duration of riverine overflow, determine the impact of flood frequency on Ross River virus activity and mosquito data, and determine whether residents within proximity to flood-prone areas are at greater risk of disease than those living in higher altitudes.

As the conditions encouraging the spread of infectious diseases persist, several national and international health organizations have developed and implemented plans to address infectious diseases. In the United States, the Centers for Disease Control and Prevention applies 3 elements to the framework for preventing infectious diseases: (1) strengthening public health fundamentals, including infectious disease surveillance, laboratory detection, and epidemiologic investigation; (2) identifying and implementing high-impact public health interventions to reduce infectious disease; and (3) developing and advancing policies to prevent, detect, and control infectious diseases.[40] General implementation programs have progressed through national governments, the WHO, or nongovernmental organizations. However, many of the most impacted regions still have limited ability to develop their capacity to respond to VBDs resulting from natural disaster events. Notably, after Typhoon Haiyan in the Philippines, a wide range of national and international stakeholders initiated the rapid re-establishment of an effective surveillance system to identify new dengue cases quickly, monitor trends, and determine the geographical distribution of cases 12 days after Haiyan.[29]

The efficient use of humanitarian funds to control VBDs depends on many factors. Ideally, a comprehensive risk assessment should identify (1) endemic and epidemic diseases that are common in the affected area; (2) living conditions of the affected population, including number, size, location, and density of settlements; (3) availability of safe water and adequate sanitation facilities; (4) underlying nutritional status and immunization coverage among the population; and (5) degree of access to health care and effective case management.[41]

To help mitigate outbreaks, prevention and control strategies should include reducing vector density, vector-human contact, vector breeding sites, and the duration of infectiousness in humans by prompt identification, isolation, and treatment of cases.[5]

Based on the gaps identified in this literature review, the evidence suggests that disaster trends, combined with the geographical distribution of vectors such as arthropods, will likely impact the length of transmission and the geographical range of VBDs, making them increasingly suitable for malaria and dengue in undetected areas. Therefore, 3 recommendations have been highlighted to further investigate the relationships between natural disaster events and VBD risks:

- **Risk assessments before and during disaster periods:** Risk assessments should be undertaken at the local and national levels. Throughout my research, most of the affected areas were middle- to lower-income countries. Consequently, when disasters strike, most areas require additional support from foreign entities, such as the United Nations Office of Disaster Risk Reduction, WHO, nongovernmental organizations, or other private entities. Therefore, these assessments may be used to drive post-event humanitarian aid. Subject matter experts should be active participants during this phase and throughout the response period to better implement risk reduction strategies and support future response efforts.
- **Research:** Future research should rely on well-defined, consistent case detection and enrollment procedures, preferably at various lag periods following a natural disaster event, to examine long-term effects due to lags in recovery or changes in vector ecology and human susceptibility.
- **Investment in surveillance:** To effectively support risk assessment efforts, pre-event funding is critically needed to build active and passive surveillance systems in areas at greater risk for VBD transmission.

This review demonstrated much heterogeneity in the literature. The findings indicated a broader problem with collecting post-event data, especially in regions at the highest risk for natural disaster events. There lacked consistency in the data of interest; therefore, wide variability in methodology and reporting across the articles were encountered. For example, interest in capturing disease outbreaks across decades was difficult to satisfy because a few articles did not provide case counts or specify the number of disease occurrences. Another review did not specify the year(s) of the disaster event, complicating the potential to examine the long-term effects of VBDs. Other studies reported different analyses for the same natural disaster event; therefore, mixed results may have stemmed from the study sites, timelines, or study metrics. For studies reporting on flooding events, these events can have the potential for differential disaster categorization. Flood events are often a sequela of hurricanes, tsunamis, and monsoons, making it difficult to understand the tipping point for VBDs in the future. This methodological variability challenged the attempt to collectively summarize and interpret results, even for studies that examined the same events.

Conclusions

There is evidence that vector activity and abundance increase following natural disasters. The complexity of VBD systems becomes evident when examining the associations between an extreme weather event and actual disease. While disease prevention services may not follow the same protocols worldwide, re-establishing vector control strategies in endemic areas is critical to minimizing human mortality and morbidity. Malaria and dengue are not always a priority immediately after a natural disaster event. Prevention of VBDs like these requires collaborative effort at the national and local levels to improve vector control and selective pathogen elimination from the environments of the most vulnerable populations. The infrastructures necessary to treat diseases will require a well-versed and trained workforce as problems emerge and evolve. Health and humanitarian operations should consider evaluating disease patterns before funding and launching massive response efforts. National and state health ministries can be the source of the needed information; however, surveillance systems require more research and development to address gaps in response coordination.

Surveillance research may help mitigate future outbreaks in geographic areas prone to annual disasters. Therefore, subject matter experts or key national health officers should be consulted immediately after a natural disaster event regarding the risk of outbreaks. Further, studies of baseline incidence in disaster-affected populations will help understand the changes over time. More importantly, this and future evidence may lead to formulating better policies to address disease risk in natural disaster–prone areas.

Abbreviations

CHIKV Chikungunya virus
DENV Dengue virus
JE Japanese encephalitis
MVE Murray Valley encephalitis
RVF Rift Valley fever
RRV Ross River Virus
SLE St. Louis encephalitis
VBD Vector-borne disease
WEE Western equine encephalitis
WNND West Nile Neuroinvasive Disease
WNV West Nile virus
ZIKV Zika virus

Disclaimer

The opinions and assertions expressed herein are those of the author and do not reflect the official position of Georgetown University.

Conflict of Interest

None reported.

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