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A REVIEW ABOUT FLOOD PREPAREDNESS OF HEALTHCARE FACILITIES

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ABSTRACT

Hydrometeorological hazards, especially floods and cyclones, present considerable risks to public health, leading to fatalities, physical damage to healthcare facilities (HCFs), and major disruptions in healthcare delivery. This study undertook a systematic review of academic literature to explore both the direct and indirect effects of flooding on HCFs, along with the risk management approaches employed to mitigate these impacts. We conducted searches across four major databases (MEDLINE, Embase, Web of Science, and Scopus) for English-language publications, using keywords related to floods, cyclones, healthcare facility types, and disaster risk reduction. The review was conducted according to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines. We screened 7500 records, ultimately selecting 74 studies that met the inclusion criteria. Roughly 76% of the selected studies focused on cyclone-induced flooding and were mostly based in the United States. Hospitals emerged as the most frequently studied HCF type (n = 54), followed by long-term care facilities (n = 11). A prevalent issue reported was basement flooding, which affected critical systems such as equipment storage, medical supplies, and backup power. Disruptions to electricity and water services also posed severe operational challenges. While more than two-thirds of the studies referenced patient evacuation procedures, relatively few reported the use of structural mitigation strategies. Over one-third mentioned the presence of emergency preparedness plans. However, the review uncovered a lack of consistency in the preparedness levels among HCFs. To improve resilience, the main policy recommendation is to develop standardized guidelines and strengthen oversight of preparedness planning.

Keywords: flood; preparedness; healthcare; risk; management

1. Introduction

Flooding is one of the most damaging natural hazards in the world. When a flood happens, critical structures such as healthcare facilities (HCFs) are at risk of damage. As climate change intensifies flood risks, strengthening healthcare preparedness becomes increasingly critical. Globally, floods are among the most frequent and devastating natural hazards, often overwhelming health systems by damaging facilities, disrupting essential services, and limiting access to care. These impacts can be both direct (such as physical destruction of infrastructure) and indirect, including interruption of supply chains, displacement of populations, and particularly on healthcare facilities. The 2021 European floods in Germany, Belgium, and the Netherlands had a profound impact on healthcare systems. The European experience underscores the urgent need for resilient, adaptable healthcare systems in flood-prone regions worldwide.

This paper is part of a 5-year multi-sited, interdisciplinary project titled “Pandemic lessons for flood disaster preparedness” which includes literature reviews on: (i) the (in)direct impacts of floods on healthcare, (ii) disaster decision-making strategies and (iii) patient logistics during crises (Borst et al., 2025). The PDPC Programme presents a holistic and interdisciplinary framework for enhancing flood preparedness within healthcare systems. By bridging disciplines such as healthcare governance, disaster risk management, logistics, and hydraulic engineering, it offers a distinctive perspective on resilience. The use of a simulation game further

strengthens the study by facilitating practical application of the findings. Nonetheless, engagement with time-constrained professionals in healthcare and emergency response may be limited. Additionally, while representative organizations were consulted, the lack of direct involvement from the public and patients poses a constraint. The difficulty in securing real-time data from flood situations also presents the risk of recall bias, though this is addressed through data triangulation. Overall, the integration of recent flood data and emphasis on healthcare-specific crisis governance makes a significant contribution to advancing disaster preparedness.

This paper addresses (i) and (ii). This review is considering previous studies which investigated flood impact to healthcare facilities, alongside risk management strategies of prevention, preparedness and recovery plans. The aim of this study is to identify: (i) impact to HCFs from flood and cyclones events, as recorded; (ii) strategies (if any) implemented by HCFs to reduce flood risk; (iii) draw recommendations for decision-makers.

2. Method and data analysis

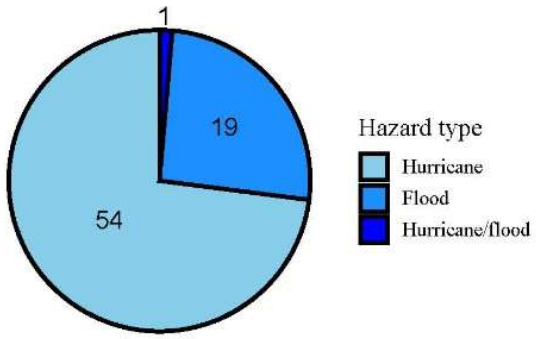
Four electronic databases were searched for this systematic review: MEDLINE ALL, Embase, Web of Science Core Collection and Scopus. The literature search was performed until Nov 20, 2023. The search terms were grouped into three categories: (i) flood and cyclone hazards; (ii) HCFs including hospitals, long-term care facilities, dialysis centers and pharmacies; (iii) disaster risk management. After removing duplicates, two authors independently screened the resulting records using Rayyan , i.e. a systematic review online platform (https://www.rayyan.ai/).

Inclusion criteria consisted in: presence of one of the hazards; description of their impacts primarily on HCFs; presence of disaster risk management strategies before, during or after the natural hazard. Exclusion criteria consisted in: focus on COVID-19 or other types of hazards (e.g. earthquake); focus on public health issues in general; focus on impacts on residents or medical staff; discussion on broader disaster risk management aspect; review articles; records that are neither articles nor in English. We collected data on: (i) the record (publication year, and country); (ii) the case study (hazard, HCF structure); (iii) reported impact (e.g. damages, victims, etc.); (iv) reported risk management strategies.

We used Microsoft Excel to tabulate and categorize the reports based on the above thematic categories and variables. Our search strategy, study selection and data analysis were conducted following the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) 2020 guidelines (Page et al. 2021). More than 7500 records were identified by the initial search, and after scrutiny 74 publications were retained. Presented results are from these 74 records.

3. Results and discussion

The analysis shows that most of the studies are USA-based and hospital-focused; also hurricanes are the dominating hazard (Figure 1). Two studies were published in the 1970s, whereas the rest were published after. The number of studies increased after 2005, i.e. the Atlantic hurricane season, which includes Hurricane Katrina in the USA.



(a)

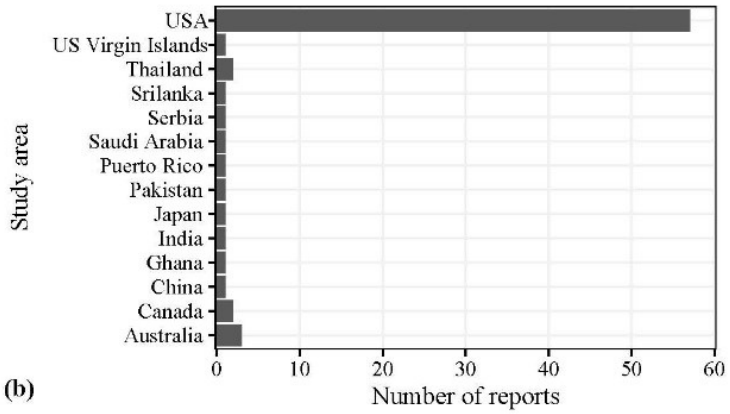


Fig. 1. Analysis of the selected studies according to: (a) hazard type, (b) country.

In terms of physical impact, several studies reported that hospital basements were flooded and caused major disruptions (e.g. Berte and Naraparedy 2018). Only a very few studies reported direct (wind) damages by hurricanes, e.g. roof damage to a dialysis center (Kleinpeter et al. 2009). Only a few studies explicitly mentioned patient death at hospitals (Gray and Hebert 2007; Taylor 2007).

In terms of utilities interruption, especially power outages posed a significant threat to the functioning of HCFs. For example, power outage due to Tropical Storm Allison in Memorial Hermann Hospital (Houston) interrupted vital functions such as electrical ventilators, laboratories and pharmacy (Nates 2004). In addition, lack of water can also severely challenge hospital services (e.g. Brevard et al. 2008).

In terms of other impacts, flooded streets around HCFs could obstruct transportation creating staff shortage, limiting supplies, accessibility and help to facilities (Sirbaugh et al. 2002; Stephens et al. 2019). Moreover, ambulances are forced to reroute. Financial loss related to revenue loss was another indirect impact of floods, due to the closure of facilities and related additional expenses. Such losses could reach tens of millions of US dollars (Verni 2012).

In terms of risk management, the main reported flood risk management strategies included patients evacuation (Jarrett et al. 2018), shelter in place (Campese 2000), permanent structural (e.g., watertight flood doors and elevating access roads; e.g. Stephens et al. 2019) or temporary measures (e.g., sandbags, placing movable items/equipment in higher floors; e.g. Jarrett et al. 2018). Disaster plans could also help the overall preparedness, when including evacuation plans (Jiang et al. 2018) or evacuation drills (Seale 2010).

4. Conclusion and future research

Recognizing the essential function of healthcare facilities (HCFs) during disasters and the growing threat floods pose globally, we carried out a systematic review to evaluate the effects of flooding on HCFs and the risk management strategies they employ. This review illustrated that healthcare facilities (HCFs) are hardly hit by floods, in terms of direct and indirect damages. Multiple strategies are available and known for risk management, however standard protocols are missing. It is essential that preparedness of HCFs is re-thought in a more systematic way, in order to facilitate a major shift towards flood disaster resilience.

Among the most commonly reported impacts was basement flooding, which led to damage of infrastructure, medical equipment, and building systems. Utility disruptions—especially to electricity and water—also significantly impaired healthcare delivery. While evacuation of patients emerged as the most frequent response, implementing it proved to be logistically complex. Few facilities reported using structural flood protection measures, whether temporary or permanent. Although many HCFs had preparedness plans, their content and application varied widely.

From these findings, we offer several directions for research and practice. On the research side, studies have mainly focused on hospitals, yet other healthcare providers—such as outpatient clinics and elderly care centers—are equally vital and vulnerable. Understanding their preparedness is necessary to reduce pressure on hospitals during disasters. There is also a pressing need to study HCF flood resilience in underrepresented, flood-prone regions including parts of Asia, Africa, South America, and Europe. Additionally, using flood scenario modeling can enhance preparedness by clarifying potential impacts and informing adaptation options. Including gray literature in future reviews would also broaden the evidence base.

For practice, the review highlights that flood preparedness in HCFs is complex and often inconsistent. Authorities should spearhead the creation of clear protocols and standards to help facilities evaluate flood risks and identify suitable mitigation strategies. HCFs need guidance on developing, maintaining, and testing standardized preparedness plans. Regular drills can ensure that staff and patients are familiar with emergency procedures. Coordinated large-scale exercises involving key emergency services would further enhance readiness. Lastly, building codes tailored to healthcare settings should promote climate-resilient design, including elevating critical infrastructure and installing flood-proof basements for non-essential functions.

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References

Berte E, Narapareddy V (2018) Building a culture of innovation in a health-care organization, Entrepreneurship Education and Pedagogy. 1(4), 330-48.

Borst RAJ, Abebe, YA, van Vuuren K, Magana J, de Graaff B, Hinrichs-Krapels S, Kolen B, Pregnolato M, Schreijer A, Comes T, Jonkman SN, Bal R (2025) Keeping healthcare afloat: a protocol for a 5-year multi-sited interdisciplinary research project into preparedness of healthcare for floods in the Netherlands. Health research policy and systems, *23*(1). 56. https://doi.org/10.1186/s12961-025-01338-4

Brevard SB, Weintraub SL, Aiken JB, Halton EB, Duchesne JC, McSwain Jr NE, Hunt JP, Marr AB (2008) Analysis of disaster response plans and the aftermath of Hurricane Katrina: lessons learned from a level I trauma center, Journal of Trauma and Acute Care Surgery. 65(5), 1126-32.

Campese C (2000) Preparation, experience, and aftermath of Hurricane Floyd. AORN journal. 72(1), 82-93.

Gray BH, Hebert K (2007) Hospitals in Hurricane Katrina: challenges facing custodial institutions in a disaster, Journal of Health Care for the Poor and Underserved. 18(2), 283-98.

Jarrett MP, Schwartz Z, Solazzo M, Tangney E (2018) Evacuate or shelter in place: A view from the water's edge, J Emerg Manag. 16(2), 95-106.

Jiang L, Tedeschi C, Subaiya S (2018) Cross-sectional survey of long-term care facilities in the Rockaway peninsula: preparedness and response during Hurricane Sandy, Disaster Medicine and Public Health Preparedness. 12(2), 194-200.

Kleinpeter MA (2009) Disaster preparedness of dialysis patients for Hurricanes Gustav and Ike 2008, In Advances in peritoneal dialysis. Conference on Peritoneal Dialysis, 25, 62-67.

Nates JL (2004) Combined external and internal hospital disaster: impact and response in a Houston trauma center intensive care unit, Critical care medicine. 32(3), 686-90.

Page MJ, McKenzie JE, Bossuyt PM, Boutron I, Hoffmann TC, Mulrow CD, Shamseer L, Tetzlaff JM, Akl EA, Brennan SE, Chou R (2021), The PRISMA 2020 statement: an updated guideline for reporting systematic reviews. BMJ, 372.

Seale GS (2010) Emergency preparedness as a continuous improvement cycle: perspectives from a postacute rehabilitation facility. Rehabilitation Psychology, 55(3), 247.

Sirbaugh PE, Bradley RN, Macias CG, Endom EE (2002) The Houston flood of 2001: the Texas Medical Center and lessons learned, Clinical Pediatric Emergency Medicine. 3(4), 275-83.

Stephens CT, Ortiz J, Pivalizza EG (2019) The Anesthesiologist's Response to Hurricane Natural Disaster Incidents: Hurricane Harvey, Anesthesiol Clin. 37(1), 151-160

Taylor IL (2007) Hurricane Katrina's impact on Tulane's teaching hospitals, Trans Am Clin Climatol Assoc,118, 69-78

Verni C (2012) A hospital system's response to a hurricane offers lessons, including the need for mandatory interfacility drills, Health Affairs, 31(8), 1814-21