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Title: Earthquake Early Warning Systems in Hospitals: A Narrative Review

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Abstract

Background: Earthquakes are among the most destructive natural hazards, posing serious threats to public safety and urban infrastructure. Hospitals, as critical components of emergency response systems, are particularly vulnerable to seismic events. Their structural and operational fragility during earthquakes can severely disrupt healthcare delivery. This narrative review aims to explore the integration of Earthquake Early Warning Systems into hospital settings as a proactive strategy to enhance institutional resilience and ensure continuity of care during seismic emergencies.

Materials and Methods: Using a narrative review approach, this study synthesizes existing literature, technical reports, and case studies on Earthquake Early Warning Systems integration in hospitals. The search was conducted across major electronic databases including Scopus, Web of Science, PubMed, Google Scholar and ProQuest, as well as Iranian databases such as Magiran, CIVILICA, SID and IranDoc. Publications from 2000 to 2025 were screened, resulting in 5 final articles that met the inclusion criteria. The review examines current practices, successful implementations, and challenges across earthquake-prone regions to identify key strategies and gaps.

Results: Earthquake Early Warning Systems detect primary seismic waves and issue alerts before destructive secondary waves arrive, offering hospitals a brief but critical window to initiate protective actions. These may include securing equipment, safeguarding patients, and activating emergency protocols. Evidence from countries such as Japan, Mexico, and Taiwan shows that Earthquake Early Warning Systems can significantly reduce service disruptions and improve institutional readiness. However, barriers such as limited funding, lack of standardized protocols, and technological constraints hinder widespread adoption.

Conclusion: Integrating Earthquake Early Warning Systems into hospital systems presents a promising strategy for minimizing earthquake-related disruptions and safeguarding healthcare services. To ensure effective implementation, coordinated efforts are needed across policy, operational, and technological domains. The study recommends investing in interoperable technologies, developing clear guidelines, and fostering collaboration among stakeholders to overcome existing limitations and promote resilience.

Keywords: Early Warning System; Earthquakes; EEWS; Hospitals

1. Introduction

Earthquakes, as a natural hazard, not only cause immediate and significant loss of life and property but also pose substantial risks to critical infrastructures, including hospitals, which serve as essential components in community response and recovery during disasters (1). The seismic vulnerability of hospital facilities is a pressing concern, as these institutions must remain functional and ready to provide essential medical services during and after seismic events (2). The unpredictable nature of earthquakes underscores the necessity of adopting preventive measures to enhance hospital resilience and minimize adverse impacts on patient care and safety.

According to the Hyogo Framework for Action (2005–2015), 168 countries committed to integrating disaster risk reduction into health systems by reinforcing existing hospitals and constructing new ones with safety and sustainability standards that ensure their continued functionality during disasters (3). The Sendai Framework for Disaster Risk Reduction (2015–2030) further emphasizes the need to strengthen hospital resilience against disasters caused by natural hazards, ensuring uninterrupted delivery of critical healthcare services in times of disasters. It also highlights the importance of training healthcare personnel and developing emergency plans to maintain hospital operations under adverse conditions (4).

Natural hazards can disrupt hospital operations in multiple ways, including delayed timely communication, staff confusion, rapid saturation of emergency departments capacity, shortages of equipment and supplies, and overcrowding (5). Specifically, earthquakes may cause structural damages to hospitals, harm vital infrastructures, and compromise the continuity of patient care (6). The imperative of maintaining hospital functionality following seismic events has fostered growing interest in innovative technologies capable of providing early warnings and mitigating disaster impacts on healthcare facilities.

EEWS offer a promising solution to address the unique challenges posed by seismic events, reducing anxiety, fear, and helplessness among hospital staff and patients (7). These systems utilize real-time seismic monitoring to detect primary earthquake waves and issue alerts seconds to minutes before the arrival of more destructive secondary waves (8). This time advantage enables hospitals to activate emergency protocols, secure medical equipment, and, if feasible, initiate patient evacuation (9). By incorporating EEWS into disaster preparedness strategies, hospitals can enhance their capacity to withstand earthquakes and maintain the continuity of essential healthcare services.

The aim of this narrative review is to examine the current status of EEWS in hospitals, evaluate their effectiveness in improving preparedness, identify challenges and limitations in their implementation, and provide recommendations to strengthen EEWS as a means of enhancing hospital resilience during seismic events. This study has been carried out in Iran in 2025.

1.1. Earthquake Early Warning Systems: A Global Perspective

EEWS have achieved remarkable success in seismically active regions worldwide, and many countries—particularly earthquake-prone ones—are increasingly investing in research and implementation of these systems. Among them, the systems in Mexico, Japan, South Korea, and Taiwan are capable of issuing public alerts. In contrast, systems in India, Romania, Türkiye, and the United States provide warnings to selected users, while countries such as Chile, China, Costa Rica, El Salvador, Italy, Nicaragua, and Switzerland are still conducting research and developing their EEWS (8, 10). In Tehran, the capital of Iran, extensive research and development efforts for the EEWS have been conducted over the past two decades, and now only the final approvals for system deployment remain (11, 12). Japan has an established EEWS that issues alerts within seconds to minutes, thereby contributing to enhanced resilience and structural stability in the face of seismic events (13). In the United States, the “ShakeAlert” system in California uses real-time data from seismographs to detect seismic waves instantly and disseminates warnings to multiple sectors, including hospitals (14, 15). Mexico’s SASMEX, the first system to broadcast earthquake warnings to the general public, has been operational since 1993. Using a communication network, it disseminates alerts via radio, television, and city loudspeakers across Mexico City. During the September 2017 earthquake (Mw 8.2), the system issued alerts nearly two minutes before the strong shaking reached the city (16). Overall, EEWS are valuable tools for balancing cost and performance, and continuous assessment of their effectiveness provides deeper insights into their applicability in diverse seismic contexts (17).

1.2. Impact of Earthquakes on Hospitals

Lessons learned from past disasters highlight the vulnerability of hospitals to seismic events. For instance, during the 1985 Mexico City earthquake, 13 hospitals collapsed, resulting in 866 fatalities, including 100 healthcare staff (18). The 1994 Northridge earthquake in California caused significant damage to hospital infrastructure, disrupting medical services and patient care (19). Similarly, the 2003 Bam earthquake in Iran severely damaged two hospitals, drastically reducing their operational capacity (20, 21). The October 2005 Pakistan earthquake destroyed 50% of healthcare facilities in the affected regions. In the August 2007 Pisco earthquake (Mw 8.0) in Peru, 97% of hospital beds in the city were destroyed within just two minutes (22). Following the 2010 Haiti earthquake, 30 out of the 49 hospitals in the impacted area were partially or completely destroyed (23). Following the 2012 Varzeghan-Ahar earthquake in Iran, the two main hospitals in the affected cities of Ahar and Heris sustained severe damage, leading to the suspension of their operations (24). During the two major earthquakes that struck Nepal in April and May 2015, approximately 90% of healthcare infrastructure in the affected areas was either destroyed or severely damaged (25). In the 2017 Mexico earthquake with a magnitude of 7.1, hospitals accounted for 1.9% of structural damage, ranking fifth among different facility categories. Most hospitals were classified as having moderate damage (26). The 2017 Kermanshah earthquake in Iran, with a magnitude of 7.3, caused significant damage to hospital infrastructure due to the lack of both structural and non-structural safety measures (27). In the 11 provinces affected by the 2023 earthquake in Türkiye, at least 15 hospitals were either completely destroyed or suffered irreparable damage (28). These cases reveal that hospitals’ lowest level of preparedness against earthquakes lies in structural safety, which often leads to severe operational disruptions. Factors such as aging buildings, poor construction oversight, unaddressed structural vulnerabilities, and inadequate funding for retrofitting and reconstruction significantly increase hospital susceptibility to collapse during seismic events (29, 30).

1.3. Effectiveness of Earthquake Early Warning Systems in Hospitals

Some approaches suggest that increasing the warning time can directly lead to a significant reduction in fatalities and injuries. For instance, a 3-second earthquake early warning may reduce mortality and injury rates by up to 14%, a 10-second warning by up to 39%, and a 20-second warning by up to 63% (31). In contrast, another perspective interprets the effectiveness of EEWS not as a fixed numerical value, but as dependent on a combination of factors, including the lead time, alert accuracy, and the population exposure. Accordingly, the earlier the warning is issued, the more accurate it is, and the larger the population within the effective alert zone, the greater the potential for reducing human casualties and damage (32).

Studies evaluating the effectiveness of EEWS in hospitals have also yielded promising results. Research conducted in seismically active regions indicates that hospitals equipped with EEWS experience reduced casualties and less damage to critical infrastructure (33). Additional benefits include enabling safe surgical procedures, temporarily pausing ventilators, unlocking doors to facilitate evacuation, closing curtains to reduce the risk of glass shattering, securing radioactive sources, placing equipment in safe positions, and allowing operating room staff to stabilize patients immediately upon receiving initial alerts (34).

1.4. Challenges and Limitations

EEWS face difficulties in accurately estimating earthquake source parameters, predicting ground motion intensity, and minimizing false alarms. Effective implementation also requires integration of technical components with socio-organizational factors, including operational, political, social, behavioral, and institutional domains (35). To fully benefit from EEWS, hospitals must invest in staff training and infrastructure improvements, as these are critical to optimizing system effectiveness within healthcare settings.

2. Methodology

An initial scoping exercise revealed that the research literature was too heterogeneous and limited to allow for a systematic review. Therefore, a narrative review approach was adopted, structured around the four stages proposed by Gregory and Denniss (2018): (1) defining the topic, (2) searching scientific literature, (3) critical appraisal, and (4) logical structuring (36). This approach is particularly valuable in fields with limited prior research or where new interpretations are required. Accordingly, this study aims to provide a comprehensive and critical review of existing literature to describe the current status of EEWS in hospitals and offer novel insights for theoretical and practical development (37).

2.1. Topic Definition

This study focuses on hospital response mechanisms in the face of earthquakes, with particular attention to the integration and utilization of EEWS in healthcare facilities.

2.2. Literature Search

The literature search was conducted in major databases including Scopus, Web of Science, PubMed, Google Scholar and ProQuest, as well as Iranian databases such as Magiran, CIVILICA, SID and IranDoc. The following terms were incorporated into the search process: (“Earthquake Early Warning” OR “EEW”) AND (“Hospital” OR “Healthcare center” OR “Medical center” OR “Healthcare facilities”). The review covered publications from 2000 to 2025, with the objective of examining the integration of EEWS into hospitals, preparedness and emergency response measures following alerts, and the challenges and successes associated with implementation. The time frame was selected because significant advances in digital sensing technologies and applications of EEWS began to emerge in the early 2000s, as highlighted by studies such as Gasparini et al. (2009)(38), which emphasized the growing role of modern technologies in shaping effective early warning systems.

Inclusion criteria targeted studies focusing on EEWS in hospitals, their effectiveness, efficiency, challenges, limitations, and technological advancements. Only peer-reviewed and reputable publications in English and Persian were considered for inclusion in this study.

Articles were included if they explicitly addressed the application, implementation, or evaluation of EEWS within hospital or healthcare facility settings. Studies focusing on EEWS at regional, urban, or purely technical levels without direct applicability to hospitals were excluded. Additional exclusion criteria included insufficient methodological detail and lack of relevance to hospital preparedness or response. Based on these criteria, five peer-reviewed articles were selected for inclusion in the final analysis.

2.3. Critical Appraisal

The identified sources were systematically evaluated, and five relevant and credible scientific articles were selected. These included studies with diverse designs from countries such as Greece, Japan, China, Mexico, and several African nations. The present review provides a comprehensive summary and critical analysis of the existing literature, aiming to identify knowledge gaps. The authors carefully examined each study, extracting critiques, recording key findings and research methodologies (see Table 1).

2.4. Logical Structuring

The review follows a clear structure, including Introduction, Methodology, Results, Discussion, and Conclusion, to present the findings in an organized and systematic manner.

3. Results

This section is dedicated to the analysis and examination of five selected articles on hospital preparedness and resilience against earthquakes, with a focus on the role of EEWS. A synthesis of the reviewed studies reveals several recurring themes regarding the role of EEWS in hospital settings. First, EEWS were consistently reported to enhance operational effectiveness by providing critical lead time for protective actions, contributing to reduced risks for patients and healthcare personnel. Second, technological and infrastructural challenges, such as high installation and maintenance costs, system complexity, and the risk of false alarms were commonly identified as barriers to implementation. Third, organizational and social factors, including staff preparedness, training, public awareness, and institutional coordination, emerged as key determinants of system effectiveness. Finally, the studies emphasized the importance of integrating EEWS with other hospital preparedness measures, such as structural health monitoring and standardized emergency protocols, to strengthen overall hospital resilience.

The findings of each study are examined based on their methodological approaches. The table below (Table 1) summarizes the results, including author name, study design, year of publication, country/location, main question of the article, authors' critique of the article, and key findings.

The findings of Horiuchi (2009) indicated that the implementation of EEWS in hospitals can effectively create valuable time for emergency response measures, such as the automatic opening of doors and elevators to facilitate the evacuation or relocation of patients and staff. Although the costs of installation and maintenance, along with the need for advanced technical expertise, were reported as major challenges, the study concluded that this technology is fully justifiable when compared with potential human and financial losses, and it can play a significant role in enhancing hospital safety (33).

Pitilakis et al. (2016) presented the outcomes of implementing a combined structural health monitoring and EEWS in the AHEPA Hospital in Greece. The findings demonstrated that integrating real-time structural monitoring with EEWS contributes to the rapid assessment of hospital vulnerability and functional capacity, thereby strengthening earthquake preparedness. Despite the high cost of instrumentation and technical complexities being reported as major obstacles, the project successfully introduced a transferable model that could also be applied internationally (39).

The results of Zhou et al. (2017) showed that the deployment of EEWS in hospitals, in addition to improving emergency response, can also significantly raise public awareness of earthquake risks. The study highlighted that although technical complexities and the absence of systematic innovative management remain considerable barriers, social acceptance and organizational coordination are crucial determinants of success. This article emphasized the social dimension of EEWS and the necessity of linking technological solutions with hospital management structures (9).

The research conducted by Nkurunziza et al. (2022) focused on the effectiveness of EEWS in reducing human casualties and enhancing hospital preparedness in the high-risk Virunga region. The findings revealed that such systems can serve as effective tools for disaster management, particularly in environments with vulnerable healthcare infrastructure. However, the lack of comprehensive disaster management programs and limited financial and technical resources were reported as key barriers. The study concluded that international frameworks, such as the Sendai Framework, can provide a basis for the development and standardization of EEWS in hospitals (40).

In their article, Vaiciulyte & Novelo-Casanova (2024) examined the public response to earthquake warnings in Mexico City and demonstrated that timely and appropriate reactions are critical in reducing damages and strengthening the preparedness of healthcare facilities. The findings indicated that public awareness and education have a direct influence on the effectiveness of EEWS. Although the article did not outline specific technical standards for hospitals, the results underscored the importance of effective messaging strategies and regular training to strengthen emergency response capacities (41).

4. Discussion

Addressing the challenges and limitations in implementing EEWS in hospitals requires targeted strategies. A review of existing studies offers a comprehensive perspective on hospital resilience to earthquakes, underscores the critical importance of EEWS, and highlights the need for preparedness measures to enhance hospitals' capacity for effective seismic response. From the analysis of existing studies, several strategies emerge that can enhance hospital resilience and the effectiveness of EEWS. These strategies are discussed in the following subsections.

4.1 Enhancing EEWS through Emerging Technologies and Continuous Monitoring

Based on the reviewed studies (9, 33, 39), several technological gaps were identified, including system complexity, false alarms, and limited integration of monitoring platforms. These challenges highlight the need for advanced technologies and continuous system optimization.

Research on the feasibility of adopting emerging technologies, such as Artificial Intelligence (AI), the Internet of Things (IoT), and advanced sensing systems, can contribute to the development of more efficient EEWS. For instance, reducing false alarms, which may generate public panic and economic consequences, can be achieved through refined algorithms, machine learning techniques, and continuous system updates (42-44). Moreover, the integration of different early warning systems is of critical importance. Coordination among these systems can provide hospitals with more accurate and timely information. Such integration can be realized by developing joint protocols and standardizing data formats and communication methods across platforms. With these measures, hospitals can react more quickly and effectively to warnings, taking essential actions to protect patients and staff (45). Furthermore, the development of rapid, secure, and integrated communication channels for delivering earthquake alerts to hospitals is essential. These systems should be designed to disseminate warnings instantly to all hospital staff through text messages, and audiovisual notification systems (46, 47). Equally important is ensuring accuracy and operational continuity through monitoring and evaluation processes that regularly assess system performance (48). Operational strategies for strengthening this component include investing in AI-based monitoring tools to reduce false alarms, establishing continuous update and maintenance protocols for EEWS software, and ensuring interoperability by standardizing data formats across platforms. Hospitals should also develop secure communication channels that instantly disseminate alerts to staff through text and audio-visual systems, supported by regular performance evaluations to maintain accuracy and reliability.

4.2 Standardizing Hospital Preparedness Protocols for Earthquakes

The findings (33, 39, 40) revealed considerable variability in hospital-level preparedness and a lack of standardized response protocols following EEWS alerts. This inconsistency emerged as a recurring limitation affecting the effectiveness of EEWS implementation. Standardization refers to the process of developing, agreeing upon, and implementing technical specifications, criteria, methods, processes, designs, or procedures in a uniform manner, thereby increasing compatibility, interoperability, safety, repeatability, and quality (49). The standardization of hospital preparedness protocols for earthquakes is crucial, as it enhances efficiency and coordination in disaster management. This can improve collaboration among hospital departments and related organizations, thereby strengthening disaster response effectiveness (50). Standardized protocols not only help minimize human and financial losses during earthquakes but also improve the quality of healthcare services during disasters by ensuring faster and more efficient responses to patient needs (29). Furthermore, integrating EEWS into standardized preparedness protocols allows sufficient time for risk reduction measures, such as patient evacuation, equipment protection, and staff mobilization. Thus, standardized preparedness protocols incorporating EEWS can play a vital role in enhancing hospital resilience to earthquakes. Operational strategies for strengthening this component include drafting unified hospital preparedness manuals, integrating EEWS procedures into daily hospital operations, and conducting joint drills with emergency agencies to ensure consistency and effectiveness.

4.3 Training for Strengthening Hospital Staff Preparedness

The reviewed studies (9, 40, 41) emphasized that insufficient staff training and limited familiarity with EEWS procedures reduced the effectiveness of early warnings in hospital settings. This underscores the need for structured and continuous training programs. Training hospital staff in the use of EEWS and in rapid, effective responses to alerts is of paramount importance, given their central role in saving lives and reducing patient suffering during disasters (51, 52). Regular training programs for all staff, including physicians, nurses, and administrative personnel, can improve familiarity with EEWS and enhance disaster response performance (45). Training should cover detailed operational aspects of these systems and provide staff with the necessary skills. Simulation exercises are also highly effective in increasing preparedness, as they allow staff to practice response strategies under realistic earthquake scenarios (53). Such drills help evaluate the effectiveness of emergency response protocols and identify strengths and weaknesses in both systems and personnel. Overall, continuous training and regular drills on EEWS usage can significantly improve hospitals' response capacity during seismic events (16). Operational strategies for this component involve scheduling mandatory EEWS training sessions for all hospital staff, incorporating simulation exercises into annual disaster preparedness programs, and conducting regular drills under realistic earthquake scenarios. Hospitals should also establish evaluation mechanisms to assess staff performance during these exercises, identify gaps, and provide targeted refresher courses to ensure continuous improvement in response capacity.

4.4 Strengthening Inter-Sectoral Collaboration

The analysis highlighted fragmented coordination between hospitals, technical institutions, and emergency agencies as a major barrier to effective EEWS implementation (9, 39, 40). For this reason, collaboration between engineers, seismologists, and hospitals is essential for the development of advanced algorithms that minimize false alarms while maximizing early detection accuracy (54). Supporting innovative joint initiatives between hospitals and EEWS developers is also important to ensure system customization according to hospital-specific needs. In addition, developing and implementing joint protocols with emergency agencies and government authorities can promote coordination and improve earthquake response efficiency. These institutions can provide necessary support and work closely with hospitals to enhance response processes, ultimately reducing casualties and damages (55). Periodic reviews and updates of these joint protocols based on lessons learned, experiences, and new data are also critical for sustaining their effectiveness. Operational strategies for strengthening collaboration include forming multidisciplinary working groups between hospitals, engineers, and seismologists, signing memorandums of understanding (MoUs) with emergency agencies and government authorities, and organizing periodic joint meetings to update protocols based on lessons learned. Hospitals should also support innovative partnerships with EEWS developers to customize systems according to hospital needs, thereby ensuring coordinated and effective earthquake response.

4.5 Hospital Earthquake Early Warning System (HEEWS)

The key findings of this review synthesize the proposed Hospital Earthquake Early Warning System (HEEWS) implementation strategy, as presented in Figure 1. The framework illustrates the interconnections between technological components (e.g., EEWS platforms, sensors, communication systems), organizational preparedness (including standardized protocols and staff training), and inter-sectoral collaboration among hospitals, emergency agencies, and technical institutions. As shown in Figure 1, the effectiveness of HEEWS depends not only on timely and accurate alerts but also on the integration of warning systems with hospital preparedness measures, continuous monitoring, and coordinated response mechanisms. This integrated approach aims to enhance hospital resilience by enabling rapid decision-making, minimizing operational disruptions, and reducing risks to patients and healthcare personnel.

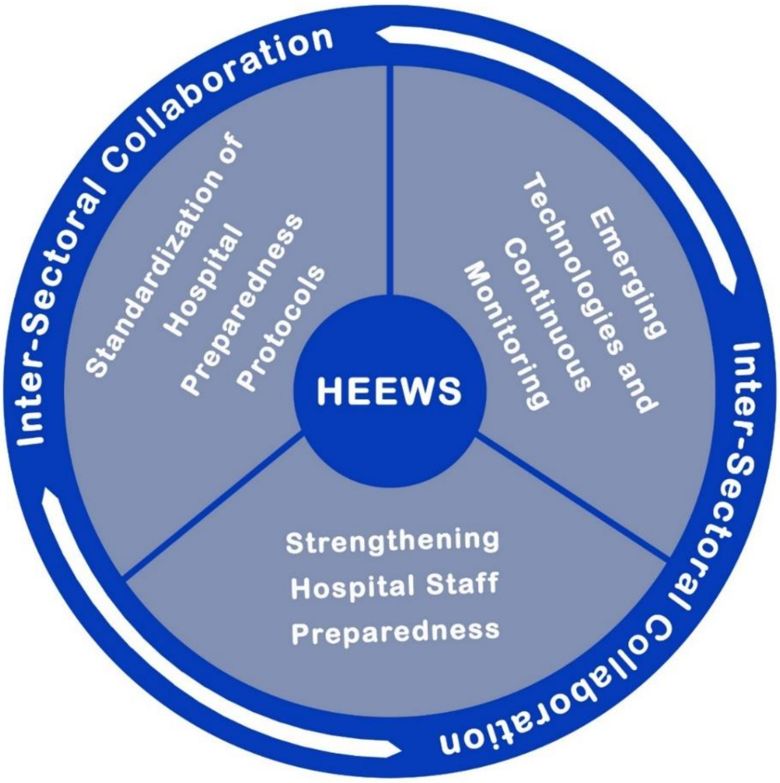

Figure 1: Hospital Earthquake Early Warning System (HEEWS) implementation strategy

5. Conclusion

The findings of this review clearly demonstrate that the integration of EEWS into hospitals holds significant potential for reducing casualties and minimizing structural and functional damages caused by seismic events. Hospitals, as critical infrastructure, require rapid and coordinated responses during disasters. The studies reviewed indicate that EEWS provide a crucial window of time, even if only a few seconds, to initiate protective actions, such as pausing surgical procedures, securing sensitive medical equipment, relocating vulnerable patients, and mobilizing emergency staff. These measures directly contribute to safeguarding both human lives and the continuity of essential medical services.

The evidence suggests that while technical and financial challenges remain substantial, the benefits of EEWS implementation in hospitals are both economically and ethically justified. The capacity of these systems to prevent large-scale human losses outweighs the costs associated with their deployment and maintenance. Furthermore, beyond the technical domain, EEWS also play a social role, as they foster public awareness and institutional readiness. Hospitals that incorporate EEWS into their preparedness strategies not only improve their internal resilience but also serve as trusted hubs of safety for the wider community during disasters.

To maximize effectiveness, several critical measures must be prioritized. First, leveraging emerging technologies such as AI, IoT, and advanced sensing systems can refine detection capabilities, reduce false alarms, and enhance the precision of warnings. Continuous system updates and machine learning–based algorithms should be adopted to ensure reliability and responsiveness. Second, the integration of multiple EEWS platforms and the development of interoperable communication protocols are vital. Hospitals should not rely on a single source of seismic information but rather benefit from coordinated, multi-source data streams that provide redundancy and accuracy.

Equally important is the standardization of hospital preparedness protocols. Establishing uniform guidelines for how hospitals respond to EEWS alerts can increase efficiency, improve interdepartmental coordination, and ensure that staff act quickly and decisively when warnings are issued. These standardized protocols must incorporate EEWS-specific procedures such as patient triage under time pressure, equipment protection, and emergency evacuation drills. In addition, staff training and simulation exercises should be a routine practice. Regular drills build familiarity with EEWS processes, identify gaps in preparedness, and foster a culture of readiness among healthcare workers.

Another key recommendation is the strengthening of inter-sectoral collaboration. Hospitals, engineers, seismologists, emergency agencies, and policymakers must work together to design context-specific EEWS applications. Such cooperation ensures that systems are tailored to hospital needs while also aligning with broader disaster risk reduction strategies. International frameworks, such as the Sendai Framework for Disaster Risk Reduction, can provide guiding principles for the integration and standardization of EEWS in healthcare settings.

Finally, continuous monitoring and evaluation of EEWS performance are necessary to ensure sustainability and long-term functionality. By regularly assessing operational outcomes and incorporating lessons learned from real earthquake events and simulations, hospitals can enhance their preparedness strategies and maintain public trust in these systems.

In summary, integrating EEWS into hospitals is more than a technological upgrade—it represents a comprehensive resilience strategy. It brings together advanced technologies, standardized protocols, trained personnel, and cross-sectoral cooperation to safeguard the most vulnerable populations during earthquakes. The pursuit of research and investment in this area is therefore not only economically and socially valuable but also a moral and ethical imperative. Ensuring that hospitals remain functional and prepared in the face of seismic hazards is central to protecting lives, preserving healthcare delivery, and promoting societal resilience.

From a regional perspective, the findings of this review are particularly relevant for countries with high seismic risk, such as Iran. Iran is located in an active seismic zone and has experienced numerous destructive earthquakes that have severely affected healthcare facilities and hospital functionality. Despite these risks, the systematic integration of EEWS into hospitals remains limited. Strengthening hospital-based EEWS in Iran requires targeted investment in technological infrastructure, capacity building, and interdisciplinary research tailored to local contexts. Future studies should focus on hospital-centered pilot projects, evaluation of system effectiveness, and the development of national guidelines aligned with international disaster risk reduction frameworks. Prioritizing research and investment in this field can significantly enhance hospital resilience and protect vulnerable populations during seismic events.

Limitations of the study

Although a comprehensive search strategy was applied across major academic databases, the number of peer-reviewed studies explicitly focusing on hospital-based EEWS was limited. Additional searches conducted in dissertation repositories (ProQuest and IranDoc) and reviews of technical reports from international organizations such as WHO and UNDRR did not identify further sources directly aligned with the study objectives. Moreover, as a narrative review, this study did not include a formal quality appraisal or quantitative synthesis of the evidence. Finally, the heterogeneity of study designs, contexts, and outcome measures may limit the generalizability of the findings. These limitations reflect the current scarcity of hospital-specific EEWS research and highlight the need for further empirical studies in this field.

Author Contribution

Both authors contributed substantially to the conception and design of the review. Amin Rahmatali-Khazaee was primarily responsible for literature search, data extraction, and drafting of the manuscript. Ali Nasiri contributed to the analysis, interpretation of findings, and critical revision of the manuscript. Both authors approved the final version of the manuscript and agreed to be accountable for all aspects of the work.

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Conflict of Interest Statement

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Table 1: Reviewed articles with their main characteristics and key findings

Authors	Country	Year of publication	Type of study	Main Question of the Article	Authors' Critique of the Article	Key findings
Horiuchi (33)	Japan	2009	Qualitative	How can EEWS be effectively applied in hospitals to reduce casualties and improve disaster response?	Conceptual/technical focus; limited empirical hospital data.	- Preparedness and Response: Automated hospital alerts (e.g., opening doors / elevators and warning messages) - Challenge: High costs and maintenance requirements / need for technical expertise - Strength: Potential to reduce casualties in healthcare facilities - Standard: Internal protective protocols
Pitilakis et al. (39)	Greece	2016	Quantitative	How can structural monitoring and EEWS be implemented in the AHEPA hospital to enhance safety, resilience, and rapid response during seismic events?	Single-hospital implementation; high instrumentation costs.	- Preparedness and Response: Structural health monitoring integrated with EEWS - Challenge: High costs and extensive instrumentation requirements - Strength: International collaboration and integration of early warning with monitoring - Standard: European earthquake engineering standards
Zhou et al. (9)	China	2017	Quantitative	How can EEWS be applied in hospitals to effectively reduce earthquake disaster impacts?	Limited institutional evaluation; emphasis on social awareness.	- Preparedness and Response: Enhancing public awareness and facilitating rapid hospital response - Challenge: Socio-technical complexity and need for innovative management - Strength: Emphasis on the social dimension of EEW in health systems - Standard: Socio-technological perspective without specific standards
Nkurunziza et al. (40)	Virunga region countries (Democratic Republic of Congo, Rwanda,	2022	Qualitative	How can an EEWS be implemented in health facilities of the Virunga region to save lives and mitigate	Context-specific (high-risk region); limited technological detail.	- Preparedness and Response: Developing an EEWS to save lives in healthcare facilities in high-risk Virunga regions - Challenge: Need for comprehensive disaster management and limited infrastructure - Strength: Increasing awareness and strengthening hospital preparedness - Standard: Sendai Framework for Disaster Risk Reduction

	and Uganda)			risks for the wider population?		
Vaiciulyte & Novelo-Casanova (41)	Mexico	2024	Qualitative	What is the pertinence of EEW for safeguarding vulnerable populations in hospitals in Mexico City?	Focus on public response; lack of hospital-specific technical standards.	- Preparedness and Response: Assessing population response to EEW in Mexico City - Challenge: Need for effective education and communication - Strength: Positive population response and improved hospital preparedness - Standard: Focus on population behavior without specific standards