Social Determinants of Health in Post-Flood Disease Outbreaks: Insights for Effective Disaster Mitigation amid Climate Change

Abstract

Floods are the most frequently occurring natural disaster, comprising 44% of all major disasters globally. The intensity and frequency of flooding events have increased and are predicted to escalate further due to climate change, driven by rising temperatures and shifting precipitation patterns. Infectious disease outbreaks pose significant health risks following floods, underscoring the critical need to understand the factors driving these outbreaks to develop sustainable and effective disaster mitigation strategies. This systematic review aimed at identifying the social determinants of health that influence the risk of infectious disease outbreaks in post-flood scenarios. A systematic search of PubMed was conducted on November 19, 2024, identifying 215 studies, of which 13 met the inclusion criteria and were analysed. Nine social determinants of health were identified. The living environment (encompassing geographical setting, sewage contamination risk, and power outages) and structural (governmental) responses, including vaccination campaigns, emerged as key factors affecting disease outbreak risks. Additionally, determinants such as socio-economic status, staying in evacuation shelters, education, and gender were also found to influence disease outbreak. This review further examines the relationship between structural responses and the other identified determinants, offering practical implications based on observed trends. Future research linking social determinants of health to specific diseases will be invaluable for developing targeted and effective disaster mitigation strategies.

Plain language summary

Flooding is the most common natural disaster globally, affecting over 1.6 billion people in the past 20 years and making up about 44% of all major disasters. Due to climate change, the number and intensity of floods are expected to increase. One major health risk after floods is infectious disease outbreaks. These diseases are caused by harmful microorganisms entering the body and can result in disease outbreaks among people. While some, like the common cold or chickenpox, are mild, others, like COVID-19, malaria, or Ebola, can be severe with even death as a consequence. Understanding what causes these outbreaks after floods is crucial for creating strategies to prevent them or reduce their impact. This study reviewed 13 papers to identify factors related to people's living conditions that influence the spread of these diseases after floods. Governments and other organizations can use this information to improve these conditions before floods happen or to identify vulnerable areas at higher risk of disease outbreaks after a flood has happened.

Nine different factors were identified in the papers. The environment someone lives in came up as a key factor in influencing disease outbreak. This includes whether a person lives in a city or rural area, the contamination of drinking water with sewage and household trash, and the occurrence of power outages. Another factor that was identified as very important in the spread of infectious diseases is the way the government handled the flood. Effective government actions, such as disinfecting all water sources, providing fresh food to flood refugees, training doctors and nurses to identify infections and setting up vaccination campaigns, is of great importance for preventing the spread of infectious diseases after floods. Other factors also contribute to the risk of infection. These include a person's financial and social situation, staying in evacuation shelters, knowledge about infectious diseases, and gender. For example, women may have unique hygiene needs during floods, and men may face health risks from cleanup activities.

The findings from this review additionally highlight the importance of a strong governmental response after flooding, as every other identified factor can be linked to it. For example, the government is largely responsible for maintenance of safe living environments, preventing power outages and making sure human waste can be properly disposed. This review also emphasizes the importance for governments to continuously improve their flooding disaster response, especially given the increasing flood risks from climate change and the (shocking) global unpreparedness for major new disease outbreaks revealed by the Covid-19 pandemic. Future research should focus on unravelling these kinds of factors for every disease specific so that the government can continue developing effective and specific strategies to limit the spread of infectious diseases following flooding disasters in a rapidly changing world due to climate change.

Introduction

Between 2000 and 2019, over 3,250 major floods were reported, more than double the number recorded in the previous 20 years, affecting more than 1.6 billion people globally and comprising 44% of the total amount of major disasters happening globally (*The Human Cost of Disasters: An Overview of the Last 20 Years (2000-2019)*, 2020). This can be expected to continue, and even worsen as research has demonstrated that climate change is altering the hydrological cycle, leading to shifts in precipitation patterns, changes in groundwater availability, and variations in evapotranspiration rates (Dagbegnon et al., 2016). These disruptions have contributed to an increase in extreme precipitation events which, combined with reduced infiltration capacity of the soil, have been linked to the increasing frequency and intensity of flooding events. As the temperature continues to rise, these trends are expected to worsen. The increasing severity of these disasters is exemplified by the drastic increase in "billion-dollar" weather and climate disasters (i.e. a disaster causing a billion dollars in damage) in the U.S. Between 2015 and 2019, there was an annual average of 13.8 billion-dollar disasters per year, whereas the (inflation-adjusted) average between 1980 and 2019 was only 6.5 events per year (*2010-2019: A Landmark Decade of U.S. Billion-dollar Weather and Climate Disasters*, 2020).

Various types of floods exist, each arising from distinct processes and mechanisms. However, they always involve the inundation of land that is otherwise supposed to be a dry area (Viglione & Rogger, 2014). Common types of flooding are river floods, flash floods, dam-break floods, urban floods and coastal floods. River floods and flash floods are caused by heavy rainfall and water runoff due to saturation excess or infiltration excess of the ground. Dam-break floods are the result of the breaking down of a dam, caused by different potential factors, often including exceeding the max capacity of the dam. Urban floods (or more specifically pluvial floods) are caused when rainfall exceeds the capacity of the drainage system. The lack of soil capable of taking up excess water in cities contributes to the vulnerability of urban settings to these kinds of floods. Lastly, coastal floods are the result of sudden surges of water due to severe storms causing winds that push water up onto coastal land. Floods can also be the result of various natural disasters, such as earthquakes (e.g. via tsunamis) and tropical cyclones/hurricanes.

The Intergovernmental Panel on Climate Change (IPCC) AR6 report has identified multiple changes in the climate that most likely will contribute to an increase in the frequency and severity of floodings as well as increase the damage done during the flood (*AR6 Synthesis Report: Climate Change 2023*, n.d.). A temperature increase of 1.1 ºC has been recorded in the period from 2011-2020 compared to the temperature from 1850-1900, most likely caused by the human emission of green house gasses (GHG). This is predicted to increase to 1.5 ºC before 2040 and may rise to 4 ºC by 2100 if no drastic measures against GHG emissions are implemented. The observed increase in global temperatures has caused a rise in the frequency and intensity of heatwaves and droughts. Additionally, a rapidly increasing rise of sea level has been observed (1.3 mm/year in 1901-1971 compared to 3.7 mm/year in 2006-2017) as well as increased heavy precipitation events and shifted precipitation patterns. Research has shown that climate change is disrupting the hydrological cycle in virtually all points of the cycle, although the mechanisms how are not completely understood (Dagbegnon et al., 2016). An emerging trend shows that precipitation events are becoming more intense, even though their overall frequency seems to decline. Together with greater evapotranspiration, reduced groundwater recharge and increased surface runoff, this increases the risks of flooding events. Though individual floods can't be directly linked to climate change, their growing frequency and severity are closely tied to these changes.

Flooding has been linked to both direct and indirect health impacts (Ohl, 2000, Du et al., 2010). Direct health impacts are health effects that result immediately from the disaster itself, whereas indirect health impacts arise as a secondary consequence influenced by the aftermath of the flood. Direct impacts are events such as drowning, injury, hypothermia and animal bites that occur following direct exposure to the flooded environment. Indirect impacts are events such the disruption of health services, either by damage to the buildings and the infrastructure needed to deliver proper services or by the loss of medical records, medication, medical devices and medical consumables. Other indirect health effects of flooding are health risks associated with displacement. Staying in evacuation shelters after a natural disaster has been linked to below-standard sanitary conditions, malnutrition, shortage of medication and overcrowding (Tokumaru et al., 2021). Another major health concern after flooding is the outbreak of infectious diseases, which can be driven by the flood itself or changes in activity following a flood (e.g. over-crowding in evacuation shelters) (Paterson et al., 2018). Skin, respiratory, and gastrointestinal infections tend to occur within the first 10 days post- flood, whereas leptospirosis, mosquito-borne illnesses and Hepatitis A or E virus infections tend to occur after the 10-day mark. The causes of infection can vary depending on the context. For example, skin infections can be caused by trauma obtained by trying to escape fast-moving water or cleaning up after floods. By contrast, gastrointestinal infections are often the result of disruptions to the sewage system and contamination of drinking water.

The relationship between climate change, flooding, and infection is complex as flooding, rain, humidity and temperature have all been associated with increases of infectious diseases (Ivers & Ryan, 2006, Wu et al., 2015). Climate change causes alterations in temperature, precipitation patterns, humidity and wind dynamics, which impacts the infectious disease cycle on almost every level in both beneficial and adverse ways. Temperature shifts can affect the distribution and viability of pathogens as well as their vectors or hosts, as most possess specific temperature ranges within which they thrive. Shifts in precipitation patterns can also lead to altered dissemination of water-borne disease pathogens. For example, heavy precipitation, particularly following extended droughts, can lead to the accumulation of faecal pathogens in water bodies as pathogens, which had accumulated on the land during the drought, are rapidly mixed into water bodies. Rain can also improve and accelerate the larval development of mosquitos, causing an increase in mosquitos and thus mosquito-borne diseases. However, breeding sites can also be swept away during heavy rainfall, resulting in the eradication of mosquito populations and decrease of mosquito-borne diseases. Accurately predicting the direct impacts of climate change on infectious diseases remains challenging due to the complexity and variability in the environmental conditions that affect pathogen survival and transmission dynamics. Climate change also indirectly impacts disease spread by affecting transmission routes, mainly because of altered human behaviour such as changes in occupations, seasonal lifestyles and migration, resulting in altered contact patterns between humans and disease pathogens, vectors and hosts.

While flooding, infectious diseases and climate change impact populations globally, the extent of their effects on health outcomes is profoundly shaped by social determinants of health (SDOH). These are non-medical factors that influence health outcomes, encompassing conditions where people are born, work, live and age, together with a wider set of forces and systems that shape the conditions of daily life (World Health Organization: WHO, 2019). A review by Flores et al. (2024), examining health disparities in the aftermath of floods in the USA revealed that race, ethnicity, and socio-economic background commonly influence both physical and mental health outcomes following flooding events. These features are likely relevant because they intersect with other determinants of health such as income, education, and housing through systemic inequities in access to resources, opportunities, and protections, thereby shaping health outcomes in these contexts. SDOHs have also been linked to the health outcomes of infectious diseases. For instance, a systematic overview by Ayorinde et al. (2023) examined health inequalities in infectious diseases, highlighting that SDOHs such as socioeconomic status, housing conditions, and access to healthcare influenced the prevalence and outcomes of infectious diseases. The effects of SDOHs on health outcomes become even more pronounced in the context of climate change. The IPCC AR6 report indicated that vulnerable communities are disproportionally affected by the effects of climate change, causing climate change to function as a fundamental amplifying factor, widening the disparities in health outcomes driven by differences between people in SDOHs during flooding events and outbreaks of infectious diseases (*AR6 Synthesis Report: Climate Change 2023*, n.d.).

Gaining a better understanding which social determinants of health are the most vulnerable to flooding and the most impactful on the emergence of specific infectious diseases will help both during the preparation of a flood and in the prediction of which infectious disease might emerge after the flood. Therefore, to gain a better understanding in the complex interplay of these phenomena, this systematic review aims to identify which flooding-induced changes in the social determinants of health contribute to the emergence of infectious diseases in a world rapidly changing due to climate change.

Methods

Search strategy

A systematic review was performed, with the findings reported according to the PRISMA recommendations and utilizing a Population, Exposure, Comparator, and Outcome (PECO) approach. A PECO search table was created to identify the MeSH terms, keywords and phrases used to create a search string. The keywords were decided after a preliminary screening of 10 initial abstracts for commonly used words and by searching for MeSH terms in PubMed. The PECO search table and finalized search string can be found in appendix 1. Using the search string, the initial search was conducted on November 19th of 2024 using the database PubMed. The 215 initial results from PubMed were deduplicated (n=1) and screened based on the inclusion and exclusion criteria found below.

Inclusion and exclusion criteria

To be included in this review, papers had to look specifically at flooding and infectious diseases in humans. Papers focussing on other diseases, infectious diseases in animals or no/other weather extremes were excluded. Papers had to focus on situations resulting in the increase of infectious diseases after flooding or provide an explanation as to why there was no increase/decrease of infections after the flood in order to identify factors that contribute to the spread of diseases. This resulted in the exclusion of studies that concluded that there was little to no increase of infectious diseases after the flood without elaborating on factors that prevented these outbreaks. Lastly, papers had to examine social determinants of health which were affected by the flood and potentially contributed to the uprising of infectious diseases. Papers were therefore excluded if they only examined flooding and did not examine social determinants of health. Papers that specifically focussed on children, elderly people or were not written in English were also excluded. In total 19 papers were included for the full-text screening.

Data extraction

The 19 papers that were identified during the initial screening were reviewed for their full text, resulting in the inclusion of 13 papers into the final analysis. Papers that still met the inclusion criteria underwent data extraction to obtain information on the type of flood, location of flood, types of infectious diseases discussed in text, examined social determinants of health and effect of affected determinant on the infectious disease. All papers were assessed for risk of bias of their outcomes using the National Institutes of Health Quality Assessment Tool for Observational Cohort and Cross-Sectional Studies (*Study Quality Assessment Tools | NHLBI, NIH*, n.d.) and/or the Consolidated Criteria for Reporting Qualitative Research 32-item checklist for interviews and focus groups (Tong et al., 2007).

Results

Identification and quality assessment of included studies

The initial search revealed 214 unique entries, of which 19 were retained for full text screening. Of these, 6 papers were discarded, resulting in a total of 13 papers in this review, as shown in the flow diagram in figure 1. Papers were excluded for reasons such as looking at other extreme weather events or non-infectious diseases, not identifying social determinants of health and focussing on children or elderly people only. Three main kinds of studies were identified, quantitative studies examining the number of infected people after a flooding event (n=6), qualitative studies where affected communities or healthcare professionals were either surveyed or interviewed (n=4) and mixed methods studies where surveys or interviews were used together with quantitative data (n=3). The table with the data extraction from these papers and their quality assessment for the risk of bias can be found in appendix 2. A summary table highlighting the characteristics and main findings of each included paper is provided in table 1. Quality assessment for the quantitative studies was done with the National Institutes of Health Quality Assessment Tool for Observational Cohort and Cross-Sectional Studies (*Study Quality Assessment Tools | NHLBI, NIH*, n.d.). Quality assessment for the qualitative studies was done with the Consolidated Criteria for Reporting Qualitative Research 32-item checklist for interviews and focus groups (Tong et al., 2007). Studies with a mixed design study design were checked for quality by both checks. In summary, the overall methodological quality was categorized as either fair (n=3), good (n=7), or excellent (n=3). A total of nine social determinants of health were identified in this review. The determinants of sewage infrastructure, power outages, and geographical setting (urban or rural environments) were classified under the category of "living environment". Official governmental response and vaccination were combined into the category of "structural disaster response". Additional themes identified from the analysis include socio-economic status, residence in evacuation shelters, education, and gender.

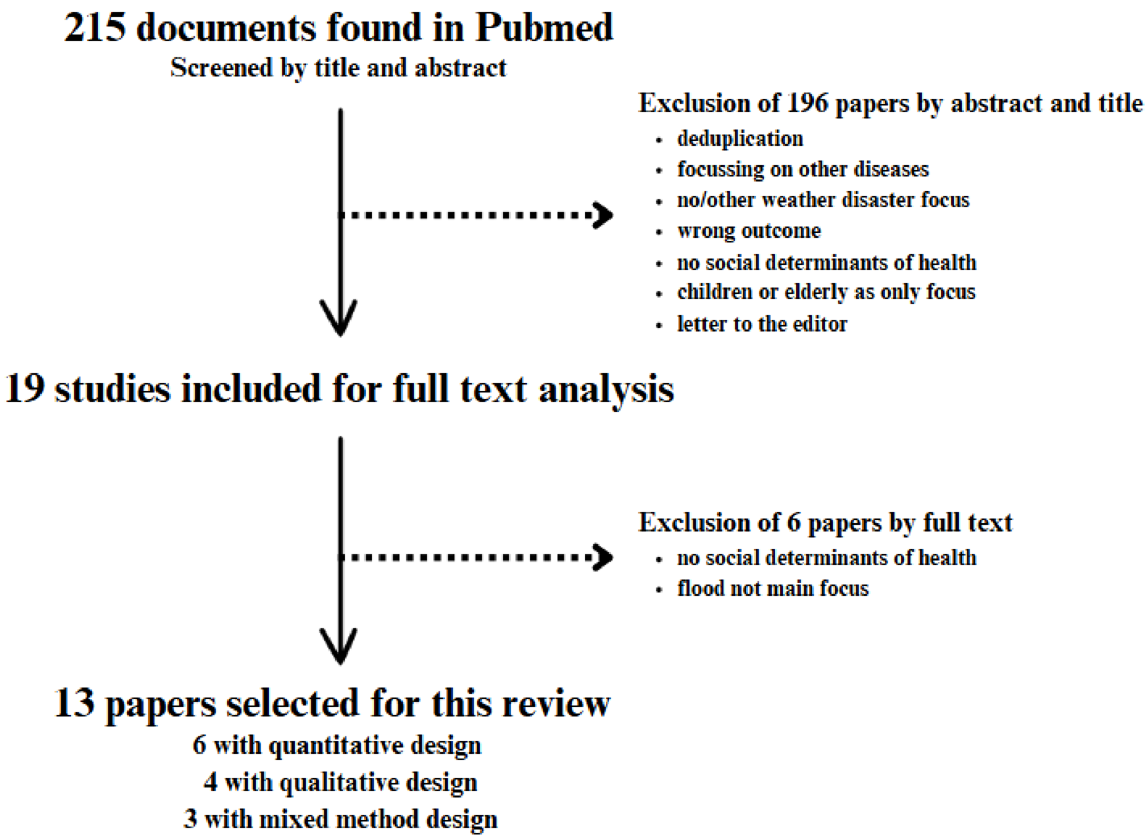

Figure 1. Flow diagram of the search strategy

Table 1. Characteristics and findings of the included studies on the association of social determinants of health, flooding, and infectious disease outcomes

Reference	Study design, study set-up	Type of flood, area	Sample size	Main findings	Quality assessment
Shackleton et al., 2023	*Quantitative design* – analysis nonlinear relationships between cholera and temperature, rainfall and sea surface temperature based on data from 1999-2019	Monsoon related floods in Kolkata, India	2479 confirmed cases of cholera	Temperature drives cholera in the summer, rainfall drives cholera in monsoon season. Sewage contamination linked to cholera during monsoon season, not open defecation practices.	Good
Deng et al., 2022	*Quantitative design* – large time series design (2002-2018) using DLNM to assess association of floods and power outages on diseases	Flash floods, coastal floods and lakeshore floods in New York state, USA	7676 patients minimum and 12.426 patients maximum for FWBD, 68.092 patients minimum and 89.882 patients maximum for respiratory infections	Increased health risk associated with flooding and power outages, showing synergistic effect when power outage and flood are combined.	Excellent
Bloom et al., 2016	*Quantitative design* – comparison of food and water borne disease hospital diagnoses between people living in storm and non-storm areas	Hurricane Sandy, Greater New York city area, USA	2372 patients, 592 from storm area and 1780 from non-storm area	Lower risks for FWBD were observed in the post-Sandy period relative to pre-Sandy period for both residents of storm and non-storm areas.	Good
Yeboah et al., 2024	*Mixed method design* – surveys in households living within 100m of river, complemented with secondary data from governmental agencies and environmental reports	River flooding of the Tano River, Ghana	400 people	Inadequate sanitation, poor hygiene practices and contamination from illegal mining activities are primary contributors to waterborne diseases. Flooding and improper waste management exacerbate these issues.	Excellent
Sampson et al., 2018	*Qualitative design* – interviews with residents about recurrent household flooding	Inland urban flooding in Detroit, USA	18 interviews	Recurrent flooding of houses leads to multiple different health threats, but victims are not supported enough to combat the difficulties arising from flooding. Flood-related local and federal relief programs should step up and take a more protective role.	Excellent
Lin et al., 2015	*Mixed methods design* – comparing serological status between people staying in shelters and people staying in communities, using surveys and interviews to understand contributing factors	Typhoon Morakot in Kaohsiung County, Taiwan	288 people for questionnaire, 128 patients with positive IHA seroconversion for telephone interviews	Amoebiasis (waterborne infectious disease) infections are higher in people that lived in shelters post flood. Seroconversion for vaccine preventable diseases was found, but no difference between shelter or community group.	Fair

Tauzer et al., 2019	*Qualitative design* – focus groups in three communities	El Niño related heavy rainfall and floods in Machala, Ecuador	65 people in 5 different focus groups	Lack of (sewage) infrastructure, social and political capital of flooded communities and governmental engagement with relevant stakeholders results in a lack of adaptive capacity of the communities to flooding.	Good
Jones et al., 2024	*Quantitative design* – comparison of confirmed leptospirosis cases from before and after hurricane to assess functionality of preventative outbreak steps that were taken	Hurricane Fiona in Puerto Rico, USA	156 patients in the post-hurricane period	Public health response to leptospirosis cases was majorly improved by streamlining surveillance data, writing educational guides for health care professionals and additional material for testing labs.	Fair
Olds et al., 2018	*Quantitative design* – sampling of water streams to quantify the sewage load based on two human genetic markers	Rain events with storm water discharges in Lake Michigan and three upstream places, USA	N/a (non-human study looking at water samples)	Rain and flood events both cause dramatic increase in sewage contamination of the river, especially combined with sewage overflow events.	Excellent
Abdullah et al., 2023	*Qualitative design* – interviews were conducted with health professionals discussing the major health and system responsiveness problems	General flooding in Pakistan	16 interviews with health professionals	The interviews showed that the government did not react timely to the floods and mainly focused on un-effective mitigation strategies, such as fundraising for money.	Good
Chitio et al., 2022	*Quantitative design* – analysis of the feasibility and costs of a cholera vaccination campaign in a flood sensitive region	General flooding and cyclones in Cuamba District, Niassa Province, Mozambique	388.906 vaccinated people after 2 rounds	Vaccination of people in Mozambique (Cuamba District) was feasible and affordable, resulting in enough coverage to massively drop the risk of cholera.	Good
Lau et al., 2016	*Mixed methods design* – cross-sectional seroprevalence study and eco-epidemiological approach to characterize risk factors and drivers for human leptospirosis infections	Cyclones and severe flooding in Fiji	2152 people	Multiple risk factors were identified on the individual level (gender, access to water, work location) and community level (rural setting, close proximity to rivers, poverty rate).	Good
Srikuta et al., 2015	*Qualitative design* – household surveys in six different rural villages exposed to flooding to assess health vulnerability	General flooding in northeastern Thailand	312 households	Around 54% of households had medium to high health vulnerability to flooding. Different coping strategies are adopted based on income, educational level, occupation and distance to river.	Fair

Living environment

Nine out of the 13 papers (5 qualitative, 3 quantitative and 1 mixed design study) indicated that the environment a person lives in contributed to the increased risk of infection after flooding (Shackleton et al., 2023; Deng et al., 2022; Yeboah et al., 2024; Sampson et al., 2018; Tauzer et al., 2019; Olds et al., 2018; Lau et al., 2016; Srikuta et al., 2015; Abdullah et al., 2023). Urbanisation and rural settings were both mentioned as factors contributing to the spread of diseases after a flooding event. Living in rural settings has been linked to having a relatively higher occurrence of commercial and subsistence animal farming in the community, and thus a higher chance of exposure to zoonotic, attributed to the removal of deceased animals and increased drinking water contamination caused by animal waste. This has been identified as a contributing factor to the leptospirosis outbreak in Fiji following cyclones and severe flooding. (Lau et al., 2016). Conversely, urbanisation was identified as responsible for the removal of natural drainage ways of rivers and precipitation runoff, often followed by the building of houses in natural water ways. This is exemplified by the increasing demand for housing and infrastructure in Ghana due to an increasing population density. To keep up with the demand, houses were built in natural water courses (Yeboah et al., 2024). As a result, communities were formed in places with an increased risk of exposure to floodwater and the concomitant risks such as the destruction of property and exposure to sewage contaminated water.

Eight papers highlighted the role of sewage contamination in spreading infectious diseases, emphasizing that drinking water sources are often polluted after heavy precipitation and flooding events (Shackleton et al., 2023; Deng et al., 2022; Yeboah et al., 2024; Sampson et al., 2018; Tauzer et al., 2019; Olds et al., 2018; Lau et al., 2016; Srikuta et al., 2015). Sewage contamination typically occurs through wastewater overflow or leaks into other water bodies, and the collapse of waste collection infrastructure. For instance, Srikuta et al. (2015) reported that 33% of families affected by floods in Thailand lost access to waste disposal services, leading to trash being thrown into floodwaters, increasing the risks for skin infections and gastrointestinal diseases. In areas without access to clean water, contaminated water is often consumed, significantly raising the risk of disease. In Ghana, surface water remains a primary source, but floods often contaminate it due to sewage overflow and runoff from open defecation sites (Yeboah et al., 2024). Beyond drinking water, sewage pollution also impacts recreational waters used for swimming and cooling off, further spreading diseases (Lau et al., 2016; Olds et al., 2018). These risks are worsened when floods coincide with power outages, as Deng et al. (2022) found. Their study showed that combined floods and power outages amplify respiratory infections and food and waterborne diseases due to contaminated water, sewage overflow, and poor hygienic conditions.

Structural disaster response

Another important factor highlighted by multiple papers (n=8) was the official government response related to flooding events (3 quantitative, 4 qualitative and 1 mixed design study) (Bloom et al., 2016; Yeboah et al., 2024; Sampson et al., 2018; Tauzer et al., 2019; Jones et al., 2024; Abdullah et al., 2023; Chitio et al., 2022; Srikuta et al., 2015). Some papers discussed the proper/ “correct” steps taken to prevent the spread of infectious diseases or to limit an outbreak. Providing clean drinking water and ready-to-eat meals and rapidly altering the healthcare system to deal with flood outcomes were identified as useful steps to combat disease outbreak. For example, freshwater access was increased in the greater New York city area after hurricane Sandy by raising chlorine levels, using UV disinfection, and the rapid replacement of drinking water reservoirs, minimizing the change of exposure to water-borne diseases (Bloom et al., 2016). Together with providing fresh meals, this even resulted in a decrease in the number of food and water-borne disease diagnoses for areas that were affected by the flood compared to areas that were not. It should be noted that almost a doubling in patients was found for people over 65, suggesting elderly people were considerably more at risk. However, this observation was made in a relatively small patient group and could be attributed to a chance observation (65 patients vs 440-687 patients in the other age groups). Similarly, a leptospirosis outbreak was minimized in Puerto Rico after rapidly altering the healthcare system to quickly identify and test patients for infection (Jones et al., 2024). Specifically, outbreak surveillance was improved, reporting of infections was centralized into one system with a massive drop in reporting time (5 days to 24h), healthcare staff were trained to identify leptospirosis infections via additional educational training sessions and information booklets, and additional supplies were sent to the laboratories to keep up with the increase in tests.

Another important structural response to prevent disease outbreak that was identified is herd immunity provided by vaccinations (Chitio et al, 2022, Lin et al., 2015). Vaccination campaigns have been shown to be useful in the prevention of infectious disease outbreaks following floods. After flooding caused by a typhoon in Taiwan, seroconversion (the detection of antibodies against a specific disease) for vaccine preventable diseases was observed in people that had to evacuate their home, measles, mumps and rubella specifically. Two rounds of seroconversion tests were done 5 months and 11 months following the floods to identify people who were infected in post flood circumstances. Due to the relatively high vaccination level in Taiwan, this did not result in a massive disease outbreak both in people that found shelter in other communities or in evacuation shelters. Contrary to that, outbreaks of measles and rubella were reported in evacuation shelters in Liberia among people fleeing from the Cote d'Ivoire floodings, where the population had lower vaccination rates than Taiwanese people (Lin et al., 2015). Proper calculations of minimum vaccination level, affordable vaccines and effective coordination and microplanning among different stakeholders have been identified as important factors contributing to successful herd vaccination campaigns (Chitio et al., 2022). The prohibition and prevention of building in natural waterways and the development of flood-resilient trash disposal infrastructure were also identified as general governmental responsibilities in flood prone areas to protect people from major property damage and exposure to contaminated water, regardless of the presence of an immediate flooding risk (Srikuta et al., 2015, Tauzer et al., 2019, Yeboah et al., 2024).

A lack of proper structural response to floods has been linked to increased risks of disease outbreak by five different papers. Each paper highlighted a different aspect of structural response, but they all concluded that due to a lax attitude of the government, people were unnecessarily exposed to pathogens. An immediate and proactive response of the government is needed directly after a food to ensure adequate disaster mitigation strategies are employed. During the massive 2022 floods in Pakistan, the government failed to provide an adequate response to a flood, choosing instead to focus on raising funds as their primary mitigation strategy. However, due to what the authors labelled as "widespread corruption", none of the funds reached the communities that desperately needed them. Critical emergency facilities, such as evacuation shelters and healthcare facilities, were left unsupported, exacerbating the suffering of flood-affected populations and increasing the risk of infectious disease outbreaks (Abdullah et al., 2023). Another instance of inadequate government response to flooding is the failure to provide rapid cleanup support in post-flood situations. This shortfall has been associated with increased pathogen exposure, as individuals often take it upon themselves to clear flood debris without proper protection against infectious diseases (Sampson et al., 2018).

Socio-economic status

Socio-economic status was addressed in five different papers; however, not all of them elaborated on how it specifically contributes to the increased risk of infectious diseases after floods, instead merely mentioning it as a contributing factor (Srikuta et al., 2015; Deng et al., 2022). Low socio-economic status can lead to increased or prolonged exposure to infectious disease pathogens through mechanisms such as attempting to cut costs by personally cleaning up flood debris without proper protection or delaying necessary repairs (Sampson et al., 2018; Tauzer et al., 2019). Another factor is the lack of stable access to clean drinking water due to the associated costs. Households without metered water or a (rooftop) cistern for fresh water were identified as often more vulnerable to contamination of their drinking water sources, highlighting the link between low socio-economic status and increased risk

(Lau et al., 2016, Tauzer et al., 2019). Additionally, the absence of a second floor to seek refuge or store personal belongings further exposed individuals to direct and prolonged contact with floodwater and its associated contaminants (Tauzer et al., 2019).

Evacuation shelter

While shelters were often utilized for temporary/emergency accommodation flooding, staying in evacuation shelters after flooding was linked to an increased risk of infection. Stagnant contaminated water and poor living conditions were identified as the main contributors of disease spread (Lin et al., 2015, Abdullah et al., 2023). The lack of space and supplies to take care of patients who needed inpatient care (e.g. hospitals were destroyed or made inaccessible by the flood) also contributed to the severity of infectious diseases cases within evacuation shelters (Abdullah et al., 2013). Another paper suggested that the absence of large population displacements after flooding disasters, with the consequent absence of evacuation shelters, in high-income countries contributed to lack of infectious disease outbreaks (Bloom et al., 2016). It must be mentioned however that they do point out that shelter-based outbreaks are unlikely to be captured by the database they used for their analysis.

Education

Another factor that was identified to influence a person's risk to infectious disease was their understanding of risks and dangers associated with floods and infectious diseases. Misunderstandings in disease transmission pathways have been reported among flooded communities, potentially leading to ineffective and insufficient protection measures being taken to protect against infectious diseases following floods (Tauzer et al., 2019). Multiple papers also promoted the active education of communities, especially after a flooding event, to raise awareness around the dangers that may occur, disease transmission pathways, the impact of their actions on health outcomes for others, and to promote sustainable practices for the future (Tauzer et al., 2019, Yeboah et al., 2024). One way this concept is already being implemented was by the use of social media to inform people about the dangers of wading through potentially infected water in the case of potential leptospirosis outbreak after the 2022 hurricane Fiona in Puerto Rico (Jones et al., 2024).

Gender

Out of the 13 papers, only two papers mentioned the contribution of gender in the development of infectious diseases after flooding. One paper discussed the impact of cultural practices, where women were only allowed to visit female doctors (Abdullah et al., 2023). Interviews with health professionals indicated that there was a massive shortage of female doctors in flooded areas, at least partly due to the lack of proper hygiene and environment for a female doctor to stay, resulting in the lack of treatment for women. The other paper mentioned gender as a differentiating factor for infection post flooding, highlighting that men were more susceptible to leptospirosis, in this case specifically in Fiji (Lau et al., 2016). The main explanation for this divide was the difference in (occupational) exposure to leptospirosis, as more men tended to be farmers than women and they were responsible for going out and investigating the state of the farm and the damages done during the flood.

Discussion

This systematic review aimed at identifying social determinants of health that influence infectious disease outbreak in post-flood scenarios. It is predicted that rain-induced floods, as well as floods in coastal and low-lying areas, will increase in both frequency and intensity due to shifted precipitation patterns driven by climate change (*AR6 Synthesis Report: Climate Change 2023*, n.d.). Therefore, it is crucial to understand the determinants that drive disease outbreaks in post-flood scenarios to develop effective mitigation strategies and protect communities from the negative health impacts of flooding. The analysis revealed that components of the living environment, such as geographical setting, sewage infrastructure and power outages, have a substantial impact on infectious disease outbreaks (described in 8 papers). Another important factor that was identified was the critical need of a structural disaster response from the government (8 papers). Other factors that were identified as influential in the spread of infectious diseases were socio-economic background (5 papers), staying in evacuation shelters (3 papers), education (3 papers) and gender (2 papers). However, these factors were discussed in fewer papers compared to the number of studies that identified living environment and structural response as key factors.

The connection between structural response on other social determinants of health

The importance of an official governmental response following a flood was highlighted in eight different papers, emphasizing its role in either mitigating or exacerbating disease outbreak risks. A structural response to flooding disasters to prevent disease spread intersects with the other social determinants of health identified in this systematic review. For instance, large-scale preventative actions of improving sewage infrastructure to prevent water contamination, which is critical in halting the spread of waterborne diseases in post-flood scenarios, cannot be undertaken at the individual level but must be overseen by the government. Similarly, governments can ensure that during urban planning, the development of new residential neighbourhoods, infrastructure, and healthcare facilities is conducted in a flood-resilient manner. Measures such as prohibiting construction in natural waterways, incorporating vegetation in urban planning to reduce water runoff and urban heat islands, and establishing efficient stormwater drainage networks to prevent waterlogging are all examples of how governments can create flood-resilient communities. These intersections illustrate the crucial link between structural responses and social determinants of health related to the living environment.

Another way structural response is connected to other determinants is through protecting people with lower socio-economic status. Increased exposure to pathogens among low-income households can occur in various ways, such as the lack of access to potable water, forcing reliance on quickly contaminated river water, attempting to cut costs by cleaning flood debris without proper protective equipment, or lacking a safe place to seek refuge and store personal belongings during flooding (Lau et al., 2016; Sampson et al., 2018; Tauzer et al., 2019). Governmental actions can address these vulnerabilities for people with low incomes by (for example) providing bottled water, deploying rapid cleanup teams to clear flood debris (at no cost to affected residents), and developing safe and hygienic evacuation shelters. The findings of this review illustrate that such actions are not only important for mitigating immediate risks associated with post-flood infectious disease spread, but also for addressing broader health inequalities and improving health outcomes for vulnerable populations in post-flood scenarios.

Gender as an analytical lens

Only two papers discussed gender as a contributing factor to infectious disease risk, which was unexpected for several reasons. Firstly, women have menstrual hygiene needs, such as sanitary products and facilities for changing and disposal of menstrual waste (Emt & Flowers, 2008). Lack of access to proper hygiene products and facilities increases the risk of urinary and reproductive tract infections and bacterial vaginosis. Secondly, women also have different reproductive health needs. Access to perinatal care is essential for the safekeeping of both the mother and the baby, especially in crises such as natural disasters. Unsanitary delivery conditions and the lack of proper postnatal care can lead to sepsis and other life-threatening infections, potentially resulting in the death of the mother and the baby (Maharaj, 2007). At the same time, contraceptive access is important, especially after natural disasters as these events have been linked to increased gender-based violence, resulting in an increased risk for sexually transmitted infections (van Daalen et al., 2022).

Men, however, are often responsible for the cleanup and reconstruction activities in post-disaster scenarios, resulting in increased risk of exposure to pathogens (Lau et al., 2016). Mental health support can also be vital in post-disaster healthcare for men as challenges may arise related to social expectations in disaster recovery, such as having to provide for the family and deal with the post flood situation on their own (Akerkar & Fordham, 2017). Although mental health is outside the scope of infectious diseases in this review, it is an important additional component of differentiated healthcare needs for men and women. The gender-specific healthcare needs are differently affected by floods, suggesting that flooding also differently affects healthcare outcomes for people based on gender. Additionally, gender plays an important role beyond flood victims in health consequences following floods. For instance, during the Pakistan floods in 2022, unsanitary post-flood conditions excluded women from medical staff and rescue teams, leaving women flood victims without adequate healthcare, thereby increasing their risk of infectious (and other) disease (Abdullah et al., 2023). The information presented above underscores the importance of using gender as an analytical lens to better understand the determinants affecting healthcare outcomes and disease risks in the aftermath of natural disasters.

While two papers discussed gender as a contributing factor, none of the studies included in this review distinguished between sex and gender or used gender as a spectrum instead of a binary category. As biological sex does not always align with gender identity, it is crucial to address health needs through both lenses. For example, a transgender woman has distinct healthcare requirements compared to a cisgender woman, such as the need of consistent access to gender-affirming hormones but no need for menstrual hygiene facilities. Two recently published papers have highlighted that the impact of sex and gender on health consequences is often understudied in climate change research and underrepresented in international climate governance debates (Peters et al., 2024; Van Daalen et al., 2024). The lack of discussion on the role of sex and gender in infectious disease outbreaks within the reviewed papers further underscores and supports the observation that there is a need for more high-quality research to gain a better understand the connection between sex and gender, climate change and health outcomes.

Disaster preparedness of high-income countries

One paper included in this review discussed that there was no increase in infectious diseases after hurricane Sandy in the greater New York area (Bloom et al., 2022). The paper stated that infectious diseases are typically low following hydrometeorological disasters in what they refer to as highly "developed", high-income nations, particularly in the absence of large population displacements. However, while the outcome from hurricane Sandy was (generally) positive, it is important to recognize that wider impacts of the COVID-19 pandemic revealed that the readiness of high-income nations to handle a crisis of this magnitude was greatly overestimated (Haldane et al., 2021). During the pandemic, most high-income countries implemented intermittent lockdowns or similar restrictive measures for over two years to slow the spread of the disease, while healthcare systems were overwhelmed and severely disrupted by the surge in patients requiring inpatient care. While high-income countries might currently be able to prevent infectious disease outbreaks following flooding disasters, this cannot be assumed to be the case for future scenarios.

Flooding events are expected to increase in frequency as well as intensity as the climate continues to change, and so exposure to infectious agents (including novel entities) can be expected to increase. Conversely, prolonged moments of drought are causing desertification of regions that were normally capable of absorbing water, resulting in increased runoff and subsequent increased risk of flooding. The rapid urbanisation happening in most countries also contributes to an increase in water runoff as there is less natural ground available for water to be absorbed. Together with observations such as the ageing and deterioration of infrastructure, specifically sewage infrastructure, it becomes clear that high-income countries might not be as prepared for future flooding disasters and their following infectious disease outbreaks (Sampson et al., 2018, Olds et al., 2018). This underscores the importance for all countries, whether low-, middle-, or high-income, to continually develop sustainable and effective disaster mitigation strategies.

Practical implications

The information from this review might contribute to the improvement of flood disaster response efforts and therefore contribute to the reduction of morbidity and mortality following natural disasters. Regardless of the type of flood or its location, several proactive measures related to the determinants indicated in this review can be implemented to mitigate associated infectious disease health risks. Active education of communities about flooding dangers, including potential health risks, is critical for raising awareness and encouraging preventive behaviours. This can be achieved through various channels, such as social media platforms, posters in flood-prone regions, and informal information sessions with locals. Ensuring the provision of clean drinking water and food is equally essential, particularly in areas where sewage infrastructure is prone to overflowing and contaminating water supplies. Examples of how this can be achieved are by providing bottled water or by increasing the chlorine levels in tap water (where available) for disinfection. Moreover, enhancing the readiness of the healthcare system for major disease outbreaks following a flood is vital. This can involve developing hygienic evacuation shelters with designated spaces for healthcare units or establishing facilities where specialized infectious disease units can be rapidly deployed, either within existing hospitals or in structurally resilient, accessible locations. These strategies form a robust foundation for managing health risks and preventing infectious disease outbreaks after flooding disasters.

Strengths and limitations

The current review has several strengths. It did not exclude papers based on study design, instead only requiring that they identified factors contributing to disease outbreaks or the absence thereof. Therefore, both quantitative and qualitative studies were included, ranging from interviews with affected communities and healthcare professionals to analyses of post-flood infection rates based on seroconversion and hospital data. This broad inclusion allowed the review to capture both detailed numerical trends and personal, context-specific insights. Such inclusivity is a strength of this review, as it provides a more comprehensive understanding of the diverse factors influencing disease dynamics in post-flood scenarios by incorporating insights from various viewpoints, angles, and stakeholders.

However, several limitations of this review need to be considered. The quantitative studies included utilized varying time frames to track infections following flooding events, with durations ranging from as short as 6 days to as long as a year. This variation is understandable, as different infectious diseases have differing incubation periods. However, studies with shorter tracking periods may have overlooked infections with longer incubation times that can still be traced back to the initial flood, while those with extended time frames could capture broader trends but risk overlooking acute, short-term factors. Additionally, the papers examined a variety of diseases with differing transmission pathways. As every disease has a different transmission pathway, different determinants might be highlighted as influential on the outbreak of the disease. These differences in study durations and investigated diseases posed challenges for comparing findings across the papers, highlighting a potential limitation in synthesizing the data and drawing uniform conclusions. Despite these limitations, the analysed papers revealed general trends that provide a basis for understanding which social determinants of health contribute to disease outbreaks. It would be valuable for future research to investigate the key determinants for each disease individually. This approach could enable researchers to link these disease specific determinants to diseases endemic to the region of the flood, thereby improving and tailoring strategies aimed at preventing disease outbreaks more effectively.

Conclusion

This systematic review investigated which social determinants of health have been observed to play a role in infectious disease outbreaks after flooding disasters. Living environment and structural (governmental) response to the flood emerged as major contributors to modifying the risk of outbreaks.

However, staying in evacuation shelters, education and gender were also identified as having some degree of influence. Understanding the factors that may affect the uprise of infectious diseases following flooding events is crucial to develop resilient and sustainable disaster mitigation strategies that will protect people from disease outbreaks post flooding, especially given the rising frequency and intensity of floods driven by climate change. Practical recommendations for an improved structural response are discussed to enhance flood disaster readiness, including community education, clean water provision, and healthcare system preparedness.

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Generative AI statement

During the creation of this systematic review, Generative AI (ChatGPT 4) was used in various stages. During the initial stages it was used to brainstorm for ideas, research set-ups and to optimize the PECO table once the topic of the review was decided. GenAI was asked for synonyms of terms included into the PECO to make sure no terms were forgotten to ensure as many relevant papers as possible were included by the search string. ChatGPT was not used during the data analysis section of the review, however, a program called Rayyan was used to deduplicate papers from the selected articles and to track the papers included and excluded from the initial and full-text screening. During the writing phase, GenAI was used to find synonyms for words and suggest alternative sentence structures, however no large parts were written by GenAI and altered sentences were always double checked for meaning and/or truthfulness to the source where the information was obtained from. Apart from that, GenAI was used throughout the process to look up words or terms that I did not know before. In case of scientific importance, a reference was asked that included a paper that discussed the term to gain a more complete understanding of the term.

Appendix 1

Search table:

PECO element	Population	Exposure	Comparator	Outcome
	Human population	Climate change-induced floods	Non flood affected	Infectious diseases
	Communities	Extreme weather events	Low flood impact areas	Waterborne diseases
	Flood-affected populations	Increased precipitation	Unaffected areas	Vetor-borne diseases
	People	Hurricane		Zoonotic diseases
	Flood-exposed communities	Sea level rise		Disease emergence
		Heavy rainfall		Disease outbreak
		Floods due to climate change		Communicable Diseases [Mesh]
		Flooding disasters		
		Tropical storm		
		Hydrological disaster		
		Meteorological disaster		
		Cyclone		
		Floods [Mesh]		

Search string:

("Floods"[Mesh] OR (flood*[tiab] AND (hydrological disaster*[tiab] OR meteorological disaster*[tiab] OR increased precipitation[tiab] OR hurricane*[tiab] OR cyclone*[tiab] OR typhoon*[tiab] OR tropical storm*[tiab] OR sea level rise[tiab]))) AND ("Communicable Diseases"[Mesh] OR infectious disease*[tiab] OR vector borne disease*[tiab] OR vector-borne disease*[tiab] OR water borne disease*[tiab] OR waterborne disease*[tiab] OR zoonotic disease*[tiab])

Appendix 2

Data extraction.xlsx