Healthcare Facilities And Flood Risk Management: The July 2021 Flood In The Netherlands, Germany And Belgium

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ABSTRACT

Flooding is an escalating global challenge, causing loss of life and severe economic and infrastructure damage. Climate change is intensifying this risk by increasing the frequency and severity of extreme events such as heavy rainfall, flash floods, and storm surges. The July 2021 floods in the Netherlands, Germany, and Belgium were among the most devastating in recent European history, significantly affecting healthcare facilities (HCFs).

This study systematically reviews scientific literature on flood impacts on HCFs and related risk management measures. Following PRISMA guidelines, four databases (MEDLINE, Embase, Web of Science, and Scopus) were searched for English-language studies addressing flood and cyclone hazards, various HCF types, and disaster risk management strategies. From 7,500 initial records, 74 studies met the inclusion criteria. Most focused on cyclone-induced flooding in the United States, with hospitals as the primary facility type examined, followed by long-term care facilities. Basement flooding was identified as a critical vulnerability, as essential infrastructure (such as power systems, medical equipment, and supplies) is often located there. Disruptions to electricity and water services were also frequently reported, severely affecting healthcare delivery.

The study further analyses the impacts of the July 2021 floods on HCFs in the Netherlands–Germany–Belgium border region, examining risk management activities across preparedness, response, and recovery phases. Focusing on patient logistics and flood risk governance, the findings identify key impacts, response strategies, and governance approaches. Lessons learned aim to inform policy and strengthen flood preparedness and resilience in healthcare systems.

KEYWORDS: healthcare, hospital, flooding, preparedness, impact

1 INTRODUCTION

Floods are the most common natural hazard worldwide and pose severe risks to human health, infrastructure, and economic stability. In 2023 alone, 164 flood events were recorded globally, resulting in over 7,700 fatalities, affecting approximately 32 million people, and causing economic losses exceeding US$20 billion (CRED, 2003). Flooding has both direct health consequences, such as injuries, infectious disease outbreaks, and mental health impacts, and indirect effects including food insecurity and disrupted access to medical care due to damaged or inaccessible healthcare facilities (HCFs) (Bloomer et al., 2019).

The July 2021 floods in Western Europe were among the most extreme hydrometeorological events recorded, both in terms of rainfall intensity and impacts. Between 13 and 15 July, parts of Germany and Belgium experienced exceptional precipitation, exceeding 150 mm and 210 mm in 48 hours, which led to unprecedented water levels in the Rhine, Meuse, and their tributaries. Flood severity was intensified by emergency dam releases and debris blocking bridges, causing backwater effects. Downstream in the Netherlands, peak discharges along the Meuse reached record levels, with estimated return periods of up to 1 in 200 years on the main river and up to 1 in 1000 years on some tributaries (Dietze et al., 2022).

The floods caused widespread loss of life and severe socioeconomic damage. Germany recorded 190 fatalities and hundreds of serious injuries, while Belgium reported 39 deaths and extensive population impacts; no fatalities were reported in the Netherlands. Significant damage occurred across housing, agriculture, and critical infrastructure, including transport networks, utilities, and public services such as education and healthcare.

Beyond immediate casualties, the floods had substantial health impacts. Studies documented increased psychosocial distress, including anxiety and stress, in affected populations in both the Netherlands and Germany. Damage to and inaccessibility of healthcare facilities further worsened outcomes by disrupting routine care, contributing to more severe health conditions. These impacts highlight the vulnerability of healthcare infrastructure to extreme flooding and underline the importance of systematically documenting flood effects on healthcare facilities and associated disaster management responses.

Healthcare facilities are expected to remain operational during disasters to provide essential services such as emergency care, dialysis, laboratory services, and access to medicines (WHO, 2010). However, recent flood events have demonstrated that HCFs themselves can be highly vulnerable, as illustrated by the evacuation of a flooded hospital in the United States (Hammond et al., 2024). Ensuring continuity of care requires HCFs to reduce flood risk and recover rapidly through hazard and vulnerability assessments, preparedness planning, coordination with authorities and other facilities, and implementation of structural and non-structural risk reduction measures in line with safety guidelines and building standards (WHO, 2010).

Previous reviews have examined disaster impacts on healthcare systems across multiple hazards, with a strong focus on hospitals (Waddell et al., 2021). While all-hazard approaches to risk management are widely recommended (WHO, 2015), the increasing frequency of floods and their specific operational challenges justify a focused examination of flood-related impacts on HCFs. Moreover, non-hospital facilities such as nursing homes and outpatient centres also play a critical role during emergencies and warrant greater attention.

This systematic review therefore aims to synthesise existing evidence on the impacts of flooding on healthcare facilities and the strategies adopted to manage flood risk. The article also analyses the effects of the floods on healthcare facilities in the Netherlands, Germany and Belgium, with a particular focus on the disaster management measures adopted, especially evacuation practices.

2 METHODS

This systematic review was conducted using four major electronic databases: MEDLINE ALL, Embase, Web of Science Core Collection, and Scopus (Abebe et al., 2025). The search strategy was developed in collaboration with a biomedical information specialist and executed on 20 November 2023, covering all records available up to that date. Search terms were organised into three thematic groups addressing: *(i)* flood-related hazards, *(ii)* HCFs, including hospitals, long-term care facilities, dialysis centres, and pharmacies, and *(iii)* disaster risk management across all phases. These groups were combined using Boolean operators to ensure comprehensive coverage. Only English-language journal articles were included, and non-relevant document types such as reviews, book chapters, and data papers were excluded.

Following duplicate removal, study screening was conducted independently by two reviewers using the Rayyan platform, with disagreements resolved through discussion. Eligibility criteria required studies to address flood or cyclone hazards affecting healthcare facilities and to report disaster risk management measures implemented before, during, or after events. Records focusing on other hazards, public health outcomes, staff or patient perspectives alone, governance issues, modelling studies, animal research, or lacking abstracts were excluded. Full-text screening further removed studies that did not provide sufficient detail on flood impacts or risk management practices, or that focused on non-hydrometeorological flooding.

Data extraction was undertaken for all eligible studies, capturing information on publication characteristics, hazard type, healthcare facility type, reported impacts (including physical damage, service disruption, and financial losses), and flood risk management strategies such as evacuation, structural and non-structural measures, preparedness planning, and insurance. Data were tabulated and analysed using descriptive statistics where possible, with narrative synthesis applied otherwise. The entire review process followed the PRISMA 2020 guidelines to ensure transparency and methodological rigour (Page et al., 2021). Our assessment of how the 2021 floods affected health system governance in the three countries mainly draws from grey literature sources.

3 RESULTS

The literature search across four databases yielded 7,500 records, which were reduced to 3,719 after removing duplicates. Following screening and eligibility checks, 74 studies were included in the review. Of these, 51 were case reports on HCFs, while 23 used qualitative, quantitative, or mixed methods involving a broader range of HCFs, such as 217 long-term care facilities (LTCFs) and 64 hospitals with 186 healthcare centers (Castro et al., 2008). Most studies focused on cyclone-related floods (n = 56), particularly hurricanes like Katrina (n = 13), Sandy (n = 9), and Rita (n = 7), with some comparing multiple events (Espiritu et al., 2014). Other studies examined riverine, pluvial, or unspecified floods. Geographically, the majority were conducted in the United States (n = 57), with limited representation from Australia, Canada, Thailand, and other countries. Hospitals were the most studied HCFs (n = 54), followed by LTCFs (n = 11), with a few studies covering pharmacies, dialysis centers, primary health centers, and post-acute rehabilitation facilities.

Floods directly damaged HCFs, particularly basements housing vital services such as laboratories, morgues, and electrical systems. Above-ground floors, parking areas, and equipment rooms were also affected (Khan et al., 2018). Flooding led to patient deaths in a few instances, notably 72 hospital patients during Hurricane Katrina (Gray et al., 2007) and 35 LTCF residents (Stall, 2010), along with physical injuries and mental distress (Claver et al., 2013). Floods caused interruptions to utilities: power outages affected medical equipment, elevators, air conditioning, and refrigeration, directly influencing evacuation and reopening decisions. Water supply disruptions compromised hygiene, surgeries, and overall care, while telecommunication failures hindered coordination (Irvin-Barnwell et al., 2020). Fig. 1 offers a visual summary.

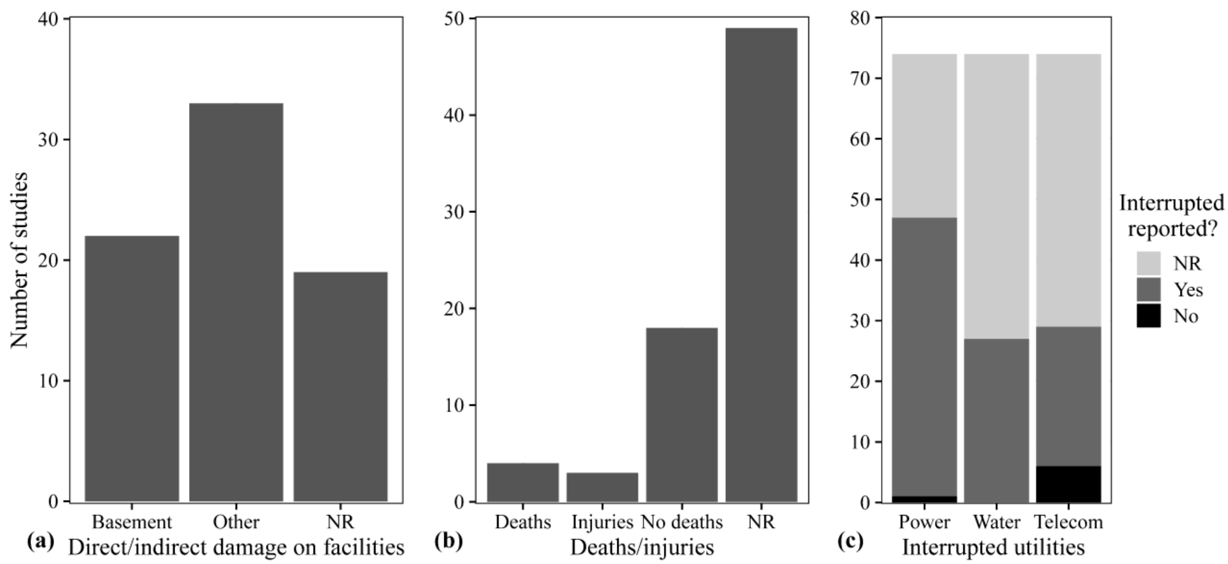

Figure 1: Result from the literature review about flood impact on HFCs: (a) direct/indirect damage on facilities; (b) people deaths/injuries; (c) interrupted utilities

Healthcare services were significantly disrupted. Hospitals and other HCFs often canceled surgeries, discharged patients, or temporarily closed for days to months, with some facilities permanently ceasing operations (Irvin-Barnwell et al., 2020). Additional impacts included blocked access due to flooded streets, staff shortages, logistical difficulties, and substantial financial losses from closures, evacuations, and repair costs (Castro et al., 2008).

Flood risk management strategies were classified into evacuation, shelter in place, structural and temporary measures, and preparedness plans with insurance. Approximately two-thirds of studies reported patient evacuations, which could occur before or after flooding. Evacuation decisions varied based on patient severity, available transport, and receiving facilities, with ambulances, buses, helicopters, boats, and even military vehicles employed (Espiritu et al., 2014). Challenges included road congestion, delayed transportation, medical record management, equipment relocation, and communication with families (Espiritu et al., 2014).

Sheltering in place was less common but practiced in some hospitals and LTCFs, sometimes due to mandatory government orders or risk assessments of evacuation hazards (Jarrett et al., 2018). Structural flood mitigation measures were implemented in a few facilities, notably at the Texas Medical Center, including floodwalls, watertight doors, elevated utilities, improved drainage, and relocation of critical equipment (Brands et al., 2013). Temporary measures included sandbags, pumping water, relocating equipment to higher floors, sealing pharmacies, and storing data off-site. The integration of structural, temporary, and procedural strategies highlights the importance of multi-layered flood risk management in HCFs.

3.1 The 2021 flood in Netherlands, Belgium and Germany

The July 2021 floods demonstrated that healthcare facilities across the Netherlands, Germany, and Belgium remain highly vulnerable to flooding, particularly due to critical functions located in basements, limited structural flood protection, and cascading disruptions to utilities and access. The events underscore the urgent need for flood-resilient design, coordinated emergency planning, and long-term adaptation strategies tailored to different types of healthcare facilities (Table 1).

In the Netherlands, the July 2021 floods primarily affected HCFs in Limburg, particularly in and around Valkenburg along the River Geul. Long-term care and residential facilities were the most severely impacted. Several Sevagram-managed facilities experienced direct inundation, with flood depths reaching up to 80 cm. Valkenheim nursing home suffered irreparable damage and was ultimately demolished, while the Geerlings hospice and Oosterbeemd nursing home required extensive repairs, leading to long service interruptions. The total damage across these facilities exceeded €40 million. Other facilities, such as the Adelante child and youth rehabilitation center and the Rothemermolen residential care complex, also experienced flooding, mainly affecting basements and technical installations, resulting in prolonged closures.

Major hospitals in the Netherlands largely avoided direct flood damage but implemented precautionary evacuations due to forecasted risks. VieCuri Medical Center and Maastricht University Medical Center (UMC+) were protected by dikes and emergency measures, including sandbags, temporary flood defenses, and power shutdowns. Although these hospitals were not flooded, hundreds of patients were evacuated as a preventive measure, highlighting the vulnerability of critical hospital functions located in basements and the reliance on accurate flood forecasting and emergency preparedness.

Germany experienced the most severe impacts among the three countries, particularly in North Rhine-Westphalia (NRW) and Rhineland-Palatinate (RLP). Numerous hospitals were directly flooded, leading to catastrophic damage to buildings, technical infrastructure, and high-value medical equipment. Basements housing emergency generators, laboratories, imaging equipment, pharmacies, and IT systems proved especially vulnerable. Facilities such as Leverkusen Hospital, St. Antonius Hospital in Eschweiler, and Marien-Hospital in Erftstadt suffered damages ranging from tens to over one hundred million euros. Several hospitals required years to resume normal operations, and at least one hospital (Klinikum Mutterhaus der Borromäerinnen in Trier-Ehrang) was permanently closed due to reconstruction costs and time constraints. Beyond hospitals, a wide range of other HCFs were affected, including rehabilitation clinics, radiology practices, nursing homes, and facilities for people with disabilities. Nursing homes faced particularly severe consequences, including prolonged closures and, in the case of the Lebenshilfehaus in Sinzig, tragic loss of life. Many facilities required complete reconstruction, often taking more than two years. The floods exposed systemic vulnerabilities related to the placement of critical systems in basements, dependency on digital patient data, and limited flood-proofing of healthcare infrastructure.

In Belgium, the floods had a major impact across Wallonia, disrupting hospitals, nursing homes, and pharmacies. Several hospital sites activated emergency plans, suspended non-essential services, and cancelled COVID-19 vaccinations. At CHR de Huy, flooding of underground levels disabled critical electrical infrastructure, while multiple sites of CHU de Liège were either flooded or rendered inaccessible due to damaged bridges and roads. Some facilities, such as the Chaudfontaine polyclinic, were heavily damaged and permanently closed, while others experienced temporary service interruptions and patient evacuations. Long-term care facilities were also significantly affected. Residence Wégimont required the evacuation of 70 residents and underwent a complete redevelopment lasting three years. Pharmacies were particularly vulnerable, with widespread damage across multiple municipalities. In some cases, relatively shallow flooding caused long-term closures due to contamination from flooded hydrocarbon storage. Overall, the Belgian case highlights how indirect impacts (such as inaccessibility, supply chain disruption, and contamination) can severely impair healthcare delivery even when buildings are not structurally destroyed.

Table 1: Comparison of the three countries: the Netherlands, Germany and Belgium.

	no. HFCs	**tot patients (across all HFCs)**	**no. evacuated HFCs**
the Netherlands	18	439	17
Germany	16	1908	14
Belgium	12	N/A	2

4 DISCUSSION AND FUTURE RESEARCH

This review highlights clear geographic and thematic imbalances in the literature on flood impacts and preparedness of HCFs. More than three quarters of the reviewed studies were conducted in the United States, a pattern consistent with earlier disaster health reviews (Sweileh, 2019). In contrast, regions that experience frequent and severe flooding (such as parts of Asia including China, India, the Philippines and Indonesia) remain underrepresented, despite their high exposure to flood risk. Expanding research beyond the US context is therefore essential to capture a wider range of experiences and lessons. The literature also focuses predominantly on hospitals, while other critical facilities, particularly LTCFs, receive far less attention, despite serving highly vulnerable populations (McCann, 2011).

Evacuation emerged as the most frequently reported flood risk management strategy, mentioned in around two thirds of studies. However, the review shows that evacuation is complex and highly variable, involving difficult decisions about timing, prioritisation of patients, transport, destinations and return procedures. Practices differ even between facilities exposed to the same flood event, echoing earlier findings on the lack of consistency in hospital evacuation planning (Khorram-Manesh et al., 2002). Similar variability was observed in decisions to shelter in place. These inconsistencies point to the need for clearer regional or national guidance on evacuation and sheltering, such as state-level frameworks already developed in some contexts (HSPH, 2014). Effective coordination with other HCFs, emergency services and authorities (through mechanisms such as healthcare coalitions) is also critical to support evacuation and traffic management during emergencies (ASPR, 2016).

Preparedness planning showed comparable shortcomings. Although many HCFs reported having disaster plans, their scope, quality and implementation varied widely. Plans are most effective when they go beyond regulatory compliance and are regularly exercised through drills and staff training (Richter, 1997). Standardised emergency management requirements, such as those set by The Joint Commission in the United States (The Joint Commission, 2021), can support more consistent preparedness, but plans must be actively used and periodically updated to reflect lessons learned from past floods (Zork, 2014).

The review also identified recurring failures in critical infrastructure. While most facilities experiencing power outages had backup generators, these often malfunctioned due to flooding of basements or fuel shortages. Locating generators above flood levels and ensuring adequate fuel supplies are therefore key resilience measures (Toner et al., 2017). Water supply strategies were similarly diverse, ranging from bottled water to storage tanks and wells, reinforcing the need for advance planning rather than ad hoc responses (van der Heijden et al., 2022). Permanent structural flood protection measures were rarely reported, largely due to cost barriers, particularly for smaller hospitals (Hines and Reid, 2023), underscoring the value of international guidance on assessing and addressing structural vulnerabilities, such as the WHO safe hospital framework (WHO, 2010).

5 CONCLUSION

Given the essential function of healthcare facilities (HCFs) during emergencies and the increasing frequency of flood events, this systematic review examined how floods affect HCFs and the measures adopted to manage flood risk. The findings show that flooding of basements is among the most damaging impacts, often leading to direct harm to buildings, medical equipment, and critical infrastructure. Disruptions to essential utilities (particularly electricity and water) were also common and had serious consequences for the continuity of healthcare services. Patient evacuation emerged as the most frequently reported response strategy, despite the significant logistical and clinical challenges it presents. In contrast, relatively few facilities reported the use of permanent or temporary structural flood protection measures. Although many HCFs had disaster preparedness plans, their scope, quality, and level of implementation varied considerably.

The review highlights several priorities for future research and practice. From a research perspective, existing studies predominantly focus on hospitals, while non-hospital facilities (such as outpatient centres, nursing homes, and long-term care facilities) remain underexplored, despite their critical role during emergencies. Disruptions to these facilities can increase pressure on hospitals, underscoring the need for more comprehensive investigation. Further research is also required in flood-prone and underrepresented regions, including parts of Asia, Africa, South America, and Europe. Scenario-based studies could support awareness-raising and help evaluate the effectiveness of adaptation measures. In addition, incorporating grey literature in future reviews would provide a more complete picture of flood impacts and preparedness.

From a practical standpoint, the findings indicate that flood preparedness is complex and unevenly implemented across HCFs. Public authorities should take a leading role in developing standards and guidance to support flood risk assessment and preparedness planning. Healthcare facilities would benefit from clearer direction on maintaining, updating, and rehearsing preparedness plans to ensure staff and patients are familiar with procedures. Coordinated emergency exercises involving multiple HCFs and response agencies are also essential. Finally, flood-resilient building codes should be promoted, including requirements for elevating critical systems and equipment, and ensuring that any necessary basements are flood-resistant and limited to non-essential uses.

The findings of this study strongly reflect the vulnerabilities observed during the July 2021 floods in the Netherlands, Germany, and Belgium. As illustrated in the cross-border cases, critical functions located in basements, limited structural protection, and cascading disruptions to utilities and accessibility significantly amplified impacts on healthcare facilities. These lessons reinforce the need for flood-resilient design, strategic relocation of essential infrastructure, and coordinated governance approaches to strengthen the long-term resilience of healthcare systems.

6 ACKNOWLEDGEMENTS

This work was carried out within the Frontrunner 3 project “Pandemic lessons for flood disaster preparedness,” and funded by the Pandemic and Disaster Preparedness Center (PDPC) [grant number 2022.003]. The authors thank Wichor Bramer for developing and updating the search strategies. The authors also thank the other PDPC Frontrunner 3 project members for their valuable feedback during the literature search and selection process. This work is partly published in Abebe et al. (2025).

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