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**Title:** A Systematic Review of an Integrated Framework for Hospital Preparedness and Operational Continuity during Storms

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## Abstract

**Background:** Storm events are now occurring with increased frequency and intensity as a consequence of climate change, creating unprecedented challenges for hospitals to maintain continuous operations. While existing research has identified critical factors for hospital resilience, a comprehensive understanding of how these factors interact within a hierarchical framework remains limited. This systematic review attempts to compile the evidence on hospital preparedness for storms and propose a novel conceptual model that prioritizes these critical factors.

**Material and Methods:** A systematic search was carried out following PRISMA 2020 guidelines across six databases (PubMed/MEDLINE, Web of Science, Cochrane, Scopus, Science Direct, ProQuest) and the Google Scholar search engine for publications between January 2000 and August 2025. A total of 32 studies out of the initial 6,115 records met the eligibility criteria after undergoing screening and full-text review. Thematic synthesis served as the analytical method for the extracted data.

**Results:** Analysis revealed five critical domains, with Leadership, Governance & Policy emerging as the foundational enabler for all other components. Our proposed "Enabling Foundation" model demonstrates that Infrastructure & Planning, Human Resource Management, Coordination & Communication, and Resource Management & Logistics all depend on this foundational layer. Supported by 28 of 32 studies, this hierarchy explains why hospitals with similar resources show divergent storm outcomes and demonstrates that technical investments only achieve maximum impact within strong governance frameworks.

**Conclusion:** The "Enabling Foundation" model represents a paradigm shift from checklist-based preparedness to a hierarchical understanding of hospital resilience. This framework provides policymakers and healthcare administrators with evidence-based guidance for prioritizing investments and developing strategies that enhance hospital readiness for future storm events, ultimately supporting the transformation of healthcare facilities into resilient institutions capable of maintaining continuous care during disasters.

**Key words:** Hospital; preparedness; Storms; Systematic review

## Introduction

Among various climate-related hazards, storms including hurricanes, cyclones, and typhoons are particularly destructive, posing severe challenges to healthcare systems worldwide. These events cause immediate physical damage and trigger cascading failures in hospital operations, from power outages and flooding to communication breakdowns and supply chain disruptions (1). With climate projections indicating increased storm frequency and intensity, strengthening hospital resilience has become critically urgent (2).

Research consistently shows that regions with well-prepared healthcare systems experience significantly lower storm-related mortality rates (3). Despite growing awareness, however, hospitals continue to face operational collapse during major events. This was starkly demonstrated during Hurricane Katrina, when over 40 facilities in New Orleans alone were forced to close (4). Such recurrent failures point to a persistent gap in prevailing preparedness models.

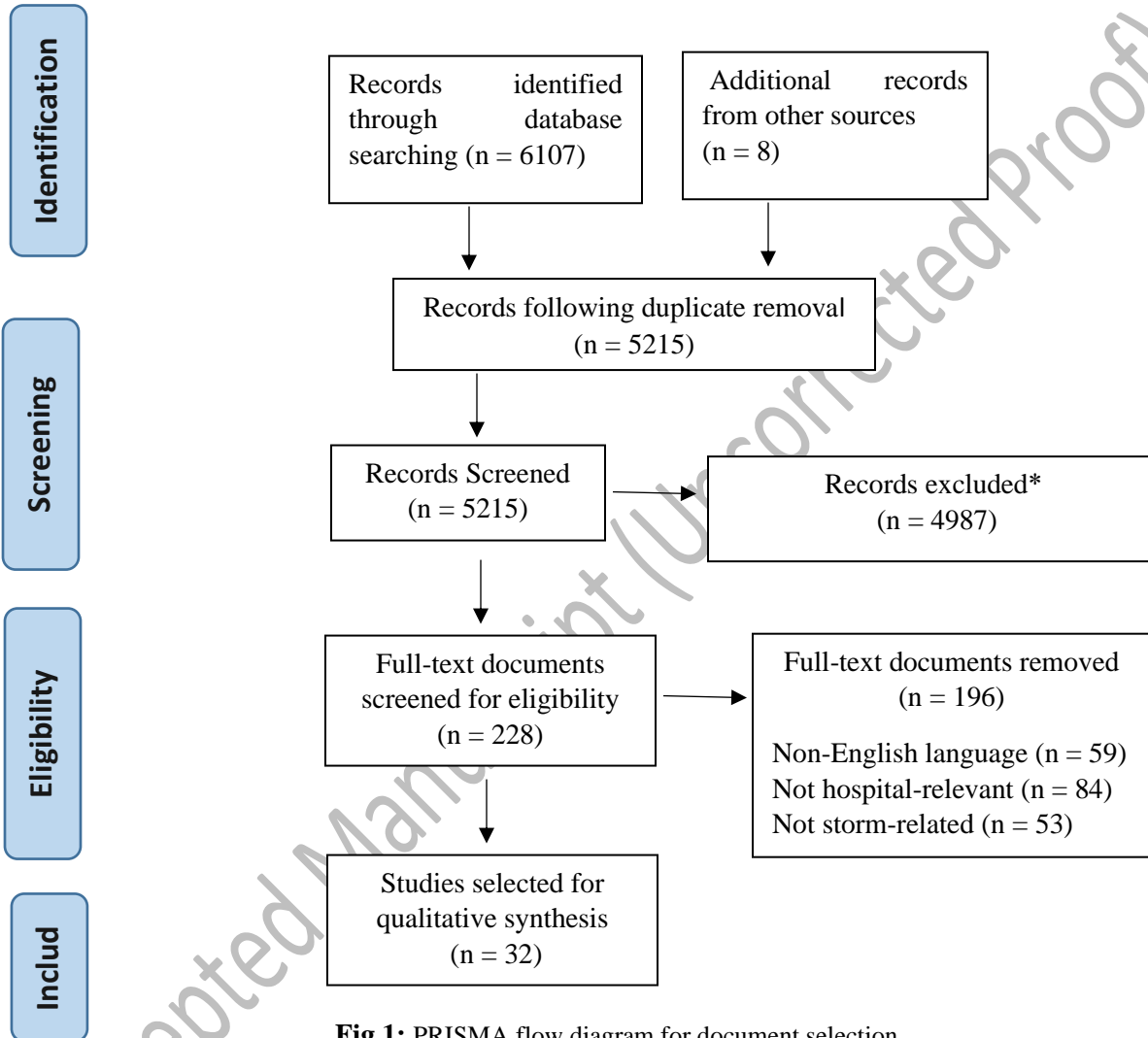
Existing frameworks, such as the WHO Hospital Safety Index and various disaster resilience guides, have been instrumental in outlining key components of preparedness from infrastructure hardening and staff training to resource stockpiling and communication planning (5,6). Yet these approaches often treat resilience domains as parallel checklists. They do not clarify the hierarchical relationships between domains, nor do they explain why hospitals with comparable resources show dramatically different outcomes during crises (3). This inability to distinguish between well-equipped hospitals that succeed and those that fail indicates a missing theoretical link in understanding the mechanics of resilience.

To address this gap identified in the literature where frameworks often treat components as parallel checklists without clarifying their functional hierarchy (5, 6) our study was designed to investigate the inherent interdependence of resilience domains. We hypothesize that the factors determining hospital storm resilience are not equally weighted but exist in a layered structure, where certain foundational domains enable and sustain the effectiveness of others (3). This is suggested by repeated evidence of well-equipped hospitals failing during events like Hurricane Katrina (4), and by studies showing that technical measures such as backup power systems (6), staff training protocols (7), and communication plans (8,9) often underperform without specific enabling conditions.

In summary, while traditional hospital storm preparedness has focused on discrete components like infrastructure and staffing (1,4,10-13), evidence shows that robust infrastructure alone often fails under inadequate governance. This reveals a critical theoretical gap: understanding the hierarchical relationships between resilience factors is essential for developing targeted and effective strategies. Accordingly, this systematic review aims to pinpoint the key factors, analyze, and map the hierarchical structure of relationships between the key factors determining hospital resilience to storms. By synthesizing existing evidence, we aim to propose a conceptual framework that clarifies the prioritization and interdependence of these factors.

## Methods

This study performed a systematic review to identify and analyze published literature including articles, reports, and guidelines on hospital storms preparedness. We performed a PRISMA-guided systematic review to identify articles and documents focused on hospital preparedness for storms(14) (Fig1).



\* **Note:** Primary reasons for exclusion at title/abstract stage: Not hospital-focused (n=2,850), Not storm-related (n=1,400), Not addressing preparedness/resilience (n=550), Non-research article (n=119), Full-text inaccessible (n=68).

### Search strategies

We worked with a medical information specialist to develop a search strategy that was both comprehensive and precise. Electronic databases (PubMed/MEDLINE, Scopus, Web of Science, Cochrane Library, Science Direct, ProQuest), together with Google Scholar and focused grey

literature sources, were systematically searched. Database-specific search strings incorporated key concepts such as "hospital", "resilien", "preparedness", "storm", and "hurricane" (see Supplementary File 1 for complete search strategies). We included only English-language studies published from January 1, 2000, through August 31, 2025.

### **Study Selection**

The selection process involved three stages. After deduplication, two reviewers independently screened titles and abstracts. Potentially eligible studies then underwent independent full-text review by both reviewers. Disagreements were resolved through discussion. We also manually examined the reference lists of the included studies to find any further relevant research.

### **Inclusion Criteria:**

This systematic review included peer-reviewed primary research studies (e.g., case studies, cross-sectional surveys, cohort analyses) that quantitatively, qualitatively, or via mixed methods evaluated the effectiveness, implementation, or identifiable factors of hospital preparedness, resilience, or response protocols specifically for storms (hurricanes, cyclones, typhoons). Studies were required to be published in English between January 2000 and August 2025, with accessible full text.

### **Exclusion Criteria (Applied during full-text screening):**

Studies were excluded if they primarily focused on other disasters such as earthquakes, pandemics, or conflicts without storm-specific analysis; addressed only pre-hospital or community-level preparedness without hospital-specific components; consisted of editorials, opinion pieces, or abstracts lacking full methodological documentation.

**Data Extraction:** Data were extracted using a form that captured the following: first author's name, year of publication, title, study design, study aim, main findings and study location (Table 1).

### **Quality Assessment and Risk of Bias**

To assess the quality of the retrieved articles, the Critical Appraisal Skills Programme (CASP) tools and the STROBE (Strengthening the Reporting of Observational Studies in Epidemiology) checklists were utilized(15,16). Two authors independently assessed bias risk; disagreements were resolved by discussion or a third reviewer.

### **Data Synthesis and Analysis**

A thematic synthesis was conducted independently by two authors through a three-stage process: coding text extracts, grouping codes into thematic categories, and abstracting the data into concise statements. Data extraction was done by one author and verified by two others for accuracy. The review was not prospectively registered.

**Table 1:** Characteristics of the included studies

Author/year of publication	Title	Study aims	Main findings	Study design/method	Study Location
Ting-I Lai et al (2003)	Strategies of Disaster Response in the Health Care System for Tropical Cyclones: Experience Following Typhoon Nari in Taipei City	Highlight the devastating toll and specific vulnerabilities experienced by a city's healthcare system when struck by a typhoon	Relocation of Essential Equipment Above Grade , Essential medical equipment, electrical rooms, transformers, and emergency generators should be relocated from basements to above-grade levels, structural integrity against winds, Communication Disruptions, making proper design disaster management plans, Hazard Assessment: Before building a hospital	Case study	Taiwan
Aucoin et al (2005)	Hurricane Katrina – one hospital's experience	To describe Regional Medical Center's experience and preparation before, during, and after Hurricane Katrina	Proactive planning, effective internal management, and resilient communication systems to maintain patient care during large-scale disasters	Case study	USA
Rodríguez et al (2006)	Hurricane Katrina and the Healthcare Infrastructure: A Focus on Disaster Preparedness, Response, and Resiliency	To analyze Hurricane Katrina's impact on healthcare infrastructure	Comprehensive planning and resource allocation, rather than relying solely on traditional disaster preparedness models	Qualitative Study	USA
Brian et al (2006)	Practicing neonatology in a blackout: the University Hospital NICU in the midst of Hurricane Katrina: caring for children without power or water	Provide a descriptive account of the challenges and experiences faced by the University Hospital Neonatal Intensive Care Unit staff during Hurricane Katrina	Power Failure and Reliance on Generators, Water and Sanitation Issues, Communication Breakdown, -Challenges in Patient Care and Evacuation: Difficult Patient Triage and Transfer, Improvisation and Resource Scarcity, Failed Evacuation Attempts, Staff Preparedness and Coping, Shift in Patient Care Focus, Long-term Hospital Closure	Case study	USA
Ginsberg et al (2006)	Sweating it out in a level III regional NICU: disaster	Share insights gained from managing a Level III Regional Neonatal	○ Infrastructure failures, communication breakdown, Security and staffing issues. Relied on pre-existing emergency plans and drills.	Case study	USA

	preparation and lessons learned at the Ochsner Foundation Hospital	Intensive Care Unit during Hurricane Katrina.	Effective resource management. Harden infrastructure. Create more robust communication systems. Enhance security and establish a dedicated command center		
Pierce et al (2007)	Medical Response to Hurricanes Katrina and Rita: Local Public Health Preparedness in Action	Practical implementation and adjustment of emergency operations plans in Hurricanes Katrina and Rita	<ul style="list-style-type: none"> <li>The utility of accurate databases, necessity of a medical presence, optimizing clinic flow, the importance of pre-training healthcare workers, the role of local government, communication strategies, and maintaining volunteer morale</li> </ul>	Case study	USA
Banks et al (2007)	Effective healthcare system response to consecutive Florida hurricanes	Characterizing systemic response, evaluating HR preparedness, analyzing emergency operations, assessing interagency coordination, and formulating evidence-based recommendations.	Prior Planning, Staff Commitment, concerns for family and pet safety, damaged personal property, and ineffective communication systems, pre-established EOP was effectively utilized to manage staffing, operations, and external resources	Case study	USA
Gray et al (2007)	Hospitals in Hurricane Katrina: Challenges Facing Custodial Institutions in a Disaster	Lessons Learned	<ul style="list-style-type: none"> <li>Advance Evacuation, Infrastructure Vulnerability, Evacuation Logistics, Coordination, Security and Influx of People, Prioritization</li> </ul>	Case study	USA
Sidney et al (2008)	Analysis of Disaster Response Plans and the Aftermath of Hurricane Katrina: Lessons Learned from a Level I Trauma Center	Compare disaster preparedness of a Level I Trauma Center with performance in an actual disaster	Vital support areas were water, food, sanitation, communication, and power	Case study	USA
Powell et al (2012)	Emergency Preparedness and Public Health the Lessons of	To analyze the public health challenges and lessons learned	Lack of Approaches for Evacuation, deployment of disaster medical personnel, resistant backup power,	Case study	USA

	Hurricane Sandy	from Hurricane Sandy	disaster exercises, Communication Breakdown		
Gibbs et al (2013)	A Holistic Approach to Ensuring that Hospitals Function to Maximum Efficiency Following Severe Hurricanes in the Caribbean	A complete system for keeping Caribbean hospitals fully operational after intense hurricanes	Professional education, robust building codes, independent design oversight, vulnerability-led retrofitting, and ongoing maintenance programs.	Case Study	USA
Brands et al (2013)	Complete Self-Sufficiency Planning: Designing and Building Disaster-Ready Hospitals	To examine the methods used and the results obtained from building a new, independent, critical access children's hospital in Florida	Lack of Coordination, Emergency planning, evacuation training, failed of powers, inadequate preparedness, inadequate of medical equipment	Case study	USA
Downey et al (2013)	External Factors Impacting Hospital Evacuations Caused by Hurricane Rita: The Role of Situational Awareness	To investigate the external factors that impacted hospital evacuations during Hurricane Rita.	Inadequate external awareness of community resources and activities impeded evacuation decisions. Lack of ambulances and helicopters was the primary external constraint. Prolonged Timelines. Poor Coordination. Ineffective Tracking.	Observational	USA
Van Minh et al (2014)	Primary healthcare system capacities for responding to storm and flood-related health problems: a case study from a rural district in central Vietnam	To evaluate how well the primary healthcare system in a rural district of central Vietnam can handle such health problems	Lack of Clear Roles and Coordination, Emergency treatment protocols, Policy Gaps, lacked specific job descriptions, Governance and Policy Weaknesses, Limited Budget, Specialist Gaps, Inadequate Training, Data Scarcity, Lack of Emergency treatment protocols, Medicine and Equipment,	Cross-sectional	Vietnam
Tanya et al (2017)	The Medical, Public Health, and Emergency Response to the Impact of 2017 Hurricane Irma in Cuba	To highlight the defining attributes of Cuba's hurricane response, particularly in the context of Hurricane Irma	Disaster Planning, Integration of Healthcare and Public Health Professionals, Rapid Power Restoration	Case study	Cuba

Lynn Jiang et al (2017)	Cross-sectional Survey of Long-Term Care Facilities in the Rockaway Peninsula: Preparedness and Response During Hurricane Sandy	To examine the preparedness and experiences of long-term care facilities during and after Hurricane Sandy	Lost electricity, heat, and telephone service, and one-half had evacuated	Cross-sectional	USA
Labarda et al (2017)	Hospital resilience in the aftermath of Typhoon Haiyan in the Philippines	The impact of Typhoon Haiyan on health service delivery	Public and private hospitals share disaster health responsibilities, flexibility is essential in preparedness, resilience is an evolving process, chaos stems from uncoordinated efforts, and disaster preparedness should be integrated into daily hospital operations	Case study	Philippines
Seltenrich et al (2018)	Safe from the Storm: Creating Climate-Resilient Health Care Facilities	To address a critical gap in preparedness for extreme weather events and climate change impacts on health care facilities	Inadequate Preparedness of Healthcare Infrastructure, need for predictive climate models, need for smarter design and construction practices	Case study	USA
Son et al (2018)	Opportunities and Challenges for Resilient Hospital Incident Management: Case Study of a Hospital's Response to Hurricane Harvey	+	Power loss and lack of hospital-wide notification systems Staff fatigue and anxiety, Insufficient leadership and community coordination, Human and physical resource management, Flexible utilization of physical space Backup supplies, Relocating critical equipment from basements, Regular drills Hospital incident command center establishment	Qualitative study	USA
Rodríguez et al (2018)	Emergency Preparedness and Hurricane Maria: The Experience of a Regional Academic Medical Center in	Impact on Healthcare Services, Recognition of Medical Staff Efforts Preparedness Strategies Post-Hurricane Response Actions	Highlighting medicine's humanistic side, Leadership and emergency preparedness.	Case study	USA

	Southwest Puerto Rico				
Ginzburg et al (2018)	Hurricane Irma: Lessons learned from a South Florida Gateway Level II trauma center and public health trust system	Lessons Learned	Effective hurricane preparedness for healthcare systems necessitates coordinated efforts among community leaders, hospital administrators, healthcare providers, and support staff, focusing on robust infrastructure and inter-organizational cooperation	Case study	USA
Allahbakhshi et al (2019)	Preparedness challenges of the Iranian health system for dust and sand storms: A qualitative study	To address the current knowledge gap and gain insight into the health system's preparedness difficulties when responding to DSS	Inadequate Understanding of Risk, Insufficient Preparedness, Limited Education and Training, Absence of Guidelines and Protocols, Weak Policymaking and Planning, Poor Collaboration and Communication, Resource Shortages such as staff, Stuff, Spaces, drugs and medical equipment's, Inadequate Prediction and Early Warning, Insufficient Drills and Exercises	Qualitative study	Iran
Ybarra et al (2019)	Hurricane Harvey One Hospital's Journey Toward Organizational Resilience	To document the hospital's journey toward organizational resilience and identify key transferable lessons for future disaster management.	Challenges in Staff Well-being, Adaptability, Key Leadership Behaviors, Empowering team members, emergency preparedness planning, lack of food choices and designated sleeping areas for contract employees, Importance of Psychological Support	Case study	USA
Newman et al (2019)	Hurricane Harvey: Firsthand Perspectives for Disaster Preparedness in Graduate Medical Education	Lessons Learned	Adequate staffing, Adequate resources, Optimal team structure, Effective communication, Safe evacuation, Thorough planning	Case study	USA

Hillier et al (2019)	Disaster Plans: Resident Involvement and Well-Being During Hurricane Harvey	To share experience as former chief residents at Texas Children's Hospital during Hurricane Harvey	Flexible staffing, strong leadership integration, and robust emotional and social support systems	Qualitative study	USA
Maciej et al (2019)	Battling Superstorm Sandy at Lenox Hill Hospital When the Hospital Is Ground Zero	Lesson learned	Unpredictability of Disasters, Sudden Patient Influx Role of a Support Center, Comprehensive Preparedness	Descriptive case study	USA
Jiang et al (2020)	Preparedness and response at long-term care facilities following Hurricane Sandy: A qualitative analysis of experiences and attitudes among staff and administrators	To examine the impact of the storm on Long Term Care Facilities 2 years after the event	Inadequate Preparedness, Inefficient Communication and Logistics, Lack of Accessible Resources, Access to electrical power, Psychological supports, the following needs were identified: communication with local government bodies, evacuation and transfer procedures in districts containing multiple hospitals, safe movement of residents, and comprehensive backup power strategies	A qualitative analysis	USA
Chambers et al (2020)	Impact of Hurricane Harvey on Healthcare Utilization and Emergency Department Operations	What impact did Hurricane Harvey have on emergency department operations?	In situations involving days-long flooding and harm to hospital buildings, flexibility and innovation are just as vital as thorough preparation ahead of time	Mixed-methods (Interviews / retrospective data)	USA
Hines et al (2021)	Hospital Preparedness, Mitigation, and Response to Hurricane Harvey in Harris County, Texas	Summarizes Harris County hospitals' flood preparedness and mitigation efforts before Hurricane Harvey	the following elements: infrastructure upgrades, a resilient hospital workforce, comprehensive pre-event planning, and established inter-organizational partnerships	Case study	USA
Gabriela et al (2022)	Hurricane María and Public Health in Puerto Rico: Lessons Learned to Increase	Review health issues and effects of Hurricane Maria	Among the pre-existing infrastructural vulnerabilities were electric power authority failures, interruption of cell phone services, and deficient leadership of relief efforts	Mixed-methods	USA

	Resiliency and Prepare for Future Disasters				
John A et al (2024)	A Simple Plan to Ensure Medical Staffing During Hurricane Idalia and Any Future Hurricane	Ensuring Medical Staffing During Hurricanes	A well-structured, pre-planned two-team staffing approach, informed by past experiences and military expertise, can effectively ensure the continuity of critical medical services during a hurricane, leading to a seamless and accomplished response.	Letter to the Editor	USA
Hertelendy et al (2024)	Hospital preparedness for one of the worst predicted hurricane seasons on record—why this time is different	Lessons Learned	Implementing a proactive hospital emergency management program with mitigation and preparedness steps will enhance hospitals' readiness for the upcoming hurricane season.	Case study	USA

## Results

### Included Studies

The systematic search yielded 6,107 records from databases and 8 records from other sources (e.g., citation searching). After removing 900 duplicates, a total of 5,215 unique records underwent title and abstract screening. At this stage, 4,987 records were excluded based on the pre-defined eligibility criteria. The primary reasons for exclusion were: not focusing on a hospital setting (n=2,850), not related to storm-type disasters (n=1,400), not addressing preparedness or resilience factors (n=550), being a non-research article type such as an editorial or news piece (n=119), and having an inaccessible full text despite exhaustive attempts (n=68). Consequently, 228 reports proceeded to the full-text eligibility assessment. Of these, 196 were excluded for the following reasons: publication in a non-English language (n=59), lack of a specific hospital-level focus upon detailed reading (n=84), and irrelevance to storm events (n=53). Finally, 32 studies qualified for inclusion and were part of the qualitative synthesis (Figure 1: PRISMA Flow Diagram). At that time, no eligible studies indexed in the databases and pertaining to our specific focus (hospital resilience to storms) had been published with a 2025 publication date. Therefore, while the search strategy was designed to capture literature up to the present (2025) at the time of writing, the results naturally did not include any 2025 publications.

### Descriptive Summary of the Literature

The 32 included studies employed diverse methodologies, including case studies (n=19), cross-sectional surveys (n=6), mixed-methods studies (n=2), and qualitative analyses (n=5), focusing on factors affecting hospital storm resilience. Analysis revealed a peak in publications (n=12) between 2017-2019, coinciding with major hurricanes like Harvey, Irma, and Maria. Geographically, over 84% of studies were from the United States (12, 18–35, 35–43), with additional research from the Philippines (44), Iran (45), Vietnam (46), Cuba (47), and Taiwan (48).

### The Proposed Model: The Enabling Foundation Framework

Our analysis confirmed five critical domains but revealed a consistent hierarchical pattern across case studies. In 28 of the 32 studies, failures or successes in Leadership & Governance were the primary determinant of outcomes in other domains, suggesting a causal rather than correlational relationship. We therefore propose the "Enabling Foundation" model (Figure 2), which consists of three constitutive layers:

#### 1- The Foundation Layer: Leadership, Governance & Policy

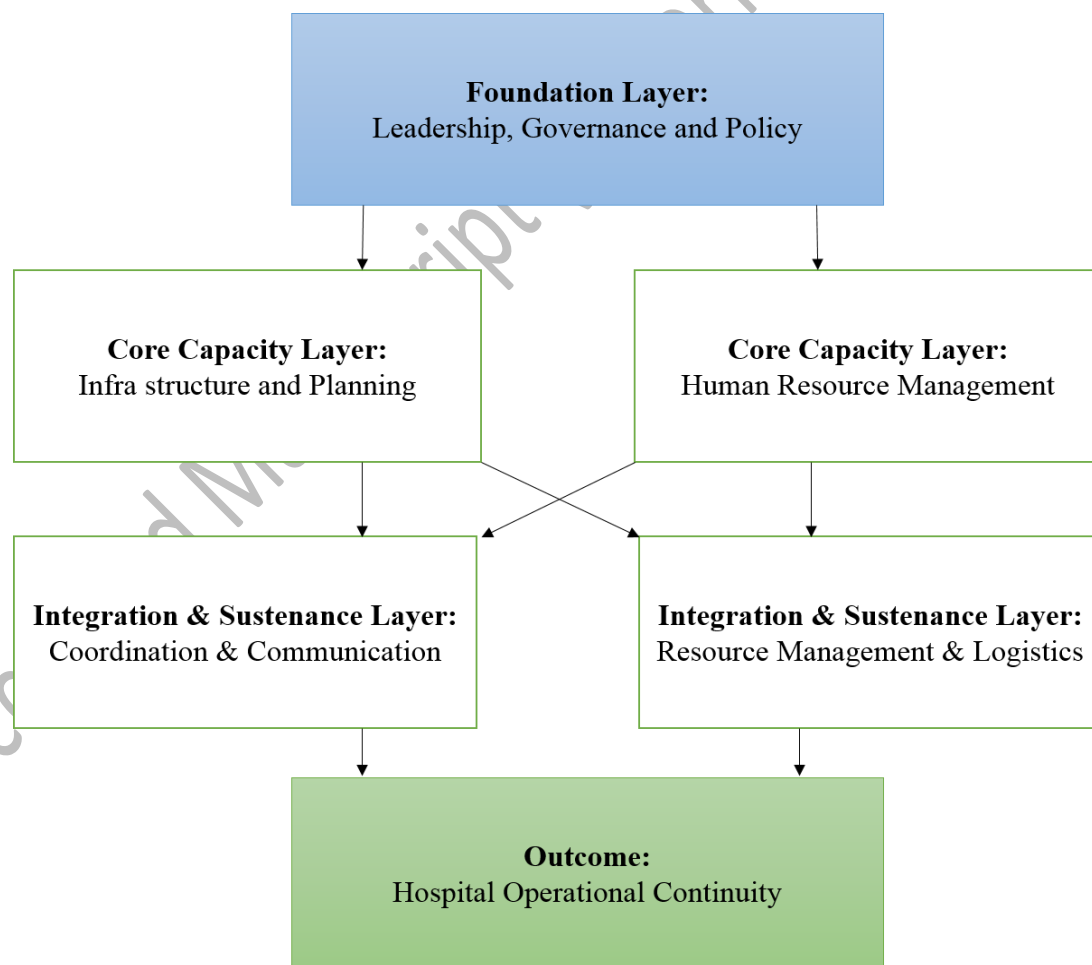
This domain emerged not as one of five equal components, but as the fundamental enabler. Studies demonstrated that without strategic leadership (36), clear policy mandates, and dedicated funding (34, 46), investments in other domains remained fragmented and ineffective. For instance, hospitals with robust physical infrastructure but weak governance failed to maintain operations during prolonged storms, as the foundational layer failed to ensure resource maintenance and coordinated response (18, 39).

## 2- The Core Capacity Layer: Infrastructure & Planning and Human Resource Management

These two domains constitute the essential operational capacities of a hospital, but they are functionally dependent on the foundation. Infrastructure & Planning—including critical assets like backup generators (20)—relies on governance for strategic investment and maintenance protocols (34, 43). Similarly, the effectiveness of Human Resource Management is contingent upon governance structures that enable staff training (45), support psychological well-being (40), and foster a resilient workforce (26).

## 3- The Integration & Sustenance Layer: Coordination & Communication and Resource Management & Logistics

This layer represents the dynamic processes that activate and sustain the core capacities during a crisis. However, its functionality is directly enabled by the foundational layer. Effective Coordination & Communication requires pre-established governance frameworks for incident command and information sharing (46). Likewise, agile Resource Management & Logistics depends on policies that allow for flexible procurement and allocation, without which supply chains and care delivery quickly break down (1, 4, and 41).



**Fig2:** The 'Enabling Foundation' Hierarchical Model for Hospital Operational Continuity in storms

## Discussion

This systematic review, synthesizing evidence from 32 diverse studies, moves beyond enumerating critical resilience factors to propose a novel, testable hierarchical model: the "Enabling Foundation" model. Our framework offers a theoretical advance by explaining a persistent paradox in disaster response: why similarly-equipped hospitals often experience dramatically different operational outcomes during crises. The model posits that resilience is not merely a function of possessing key components, but is determined by a causal hierarchy wherein effective Leadership, Governance & Policy is the non-negotiable prerequisite that enables the functionality of all other domains.

The primary novelty of our model lies in its departure from existing frameworks, which often treat resilience domains as interconnected yet equal components (1, 4, and 41). In contrast, the "Enabling Foundation" framework delineates a functional dependency between layers. It establishes that Infrastructure & Planning and Human Resource Management while physically critical are ultimately outputs of strategic policy and investment decisions (34, 43). For instance, a backup generator (20) is a core capacity, but its utility is contingent upon the foundational governance that ensures its maintenance, fuel supply, and operational protocols. Similarly, the effectiveness of pre-planned team structures and staff resilience (22, 26) is directly enabled by a governance system that provides psychological support (40), addresses basic needs (38), and fosters a culture of trust. This hierarchical structure resolves the theoretical gap by demonstrating that well-resourced hospitals fail not due to a lack of assets, but due to the absence of the enabling foundation required to actuate those assets under duress.

Furthermore, our model redefines the role of coordination and logistics. Existing literature often documents catastrophic breakdowns in communication and resource management as isolated failures (1, 41). Our synthesis, however, conceptualizes Coordination & Communication and Resource Management & Logistics as the dynamic "Integration & Sustenance" layers whose performance is acutely dependent on the foundation. The chaotic relief efforts and communication blackouts observed during events like Hurricane Maria were not merely technical glitches; they were the direct consequence of a missing governance framework that failed to establish formal mutual aid agreements, integrated community planning, and clear command structures (46). This contrasts with the success of institutions like Our Lady of the Lake Regional Medical Center during Hurricane Katrina, where strong leadership enabled effective internal management and resilient communication despite catastrophic external conditions (18). Thus, our model improves upon prior frameworks by making explicit that redundant systems and stockpiled resources are not self-actuating; they require the enabling environment of sound governance to be effectively mobilized.

The policy and practical implications of this paradigm shift are substantial. Our findings compellingly argue that investments in hospital storm resilience must be reoriented. Prioritizing "hard" infrastructure investments or "soft" training programs (45, 48, and 49) without concurrently strengthening the foundational layer of governance is a recipe for diminished returns and continued failure. Policymakers and hospital administrators must view governance reform not as one of several parallel initiatives, but as the primary leverage point for enhancing resilience. Investments in infrastructure hardening, staff training, and communication systems achieve maximum impact only when implemented within a supportive and empowering governance framework. Future research should focus on empirically validating this hierarchy and developing specific metrics to assess the strength of a hospital's "enabling foundation." This model invites empirical validation

through quantitative metrics for each layer to test its proposed hierarchy. Further research should also explore its applicability beyond storms—to events like earthquakes or pandemics—and develop it into a practical self-assessment tool for hospitals to proactively identify weaknesses in their foundational governance.

## **Conclusions**

This systematic review introduces the "Enabling Foundation" model, representing a paradigm shift in understanding hospital storm resilience. Our analysis reveals that resilience transcends checklist-based preparedness, depending fundamentally on a hierarchical organization where Leadership, Governance & Policy serve as the foundational layer enabling all other components.

The model explains why hospitals with similar resources show divergent outcomes during storms. Evidence from the reviewed literature demonstrates that infrastructure improvements, staff training, and communication systems achieve maximum impact only when supported by strong governance. Conversely, governance failures consistently undermined response efforts, leading to coordination breakdowns and resource mismanagement, as observed in numerous case studies of major hurricanes.

The practical implications are substantial: investments should prioritize governance capacity alongside physical infrastructure. This includes developing clear emergency protocols, ensuring adequate and flexible funding, and fostering leadership that empowers adaptive, frontline decision-making.

Future research should focus on quantitatively validating this model and exploring the specific governance mechanisms that most effectively enable operational resilience. Ultimately, this model provides a framework for transforming hospitals from vulnerable facilities to resilient institutions capable of maintaining continuous care during increasingly severe weather events.

## **Limitations**

This review has methodological limitations, including the exclusion of 68 unavailable full-text articles and potential language bias from focusing on English publications. More critically, implementing the proposed model faces practical challenges: resistance to cultural change, competition for resources between governance and physical upgrades, and difficulties in measuring governance strength. Moreover, we restricted to English-language publications and a defined date range (January 2000 to August 2025), which may introduce language bias and exclude relevant non-English or earlier foundational studies. To address these, we recommend creating adaptable implementation guidelines, promoting funding models that link governance to infrastructure support, and developing specific metrics such as leadership exercise frequency to quantify and sustain governance investments.

## **Ethical Considerations**

Approval was granted by the Ethics Committee of Neyshabur University of Medical Sciences (Date: 25.10.2025 /No: IR.NUMS.REC.1404.047).

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**Author contribution.** HGh and MRH: Conceptualization and design, literature search, quality appraisal, analysis, writing and editing of the manuscript. ZS, MD and SJH: Conceptualization, analysis, writing and editing of the manuscript. All authors approved the final manuscript.

**Conflict of Interest.** The authors have no conflicts of interest to declare.

**Data availability.** The data used to support the findings of this study are available upon request from the authors.

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<b>Database</b> Web of Science, PubMed, Scopus, Science Direct, the Cochrane Library, and ProQuest, as well as grey literature sources such as Google Scholar, FEMA, WHO, and UNISDR.	6115
<b>PubMed</b> (("Hospitals"[Mesh] OR "Emergency Service, Hospital"[Mesh] OR "hospital*" [tiab] OR "health facility" [tiab]) AND ("Disaster Planning"[Mesh] OR "Emergency Responders"[Mesh] OR "preparedness" [tiab] OR "resilien*" [tiab] OR "readiness" [tiab]) AND ("Cyclonic Storms"[Mesh] OR "Hurricanes"[Mesh] OR "storm*" [tiab] OR "hurricane*" [tiab] OR "typhoon*" [tiab])) NOT ("earthquake" [tiab] OR "pandemic" [tiab] OR "war" [tiab]))	1820
<b>Scopus</b> (TITLE-ABS-KEY(hospital* OR "health facility" ) AND TITLE-ABS-KEY ( preparedness OR resilien* ) AND TITLE-ABS-KEY (storm* OR hurricane* OR cyclone*) AND NOT TITLE-ABS-KEY(earthquake OR pandemic)) AND PUBYEAR > 1999 AND (LIMIT-TO(LANGUAGE , "English"))	1545
<b>Web of Sciences</b> TS=(("hospital*" OR "healthcare facilit*" OR "medical center*" OR "health institution*") NEAR/3 ("resilien*" OR "preparedness" OR "readiness" OR "disaster planning" OR "emergency management") AND ("storm*" OR "hurricane*" OR "cyclon*" OR "typhoon*" OR "tropical storm*" OR "windstorm*"))NOT TS=("earthquake*" OR "pandemic*" OR "war" OR "seismic")	987
<b>Cochrane Library (CENTRAL)</b> #1 (Hospital* or "health facility" or "healthcare system*") in Title Abstract Keyword #2 (resilien* or preparedness or readiness or plan*) in Title Abstract Keyword #3 (Storm* or Cyclone* or Hurricane* or Typhoon*) in Title Abstract Keyword #4 #1 and #2 and #3 #5 (earthquake or pandemic) in Title Abstract Keyword #6 #4 not #5	415
<b>Science Direct</b> <b>Search in:</b> Abstract, Title, Keywords ("Hospital" OR "health facility") AND ("resilience" OR "preparedness") AND ("Storm" OR "Hurricane") <b>Filters:</b> Year: 2000-2025, Subject: "Medicine and Dentistry", "Nursing and Health Professions".	921
ProQuest noft( (Hospital* OR "health facility") AND (resilien* OR preparedness OR plan*) AND (Storm* OR Hurricane* OR Cyclone*) ) AND noft( earthquake OR pandemic )	79
Google Scholar "Hospital" "storm" preparedness resilience "hurricane" -earthquake -pandemic Limits: The first 200 results, sorted by relevance, were screened. Searches included PDF/Word documents.	340
Grey Literature Sources Manual searches were performed on the websites of: <b>FEMA</b> (Federal Emergency Management Agency): Search term: "hospital preparedness hurricane" <b>WHO</b> (World Health Organization): Search term: "hospital resilience cyclone" <b>UNISDR</b> (United Nations Office for Disaster Risk Reduction): Search term: "health facility storm preparedness"	8