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Risk analysis and safety assessment of hospitals against disasters: A systematic review

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Abstract:

Both natural and man-made disasters are increasing in occurrence at the world. Hospitals and health-care centers are very complex and have a high potential for vulnerability depending on external and internal factors. Unfortunately, past experiences show that health-care centers and the health system are vulnerable to disasters. Therefore, risk analysis and safety assessment studies of hospitals and other health-care centers are absolutely necessary. This systematic review study was conducted on the basis of the Preferred Reporting Items for Systematic Reviews and Meta-Analyses guidelines. English language international databases (Pub Med, Scopus, Embase, Web of Science, and Google Scholar) were searched through January 1, 2000 up to June 20, 2019. The quality of the studies was assessed using the International Narrative Systematic Assessment tool. From 3630 titles identified in this search, 24 studies were selected. The important findings of this study were grouped into five main categories: risk analysis method, type of disaster, hospital safety methods, hospital components and key outcomes of risk analysis, and hospital safety assessments. The nature of disasters is a threat to the lives and property of the people, and therefore hospitals must be available at the incidents and disasters and they must be able to respond to the needs of the disaster-affected community. The probability of an incident and its consequences can never be reduced to zero; because the severity of many natural and even man-made disasters is unpredictable and the probability of their occurrence is different; however, it is possible to identify weaknesses and strengths through risk analysis studies as well as hospital safety assessments and implement retrofitting programs based on the type of risks and safety status and reduce the level of risk to an acceptable level.

Keywords:

Disasters, hospital, risk analysis, safety assessment

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Introduction

Both natural and man-made incidents and disasters are increasing in the world.[1] By definition, disaster is a serious disorder which leads to a significant amount of human suffering and social turmoil and can have short-term and long-term effects on health.[2] Over the past 20 years, many countries around the world have been affected by many natural and man-made disasters which have had a profound impact on nature and communities.[3] Urban development and subsequent marginalization are considered the most important factors in increasing the vulnerability of communities. In 2016, it was estimated that approximately 54.5% of people lived in large cities and urban areas.[4] Many cities are faced with kinds of natural and man-made disasters; thus, they can become the crisis centers and may be damaged in occurrence of an incident.[5] According to a report by the Centres for Research on the Epidemiology of Disasters (EM DAT) in 2019, 396 natural disasters affected more than 95 million people, killing an additional 11,755 people and causing losses worth $103 billion.[6]

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According to statistics, Asia has experienced the highest occurrence of natural disasters (44%) and has had the highest number of affected people (69.5%). Following Asia, the highest figures have been observed in America (25%), Europe (14%), Africa (13%), and Oceania (4%), respectively.[6] Therefore, it can be said that Asia is one of the most vulnerable continents in terms of the number of disasters and the number of deaths.[7] Studies have also revealed that disasters highly effect on developing countries and poor societies which account for more than 60% of the world's population, with Asia and Africa having the largest share.[8] Similarly, it is estimated that more than 97% of deadly disasters occur in developing countries located in vulnerable areas.[9] In addition to natural disasters such as floods, earthquakes, and droughts and man-made disasters including terrorist attacks, traffic accidents, and fires also occur more in developing countries due to their inadequate and inappropriate infrastructures.[10] Since 1990, natural disasters have caused about $ 1 trillion damage to Asia, which is about half the cost of the damage worldwide.[11] A study conducted on the effects of future disasters estimated that, between 2020 and 2030, people of Asia and Oceania will be at higher risks of injuries and deaths caused by different kinds of disasters.[12]

Concerning the sectors involved in crisis and disaster management, health is of great importance because it is the first and foremost thing people require after an incident.[13] Disasters can abruptly result in an increase in the demand for health services which may, on a massive scale, lead to inefficiency of the health-care system.[14] Hospitals and other health centers are responsible for the health of the injured and for preventing the deaths of people affected by disasters; it depends not only on organizing but also on strengthening their equipment and their safety.[15] The uninterrupted provision of hospital services is one of the vital issues before and after occurrence of disasters, that all authorities should pay special attention to.[16] Hospitals must keep their maximum capacity and remain available during and after incidents, emergencies or other crises, provide adequate care for the victims of disasters as well as provide essential health services to establish health in societies.[17] Thus, hospitals and other health centers are expected to be prepared to deal with any crises and disasters and to be able to provide constant services to the affected population.[18] Although health and treatment facilities are essential infrastructures at the disasters, they have equipment that is vulnerable to various disasters such as earthquakes and floods. In addition, damage to medical buildings can disrupt the provision of medical services. Therefore, health-care facilities are required to remain operational in order to be able to provide services after any disaster.[19]

Hospitals and health centers are extremely complicated and are highly vulnerable to external and internal factors.[20] Unfortunately, past experience has revealed that health centers and the health system are vulnerable to disasters. For example, in an earthquake measuring 6.6 on the Richter scale which occurred in Iran in 2003, all health centers were devastated and half of the health personnel were killed.[21] In the 2005 earthquake in Pakistan (measuring 7.6 on the Richter scale), 68% of health centers in the earthquake-stricken areas were demolished and were unable to provide services for the victims.[22] In 2007, Peru was struck by a major earthquake (measuring 8 on the Richter scale), in which 60% of health centers reported various types of damage; however, 80% of services was uninterruptedly provided for the injured and affected people.[23] In January 2015, a gas pipeline explosion at a maternity and children's hospital in Mexico City killed two infants and two adults and left many people injured. It completely destroyed the entire building.[24] According to the cases mentioned above, hospitals are considered one of the most crucial infrastructures of every society, and the damage to them can result in catastrophic losses, loss of human beings, and very serious economic consequences; therefore, their safety is of great importance.[25]

According to the definition of World Health Organization (WHO), a safe hospital is able to respond with its maximum power and capacity immediately after a disaster, is available, and is in full operational conditions.[15] During the 1990s (dedicated to the disaster risk reduction), the occurrence of some disasters around the world led to the publication of numerous articles on the effects of disasters on hospitals and their damage.[26] In order to prevent such problems, the United Nations launched the "Campaign for Safe Hospitals against Disasters" during the World Conference on Disaster Risk Reduction in 2005. The campaign was based on the commitment that the hospital must be safe in order to prevent the consequences of disasters and to continue to operate within 3 days after the disasters. Thus, a safe hospital has three indicators: life protection, capital protection, and performance protection.[24] Concerning the safety of hospitals, the Hyogo Framework for Action (HFA) and the Sendai Framework for Action (SFA) emphasized the importance of resilience of critical infrastructures such as hospitals by understanding the measures taken to reduce disaster risks. The Sendai framework has a direct impact on health. This framework promotes the safety of health and treatment facilities.[27] There are currently few methods for measuring the safety and vulnerability of hospitals. The Safe Hospital Program Guide defines a safe hospital as a place where services are available and a place which remains at its full capacity with the same existing infrastructures.[19] The WHO has

also developed a method for hospital managers, in which they can assess the level of structural, nonstructural, and functional safety by measuring weaknesses in different parts of the hospital; they then can take action to solve these problems.[4] Owing to the limited resources of communities, risk analysis is of great importance.[28] Risk analysis can identify risk factors for hospitals and can prioritize and reduce risks. In most risk and safety analysis methods, individual facilities are measured and analyzed mainly by focusing on structural aspects using: 1 – risk analysis matrix, 2 – fragility curves, and 3 – structural, nonstructural, and functional indicators.[29]

Disasters whose effects are apparent at different levels are an inevitable part of human life.[30] Therefore, new knowledge and information is required to reduce its effects as much as possible.[31] According to this report, so far, no comprehensive study has been conducted on various aspects of risk analysis and safety assessment of hospitals. Therefore, to fill this knowledge gap, this systematic review aimed to examine the different methods and factors and to offer a multifaceted approach to this issue with the following research questions:

1. Which methods used for risk analysis in hospitals? (risk analysis methods)
2. Which disasters have been considered most relevant for risk analysis and safety assessment? (disaster type)
3. Which methods used to measure hospital safety? (hospital safety assessment methods)
4. Which components have been considered in the safety assessment and risk analysis of the hospital? (hospital components)
5. What are the key outcomes of risk analysis and hospital safety assessments? (Key outcomes).

Materials and Methods

This systematic review was based on Preferred Reporting Items for Systematic Reviews and Meta-Analyses guidelines.[32] A study protocol was developed to formulate the study question, define the inclusion criteria, develop a database search strategy, retrieve the relevant studies, extract the relevant data, appraise the retrieved studies, and synthesize and report the data. The protocol was reviewed by a committee at the Institute for Futures Studies in Health, Kerman University of Medical Sciences. This search was conducted through January 1, 2000 up to June 20, 2019. The protocol was not publicly preregistered.

Search strategy

The systematic review involved the structured searching of international databases including (PubMed, Scopus, Web of Science, Embase, and Google Scholar) up to June 2019. We did limit the search to articles written in English after 2000 and those that specifically address risk analysis and safety assessment of hospitals. Furthermore, there was no limitation on the methods used in the studies. The search strategy was developed based on a combination of keywords related to the topic of research. To detect as many articles as possible, a selection of key words was done on the basis of a previous study, and MeSH terms were used. In this study, we used three groups of keywords: (a) risk analysis, risk assessment, safety assessment, safety, structural safety, nonstructural safety, and functional safety; (b) hospitals; and (c) natural disaster, earthquake, flood, landslide, drought, cyclonic storm, tornado, tidal waves, wildfire, hurricane, sand storm, man-made disaster, fire, explosion, war, terrorist attack, biological disaster, chemical disaster, and nuclear disaster. These keywords were combined using the operators of the mentioned databases. The search strategy and key terms were as follows: ("risk analysis" OR "risk assessment" OR "safety assessment" OR safety OR "structural safety" OR "nonstructural safety" OR "functional safety") AND (hospitals OR hospital) AND ("natural disaster" OR earthquake OR flood OR landslide OR drought OR "cyclonic storm" OR tornado OR "tidal waves" OR wildfire OR hurricane OR "sand storm" OR "man-made disaster" OR fire OR explosion OR war OR "terrorist attack" OR "biological disaster" OR "chemical disaster" OR "nuclear disaster"). These searches were performed in abstracts, key words, and titles. Furthermore, a reference list of published studies was evaluated to increase the sensitivity of this research and to select more studies.

Data collection

The papers from the initial search and the retrieved titles were imported into EndNote software (Clarivate Analytics, Philadelphia, PA). After removing any duplicate titles, the remaining titles, abstracts, and the full text of the articles were screened by the first author (S.M.M.) and the third author (A.A.), who also reviewed the results to reduce the potential for bias introduced by a single reviewer. The method used to identify relevant articles for the review is shown in Figure 1.

Study eligibility

Inclusion and exclusion criteria

On the basis of the research goals, only studies in the field of risk analysis and safety assessment of hospitals were selected. Articles were included for review if they met the following criteria: (1) published in English; (2) published until to June 2019; and (3) original articles and conference papers. Systematic review, letter to the editor, editorials, and articles did not attempt to investigate risk analysis and safety assessment of hospitals was excluded from the study.

Quality assessment, data extraction, and analysis

The quality of the included literature was assessed independently by two reviewers (S.M.M. and M.N.)

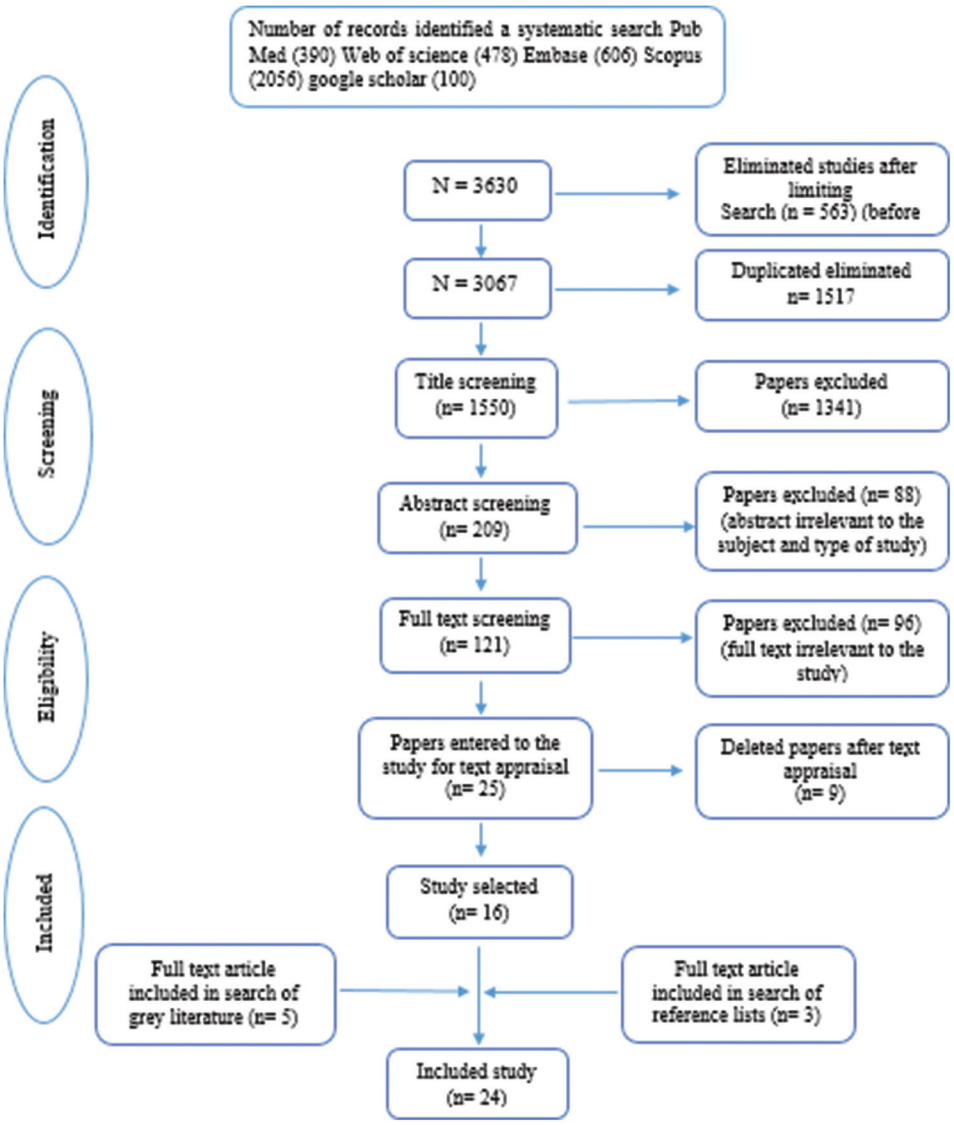

Figure 1: Flow diagram of the systematic review process

using the International Narrative Systematic Assessment tool [Table 1].[33] This tool was implemented using seven questions (with 1 point for every item). On the checklist, the maximum score was 7, and the minimum acceptable score was 5. Finally, the articles that obtained scores of 5 or above were selected and analyzed, allowing a comprehensive assessment of the quality (classified as high and low) [Table 2]. These results were reviewed by the third researcher (A.A.), and any differences identified were resolved through discussion. A data extraction form was designed according to the study goals as follows: author, year, study type, location, risk analysis method, disaster type, safety assessment method, components, and key outcomes. Data extraction was conducted by two separate researchers (S.M.M. and M.N.) to decrease the selection bias and increase the strength of research methodology, and it was confirmed that no studies had been excluded. All the extracted data were then checked by a third reviewer (A.A.). A descriptive analysis of the final studies was conducted, and its results were categorized by relation to the study questions.

Results

The initial search yielded 3630 papers, of which 563 articles before 2000, 1517 duplicate titles, and 1341 unrelated titles were removed. The abstracts of the remaining 209 titles were reviewed and 121 articles were selected. Finally, 16 articles were included from databases and also, 3 studies selected through a search of the reference lists of the retrieved articles, and 5 studies through gray literature were added to the previous articles.

The results of this review were organized by research question. The characteristics of each of the selected studies are presented in Table 2.

Table 1: International narrative systematic assessment tool for assessing scientific methodological quality of reviews

Items	Response	
	Yes	No
Background of the study clearly explained/state of the art		
Objective is clear		
Description/motivation of selection of studies		
Description of the study characteristics included is clear		
Presentation of results (paragraphs, tables, and synthesizing of data)		
Conclusion is clear		
Conflict of interest is stated		

Which methods used for risk analysis in hospitals?

From 24 articles included in this study, 11 were dedicated to risk analysis. Two studies were conducted using the HAZUS method; three were carried out by the RVS method and two by a researcher-made method. In other studies, a study was conducted using FRAME, SHM, CAPRA-GIS methods as well as the simple qualitative matrix method. Each of the abovementioned methods was performed in a specific environment which was different economically and culturally. In low-income countries, simple and qualitative methods were often performed with rapid assessments, while more developed countries often used more complex, time consuming, and researcher-made methods which required more analysis.

Which disasters have been considered most relevant for risk analysis and safety assessment?

Based on the findings of this study, twenty studies specifically focused on different types of disasters, whereas four studies considered the conditions in general and ignored the type of disaster. Of these twenty studies, 85% were devoted to natural disasters and studied their effects on hospitals. Among natural disasters, earthquakes were studied more (68%). A multi-hazard study examined both natural and man-made hazards. Another cascade study began with an earthquake but continued with the man-made hazards of explosions and fires. Among these studies, only one specifically assessed the risks of fire in a hospital.

Which methods used to measure hospital safety?

Of the 24 articles included in this review, 14 assessed hospital safety. The HSI method was used in most of these studies (85%). One study used the researcher-made method and one used the FEMA tool. Due to the low and reasonable price of the HSI method as well as rapid data collection process and allocation to the hospital environment, most low-income and developing countries make the use of this tool to determine their safety level. According to the present study, it can be seen that 9 out of 12 studies using HSI were conducted in Iran, two in Serbia, and one in Mexico.

Which components have been considered in the safety assessment and risk analysis of the hospital?

Based on the findings of this study, 58% of the studies examined all three structural, nonstructural, and functional dimensions as influential elements. Three studies (12.5%) assessed structural and nonstructural components. In other studies, three (12.5%) specifically evaluated structural components, three studies (12.5%) reviewed nonstructural components, and only one (4.5%) examined functional components. In most studies (86%), the effects of disasters were first investigated on the structures; in fact, the structure was considered the most important element, and other components were studied afterward.

What are the key outcomes of risk analysis and hospital safety assessment?

Hazard prioritization

In 39% of studies, risk analysis was emphasized to be used to identify the prioritization of hazards which had the potential to cause harm to hospitals; assessing hospital safety, unsafe components can be identified and prioritized based on their importance for the hospital activities.

Factors affecting the hospital vulnerability to risks

In this study, six articles addressed the factors affecting the vulnerability of hospitals to risks. Based on the findings of these articles, building age, building type, structural codes, type of materials used in construction, hospital design not proportional to the type of disaster, severity of the disaster, time of the disaster, type of the soil on which the hospital is built, the distance from the center of the disaster, and the construction site are the factors that increase the incidence of damage to hospitals.

Weighing risks and their impacts on safety assessment

it has been stated in seven studies that assessing safety is not highly effective without taking the weight of risks into account. Accordingly, they have emphasized that, after identifying the risks of a region, special weight should be assigned to each risk based on scientific assessments; finally, it should be used in safety assessment. Thus, the results will be more realistic and practical.

Retrofitting plans

Eleven studies (46%) have stressed the recognition of hospital strengths and weaknesses using risk analysis and safety assessment; it must result in fact-based planning for retrofitting and crisis management programs.

Table 2: Characteristics of included studies

Author name	Year	Article type	Location	Risk analysis method	Disaster type	Safety assessment method	Components	Key outcomes	Quality assessment
Lapcevic *et al.*[34]	2019	Original	Serbia	-	Flood	HSI	Structural Nonstructural Functional	The weight of the measured components in climate disasters is equal and due to the lower impact of them on the structural components, it is necessary to pay attention to nonstructural and functional components	High
Aslani and Habibi[35]	2019	Original	Iran	FRAME	Fire	-	Buildings People activities	Organizing a crisis management team in hospitals is essential and affects the results. People and hospital activities are most at risk in fires. The results show a reduction in risk after organizing a crisis management team	Low
Nenković *et al.*[36]	2018	Original	Serbia	-	Climate	HSI	Structural Nonstructural Functional	Depending on the type of risk (climate), the same weight is assumed for the components. Safety assessment should be based on the priority of the region's disasters. Existence of construction documents plays a vital role in evaluation. Due to the low impact of this type of risk (climate) on structural components, it is necessary to pay attention to nonstructural and functional aspects (emergency management program)	High
Morán and Novelo-Casanova[4]	2018	Original	Mexico	-	Earthquake	Researcher made (theoretical framework design)	Structural Nonstructural Functional administrative organization	To determine the safety status of hospitals, the vulnerability of their components has been measured. All hospitals are in very poor condition in nonstructural, functional and administrative organization components. The age of the building and the lack of design in accordance with the type of disaster are important reasons for insecurity in this study	High
Kuscahyadi *et al.*[37]	2018	Conference paper	Indonesia	HAZUS	Earthquake	-	Hospital units Medical equipment	Using tools such as GIS to draw and observe the distribution of risks is very helpful in understanding them. In this study, the interactions of structural and nonstructural components have been considered and studied as a general unit. The results show that 99.19% of hospital units and 99.41% of medical equipment are at risk. The vulnerability depends on the location and distance from the fault	High

Contd...

Table 2: Contd...

Author name	Year	Article type	Location	Risk analysis method	Disaster type	Safety assessment method	Components	Key outcomes	Quality assessment
Cruz-Vega *et al.*[15]	2018	Original	Mexico	-	Earthquake	HSI	Structural Nonstructural Functional	The results of the comparison of HSI self-assessment and evaluation by experts show a significant difference. Hospitals are reluctant to see the facts. The most damage was observed in the nonstructural components, while the self-assessment score was moderate to high	Low
Ghafouri *et al.*[38]	2018	Original	Iran	-	Natural disasters	HSI	Structural Nonstructural Functional	There is a possibility of both climatic and geological disasters in the study environment. In this study, the hospital safety was moderate and below average. Nonuniversity hospitals are in a better position than university hospitals, and public hospitals are better than private ones. The highest safety is related to performance and the lowest is related to structural components	High
Santa-Cruz *et al.*[39]	2017	Conference paper	Peru	CAPRA-GIS	Earthquake	-	Structural	In this study, first the seismic risk was assessed, then the probability of exposure was estimated and finally the vulnerability was calculated, which led to the assessment of earthquake risk for hospitals. According to the findings, in the event of an earthquake, the possibility of damage to structures due to the use of outdated structural codes is very high. Also the type of soil is very important. The age of the building is also influential	High
Marasco *et al.*[40]	2017	Original	USA	Researcher made	Cascade hazards (earthquake, explosion, fire)	-	Structural	Buildings and infrastructure are significantly vulnerable to multilateral effects. Using a multi-risk approach can improve the safety of structures and minimize life cycle costs and human losses. The sequence of earthquake hazards is unclear and depends on the location of the hospital. According to the findings, the type of materials, the type of building and the severity of the earthquake affect the probability of damage	High

Contd...

Table 2: Contd...

Author name	Year	Article type	Location	Risk analysis method	Disaster type	Safety assessment method	Components	Key outcomes	Quality assessment
Moghadam *et al.*[13]	2017	Original	Iran	-	Natural disasters	HSI	Nonstructural	In earthquake-prone areas, retrofitting of nonstructural components is as important as structural components and requires more attention, because many of them are capital and expensive, and on the other hand, their retrofitting is very cheap. Moreover, neglecting to nonstructural components can disrupt the continuation of hospital activities	High
Monfared *et al.*[41]	2017	Original	Iran	-	-	HSI	Structural Nonstructural Functional	The type of disaster should determine the weight of the components in the safety assessment. Nonstructural and functional components should be given more attention	High
Haryanto *et al.*[42]	2017	Conference paper	Indonesia	RVS	Earthquake	-	Structural Nonstructural	Using the RVS method, rapid risk assessments can be performed and, if necessary, more accurate and costly assessments can be designed. More accurate component evaluations are necessary when there is a possibility of collapse for important buildings such as hospitals	High
Gargaro *et al.*[43]	2017	Conference paper	Italy	SHM	Earthquake	-	Structural Nonstructural	The "SHF" enables remote assessment of the safety of structural and nonstructural components. This method can determine the effect of structural movements on nonstructural components. Numerical calculation of risk can provide a better understanding for managers	Low
Asefzadeh *et al.*[44]	2016	Original	Iran	-	Natural disasters	HSI	Structural Nonstructural Functional	The HSI index has been used to measure the safety of hospitals. Paying attention to nonstructural and functional components plays a vital role in keeping the hospital active and responsive. Any retrofitting program should be based on an evaluation score	Low
Ardalan *et al.*[7]	2016	Original	Iran	-	Natural disasters	HSI	Structural Nonstructural Functional	The study was conducted twice in 2012 and 2015 as a self-assessment and the results were compared. The hospital was not classified as safe. The lowest level of safety is related to functional components and the highest level is related to nonstructural components.	High

Contd...

Table 2: Contd...

Author name	Year	Article type	Location	Risk analysis method	Disaster type	Safety assessment method	Components	Key outcomes	Quality assessment
								Self-assessment can be considered as a weakness of the study. Lack of weight the risks of the study area are effective in measuring safety	
Ahmadi *et al.*[45]	2016	Original	Iran	-	-	HSI	Functional	The functional safety of hospitals has been assessed using the HSI tool. According to the findings, only half of the hospitals were in good condition in functional conditions. Disaster planning was a weakness in all hospitals	Low
Nilipour-Tabatabaei and Abbasi[46]	2016	Original	Iran	-		HSI	Structural Nonstructural Functional	Safety assessment studies should be regional and based on the most important risks. The type of risks and the level of safety should determine the safety and resilience program	High
Perrone *et al.*[47]	2015	Original	Italy	RVS	Earthquake	-	Structural Nonstructural Organizational	Seismic risk is assessed by calculating vulnerability (structural, nonstructural and organizational), risk level and exposure. The location of the hospital is very important in terms of the type of hazards in the area. The type of hazards in the area should determine the type of construction. Different building codes should be used based on the specific regional hazard	High
Djalali *et al.*[48]	2014	Original	Sweden Iran	-	-	HSI	Nonstructural	Using HSI tools, nonstructural components of hospitals in Iran and Sweden were compared. The comparison of the two countries showed that Iranian hospitals are in moderate safety condition and Swedish hospitals are in high safety condition. The level of development can be a reason for this result. For more accurate measurement, disasters in the region should be weighed and used to calculate the safety score	High
Dixit *et al.*[49]	2014	Original	Nepal	-	Earthquake	FEMA	Nonstructural	This study was performed by determining the effect of two scenarios of medium and large earthquake. According to the findings, after the moderate earthquake, all hospitals are operational and only two hospitals can be active against a large earthquake. Major nonstructural problems are: power system, water supply system, fuel storage and architectural elements.	High

Contd...

Table 2: Contd...

Author name	Year	Article type	Location	Risk analysis method	Disaster type	Safety assessment method	Components	Key outcomes	Quality assessment
								Due to the high price of nonstructural components, their reinforcement will be cost effective. In countries with weak and medium economies, a gradual approach to improving safety can be considered	
Jahangiri *et al.*[50]	2014	Original	Iran	Qualitative (simple matrix)	Multi hazard	HSI	Structural Nonstructural Functional	To risk analysis, the probability of occurrence and magnitude of risks are considered. Hospitals should be built based on the risks of the area. According to the findings, structural components had the highest risk. Nonstructural components are moderate and the most vulnerability is related to architectural components. In the functional dimension, it was the most vulnerable in emergency planning	High
Miniati and Iasio[51]	2012	Original	Italy	Researcher made	Earthquake	-	Structural Nonstructural Organizational	According to the results, the probability of an earthquake in the study area is high. The incident time plays an important role in the efficiency of the hospital. 30% of hospitals and beds are in unsafe conditions. The results of the study can be used to plan retrofitting and increase the capacity of the hospital	High
Lang *et al.*[52]	2010	Conference paper	Central America and India	RVS	Earthquake	-	Structural Nonstructural	Vulnerability is very important as an element at risk. In structural components, the type of building as well as the age of the building are vital factors. In nonstructural components, equipment and facilities are more important. There is no direct relationship between structural and nonstructural vulnerability indices, so retrofitting should be done separately	High
Tokas and Lobo[53]	2010	Conference paper	USA	HAZUS	Earthquake	-	Structural	Risk analysis can lead to the identification of the most at-risk hospitals and is essential for setting priorities. The age, type and structural building codes are factors that increase the risk of hospital collapse	High

Determining hospital construction codes

it has been highlighted in four studies that determining hospital construction codes for each region should be unique and based on risk analysis and safety assessment data. Accordingly, after risk analyze and determining the most harmful hazards in the area, their effects on hospital components should be measured, and finally appropriate construction codes and standards must be designed for each specific area.

Development level and its effect on hospital safety and retrofitting

According to two studies, development level has a significant impact on safety and retrofitting. Based on their findings, developing countries have more difficulties in dealing with risks as well as improving their safety. Risk analysis and accurate and quantitative safety assessment are fairly unlikely in these countries, and simple and qualitative methods are often used in these areas.

Self-assessment effects

Findings of two studies have revealed that self-assessment is a disadvantage for risk analysis and safety assessment programs because they may ignore or underestimate some key factors in order to exaggerate the good conditions of the assessed hospital.

Discussion

The occurrence of incidents and disasters, whether natural or man-made, can lead to a lot of damage to infrastructure which is naturally very expensive and necessary for the activities of a society.[54] In addition, disasters affect human health directly and indirectly and place additional burdens on the society. Under such circumstances, the first demand of people is health, and governments are obliged to provide people with health tools.[55] Hospitals, as the most comprehensive centers which provide services for patients and have specialized but expensive equipment, play a vital role in providing services and responding to emergencies. If hospitals are vulnerable to different kinds of incidents and disasters due to various reasons, they will be unavailable and will not be able to provide services for patients and people affected by disasters; therefore, societies will be harmed more. Accordingly, hospital risk analysis and safety assessment programs have a prominent role in identifying strengths and weaknesses and thus in improving weak points.[15] According to the research aims and questions, our discussion of this study can be categorized as follows: (1) risk analysis methods, (2) disaster Type, (3) hospital safety assessment methods (4) hospital components, and (5) key outcomes.

Risk analysis methods

Numerous methods have been developed for risk analysis in hospitals. Some are very expensive and time consuming, while others are fast and inexpensive. Selecting risk analysis method depends on several factors, some of which will be mentioned below. The history of disasters is one of the most significant factors in choosing the method. Areas with complex disasters which have enormous impact on the community having different levels of vulnerability need more accurate and comprehensive analysis so as to be able to precisely estimate the probability of an incident and be prepared for it. In a study by Jahangiri *et al*., it was exactly pointed out that risk analysis studies are absolutely necessary due to the high occurrence of various disasters in Iran and their impacts on health and treatment spaces.[50] Kuscahyadi *et al*. also emphasized in their study that in places with high incidence of disasters whose occurrence affects the performance of hospitals, it would be reasonable to conduct risk analysis studies.[37] Developed societies naturally have more disaster-resistant infrastructures. In developed societies, risk analysis is often examined before the construction of any type of space; accordingly, structures are designed proportional to the existing hazards. Developing countries, however, strive to achieve development indicators, but most of their resources are spent on livelihoods and are unlikely to achieve long-term and costly goals. Such countries are extremely vulnerable to disasters and lose most of their infrastructures in the case of a disaster. Because of the existing limitations, risk analysis is not studied in these countries and most of critical and vital facilities are built in hazardous areas. Ardalan *et al*. examined the Bam earthquake (occurred in Iran) which killed about half of the people and entirely demolished all the infrastructures. Therefore, developing countries are said to have different abilities to choose the type of risk analysis programs compared to the developed countries.[7] Another essential factor that affects the choice of method is the income level. Obviously, the development level influences the income level; developed countries have much more financial resources than developing countries and can use more expensive and more accurate projects to analyze the risks. This is obviously apparent at micro levels. Higher-income organizations and institutions seek to precisely identify the risks which threaten them so that they can be prepared in a timely manner and avoid the consequences of disasters. In their study, Djalali *et al*. compared Sweden and Iran concerning risk analysis methods and showed that the development level, and consequently, the income level of these two countries were very crucial in choosing the risk analysis method.[48] Skilled and specialized manpower is another vital factor in choosing the risk analysis method. Skillful workforce with sufficient technical knowledge can lead to more accurate analysis with their results being more reliable. Based on the findings of this study, methods such as RVS and simple risk analysis matrix are said to be cheap

and quickly applicable and therefore can be used when resources are limited. On the other hand, more exact methods such as HAZUS or researcher-made methods which combine several different methods are more expensive and time consuming, so they require more financial and human resources. Haryanto *et al*. have pointed out in their study that, when there is a need for immediate assessment, but there is insufficient expert workforce, simpler methods must be used to analyze the risks because any kind of planning fails without risk analysis.[42]

Disaster type

According to the findings of the study, 84% of the studies are devoted to natural disasters, with more studies being allocated to the earthquake (68%). More attention to natural disasters is justifiable due to several reasons. First, natural disasters are often unpredictable. Disasters of geological origin are less predictable than meteorological disasters, and therefore most efforts have been made to analyze the risks of geological hazards including earthquakes. The severity of the occurrence is the second reason why natural hazards must be taken into consideration. Even if the disaster is predicted, estimating its severity is very difficult and even impossible in some cases. An area may be located on a fault with high seismic potential, but it is virtually impossible to predict how strong an earthquake will be. The extent to which risks affect the society is also a very important factor in paying more attention to natural hazards. An earthquake, if occurs severely, is a disaster that can disrupt the society and cause the destruction of vital infrastructure as well as manpower. In this case, even the strongest structures may be at risk and may not be able to provide services due to damage to any of the structural, nonstructural, or functional components. Floods, on a large scale, have also a great impact on society and can, like an earthquake, disrupt the provision of services for the affected population. According to the findings of the studies, most recurring and destructive disasters are of higher priority in each region. Therefore, in order to conduct risk analysis studies in any region, the dominant risks must be identified, and the details of risk analysis should then be designed. In their study, Perrone *et al*. have emphasized that, since geological events especially earthquakes occur abruptly and can cause severe damage, priority must be given to this type of disaster.[47] Moreover, the multi-hazard approach should be taken into consideration in risk analysis studies. Each area may be affected by several hazards at the same time, and paying attention to them simultaneously can result in better understanding and consequently, more precise preparation plans. Paying special attention to only one type of hazard may lead to neglecting other hazards, and if they occur, society will seriously suffer damage. In addition, the cascade occurrence of disasters should not be overlooked. After the severe natural disasters occur, secondary disasters, whether natural or manmade, may happen; therefore, they need attention. A fire or an explosion may occur after an earthquake due to improper retrofitting or high intensity of the incident, and this leads to more injuries. In addition, owing to damage to infrastructure and the impossibility of providing health and treatment services, the spread of infectious diseases is very likely. Therefore, comprehensive and multi-hazard approaches are said to provide more accurate results. In their study, Jahangiri *et al*. have emphasized that multi-hazard approaches can provide decision makers with a deeper understanding as few areas may be found in the history that have been threatened by only a certain type of disaster.[50] Marasco *et al*. have pointed out that attention to cascading hazards can lead to accurate preparedness plan against disasters.[40]

Hospital safety assessment methods

According to the results of the study, 84% of the studies examining the safety of hospitals have used the HSI tool. Developed by the WHO, this tool is reliable, inexpensive, and quick; according to its items, weaknesses and unsafe hospital modules can be identified quickly, and measures can be taken to strengthen them. The great advantage of this tool is that it is allocated to the hospital, and all its items are designed based on the items available in the hospital. Since it is inexpensive, most developing countries use it because it does not require many experts and thus no accurate statistical analyses which need a lot of time and money. According to the findings, countries such as Iran, Serbia, and Mexico apply this tool more than others. When resources exist, accurate quantitative methods are apparently preferred; however, the WHO has designed this tool in order to coordinate measures and to determine the hospital safety index in all countries of the world. Ardalan *et al*. stated in their study that tools such as HSI which are dedicated to hospital safety assessment are highly effective for rapid assessments as well as for countries which do not have high financial capacity to use more precise and specialized tools.[7] Jahangiri *et al*. also emphasized that there are different methods for assessment the safety of hospitals, but they are not applicable to all communities and countries. Communities are different in level of development and level of income as well as manpower. Therefore, all countries cannot use expensive and time-consuming methods.[50]

Hospital components

Every hospital consists of three structural, nonstructural, and functional components. As stated in the research findings, more than half of the studies (56%) examined all three structural, nonstructural, and functional components. Most studies (86%) first examined the

effect of disasters on the structure and then on other components. Interaction between the components is so prominent. None of the components is able to operate independently of others, and damage to any of the components can lead to disruption of the entire system. Another key point is the role of the structure in the whole system. If the structure is severely damaged and demolished, many people are killed or injured, nonstructural components, facilities, and devices are devastated, and as a result, the hospital loses its efficiency. According to the WHO/Pan American Health Organization, when geological disasters are a priority in a region and when the risk of their occurrence is high, variable weight should be used to measure the safety of components, and 50% of the total weight should be allocated to structural components, 30% to nonstructural components, and 20% to functional components. Accordingly, the importance of structural components can be understood in geological hazards.[56] Moreover, it is recommended that the same weight be considered for all components in climatic hazards because structures are less likely to be damaged and to collapse in this type of disasters. Based on all cases mentioned above, examining only one of the components is not very logical, and all components of a complex system such as a hospital should be studied with their interactions being measured. In their study, Lapčević *et al*. have stressed that hospital components should be investigated together because these components interact with each other and a malfunction of one may disrupt the whole system.[34] Nenković-Riznić *et al*. have stated that due to the low impact of climatic disasters on hospital structures, more attention must be paid to nonstructural and functional components while studying these types of disasters and their effects on health facilities.[36] Morán-Rodríguez and Novelo-Casanova have pointed out in their research that having a single structure resistant to various types of disasters is not enough, and in the case of damage to nonstructural and functional components, the hospital fails to operate; therefore, all components must be taken into huge consideration.[4]

Key outcomes

Prioritization of risks is one of the key results obtained from the studies. No countries, whether developed or developing, have enough resources to address all kinds of risks. Therefore, when resources are limited, it is necessary to identify the most important types of risks, to recognize their priorities by conducting more detailed risk analysis studies and to allocate the necessary resources for them. Prioritization can also attract managers' attentions because risk may not be significant to them, but its importance will become clear after conducting risk analysis studies. Managers, as beneficiaries and decision makers, have a vital role in managing risks and responding to disasters; therefore, attracting their attention can remove many barriers. In a study by Tokas and Lobo, prioritization is one of the goals of risk analysis and safety assessment studies. Owing to the restricted resources, retrofitting all components against all types of disasters is impractical.[53] There are other key factors affecting the vulnerability of hospitals to risks. These factors include building age, building type, structural codes, type of materials used in construction, hospital design not proportional to the type of disaster, severity of the disaster, time of the disaster, type of the soil on which the hospital is built, and the distance from the center of the disaster and the construction site. What is important is that not all factors are required to cause vulnerability; sometimes, just one or some cases can seriously damage the hospital. For example, design which is not proportional to the type of disaster is one of the vital destructive factors. Suppose a hospital is built with structural codes against floods, while earthquake risk is a priority in the region. In these circumstances, an earthquake will surely destroy the hospital because this building is not designed to deal with the earthquake. Santa-Cruz *et al*. have stated in their study that, in addition to risk analysis, identifying factors influencing hospital vulnerability is critical to resilience planning. No accurate and effective program may be implemented without knowing the aggravating factors.[39] In their study, Tokas and Lobo have stressed that factors such as building age, material used in the construction, and structural codes affect hospital vulnerability, so they must be carefully identified and examined.[53] Another key point of the present study is disaster weighting and its impact on calculations. A disaster may be highly recurrent in a particular area but have little potential for system collapse or cause minor damage. On the other hand, it might be a potential hazard which may occur and cause serious damage to the system. Therefore, the weight of each hazard in the whole system must be taken into account in calculations and analyses. Retrofit planning is another key and vital point. In fact, all activities done for safety assessment and risk analysis are a basis for planning. Planning based on risk measurement and prioritization as well as safety assessment and strength and weakness identification can certainly reduce problems to a large extent. For example, in an area where the earthquake is considered the first hazard, and a hospital structure is considered unsafe in a safety assessment, planning for retrofitting or other structural strategies is a priority because in the case of nonstructural reinforcement, the unsafe structure will collapse, and consequently the structure and all the expenses spent for it will be lost. Lapčević *et al*. have shown in their study that the seismic risk is low while the climatic hazards and floods are prevalent in a country like Serbia. Thus, more weight should be allocated to climatic hazards while analyzing risks and assessing possibilities so as to obtain logical analyses and reliable results.[34] Another key point is to

determine hospital construction codes. Making use of a predesigned plan which is similar for all regions of a country is not rational. The design of construction codes should be based on risk analysis and on the hazard type as well as the severity of its effects. A country may be threatened by floods and hurricanes in the geographical region A and by earthquakes and geological activities in the region B. In this case, codes and standards designed for the region A cannot be used for the region B. Moreover, using the same structural codes is not cost effective. An area which is not threatened by earthquakes does not require advanced and very expensive retrofitting because it can be a waste of resources. A study by Perrone *et al*. has revealed that the hospital construction site is very prominent concerning the hazard type. The hazard type should determine the construction type. Different construction codes must be used according to specific regional hazards.[47] The development level is another key factor determining the resources available for risk analysis and safety assessment studies as well as for poststudy plans. In developing countries, resources are practically spent on the country's expenditures, and development investments are insignificant; therefore, simple risk analysis and safety assessment methods, which are usually less accurate than complex ones, are mostly used in these countries. In addition, when weaknesses are identified, not many resources are available to retrofitting and standardize them, and consequently simple and inexpensive methods are applied. On the other hand, developed countries can carry out more detailed studies, and as a result, prepare more detailed plans for retrofitting due to abundant resources. In their study conducted in Iran and Sweden, Djalali *et al*. have pointed out that, in developed countries, in addition to more accurate risk analysis studies, better retrofitting programs can be implemented because government's revenues are more than its expenses; thus, the society is able to invest in retrofitting.[48] Finally, the last key point is the impact of self-assessment on safety assessment and risk analysis results. Self-assessment is the weakness of safety assessment and risk analysis programs because people either are unwilling to be aware of their weak points or consider them trivial since they have been faced with them a lot. Therefore, many cases may be underestimated or even ignored in self-assessment. To solve this problem, team evaluations in which hospital members are also part of the evaluation team can be used, and the results must be discussed. Ardalan *et al*. have emphasized that self-assessment is the weakness of safety assessment programs in a country like Iran, and that the results may not be reliable in the absence of the specialized teams.[7]

Limitations

This study conducted to investigate risk analysis and safety assessment of hospitals against disasters has several important limitations: (1) the studies included for review were published in the English language, meaning that potentially relevant research published in other languages was excluded. (2) We did not have access to some databases such as CINAHL. (3) Selecting articles for a systematic review involves at least some reviewer bias, as judgment is involved in screening and selection. We attempted to mitigate the effects of this bias by involving multiple reviewers, both for the selection and for the subsequent analyses. (4) In the course of conducting this study, we combined studies with different methods. Therefore, generalization of the results should be considered with caution.

Conclusion

Hospitals and health centers are the most important infrastructure of any society which addresses incidents and disasters. Disasters are a threat to peoples' lives and properties, and therefore hospitals must be available at the time of the incident and be able to meet the needs of the affected communities. The occurrence and thus the consequences of disasters can never be decreased to zero because the occurrence as well as the severity of many natural and even man-made disasters is unpredictable, but it is possible to identify strengths and weaknesses, implement retrofitting programs proportional to hazard type and safety conditions, and thus minimizing the risk level by conducting risk analysis studies, understanding the risks, and assessing the safety of the hospital. The important point is that there is no single solution for all societies concerning disasters and dealing with or responding to them because societies and countries are very different in terms of geographical location, political, social, economic, and cultural status. However, this does not mean that communities stop their activities. According to their internal and external conditions and their existing resources, countries should conduct risk analysis studies for their vital infrastructure and prepare themselves for different scenarios so as to avoid serious damage to peoples' lives and properties in the case of disasters. Most developing countries are located in high-risk areas which impose heavy losses on them annually, so investing in risk analysis and taking actions proportional to the hazard type can be very efficient in future. In addition to having very expensive equipment, facilities such as hospitals have skilled manpower whose absence at the time of disasters will have devastating effects. Based on the cases mentioned in this article, it can be stated that paying special attention to hospitals, conducting risk analysis studies and assessing safety are crucial activities which, if not taken into account, can result in irreparable damage.

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