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A Hybrid Risk Assessment Approach for Assessing the Earthquake Risks in Worn-out Urban Fabrics: A Case Study in Iran

Abstract

Purpose: In order to reduce financial and human losses, managing risks associated with earthquakes is essential in practice. However, in using common risk management methods, experts are often faced with ambiguities that can create profound challenges for risk management. Therefore, it is necessary to develop a logical and straightforward risk assessment model to provide scientific and accurate answers to complex problems. This study aims to recommend an innovative combined method based on the Probability-Impact (P-I) approach and intuitionistic fuzzy set theory to identify and prioritize the essential earthquake risks associated with worn-out urban fabrics in the context of Iran.

Design/methodology/approach: The opinions of 15 experts in the fields of civil engineering and urban construction were gathered during brainstorming sessions. These brainstorming sessions were conducted to determine the probability of risks and the effect of identified risks. After calculating the severity of risks using the P-I approach and converting them to intuitionistic fuzzy sets, the risks were measured and prioritized based on their individual scores.

Findings: The study results indicated that risk of damage due to buildings' age and flooding risk had the highest and lowest priorities in causes of financial damage, respectively. Furthermore, the risk of damage due to building quality (demolition) and building age was the most important. The risk of flooding and damage to communication networks has the lowest importance among causes of fatalities in worn-out urban fabrics.

Originality/value: The study findings and recommendations can be served as a policy and consultative instrument for the relevant stakeholders in the area of urban management.

Keywords: Risk assessment; Intuitionistic fuzzy sets; Worn-out urban fabrics; Probability Impact, Earthquake risks; Iran.

1. Introduction

Investigating a city's characteristics and potential for dealing with natural disasters and proper planning for prevention and reduction of damages and fatalities caused by the resulting crises requires the use of specific strategies (Mejri et al., 2017). One of the most critical factors for reducing the risk of earthquakes is proper readiness. This readiness includes predetermined plans and strategies (Kates, 1977). One of the main goals of urban planning is reducing the vulnerability of cities against the effects of earthquakes (Salvati et al., 2019). In this regard, worn-out urban fabrics have a higher level of risk of earthquakes due to their unsuitable conditions. Worn-out urban fabrics are areas in a city whose quality, physical properties, and performance have declined over time (Nakhi et al., 2016). People from lower-income societies usually occupy these areas, do not have proper access to several urban services, and are sometimes ignored during earthquakes. Essential characteristics of worn-out urban fabrics include a low number of floors, lack of good access points, and use of traditional building materials in their construction. Usually, these buildings lack proper construction structures (Salvati et al., 2019). Worn-out urban fabrics are in critical conditions regarding vulnerability during crises. Therefore, it is necessary to use proper strategies in order to reduce the adverse effect of earthquakes in these areas (Liu et al., 2019).

Crisis management and addressing the vulnerabilities of worn-out urban fabrics is essential due to the population density, types of building materials, and high age of buildings (Tsai and Chen, 2010). In order to reduce possible vulnerabilities during earthquakes, it is necessary to identify existing challenges and factors affecting these challenges. Lack of proper and accurate evaluation for identifying these uncertain factors will create challenges for any planning and decrease the credibility of developed strategies.

Risk management is one of the essential parts of project management. One of the common characteristics of all risk analysis literature is estimating the risk probabilities (Chan et al., 2011). In many cases, due to ambiguities and the complexity of the problems, experts are faced with uncertainties that challenge their estimations and decrease the accuracy of their results. Some methods do not consider uncertainties and ambiguities or explicitly use them in risk analysis (Yazdi and Kabir, 2017). Intuitionistic fuzzy logic is a fuzzy set for creating multivariable logical models. It can be a valuable and powerful tool for solving complex and uncertain problems with high accuracy (Dabiri et al., 2021). Risk assessment provides necessary and essential information for prioritizing preventive strategies and reducing risks (Tamošaitienė et al., 2021). Based on the challenges in worn-out urban fabrics, the risk management process must focus on preventive and effective management of all predictable risks

The aim of the current study is to provide an accurate model for risk assessment during earthquakes. The proposed hybrid model combines of the Probability-Impact (P-I) model and intuitionistic fuzzy logic and sets. For the case study of this model, the worn-out urban fabrics of the Jalili region in Kermanshah city – Iran, is selected due to its complex and unique characteristics. The results of this study can be used for risk management and preventive planning in order to reduce possible dangers.

2. Literature Review

Many countries in the world are constantly facing the risk of earthquakes. Iran is one of the countries with the highest risk of earthquake in the world. Around 8% of the total earthquakes around worldwide and approximately 17% of large-scale earthquakes have occurred in Iran (Raeesi et al., 2017). In the meanwhile, with the presence of worn-out urban fabrics in various regions of cities in Iran, the probability of vulnerability increases during an earthquake.

Worn-out urban fabrics are important residential areas in many Iranian cities that require interventions and modifications based on their natural and social characteristics (Mili et al., 2018). Investigating the vulnerability of worn-out urban fabrics with old building materials, including historical and cultural resource sites as well as residential areas, is essential (Ferreira et al., 2013). Worn-out urban fabrics are usually composed of very old buildings and are mainly made of traditional and non-standard materials (Kiani et al., 2017; FEMA, 2010). The main features of Worn-out urban fabrics include the age of buildings, low number of floors, lack of proper access, and obsolescence (Sadeghi et al., 2021). Typically, these buildings do not have a proper structural system (Salvati et al., 2019). In worn-out urban fabrics, urban infrastructures such as networks and installations of electricity, gas, telecommunications, as well as water and wastewater networks are worn-out and very vulnerable. These infrastructures are faced with various challenges in times of emergency services (Cirianni et al., 2012; Dabiri et al., 2020). Due to the condition of buildings, infrastructure and urban facilities in worn-out urban fabrics, there is a possibility of fire and explosion, as well as flooding in case of earthquakes (Ruiter et al., 2017). Therefore, it is necessary to provide suitable predictions regarding worn-out urban fabrics and critical challenges during earthquakes.

In order to reduce earthquake vulnerability, integration of urban planning and risk management factors can help provide a more accurate risk and vulnerability assessment. These results can then be used for creating strategies and plans for dealing with the aftermath of earthquakes (Ruiter et al., 2017). Risk management process helps better understand earthquake risks and can affect future decision-making of managers (Dabiri et al., 2021). Risk management is a multi-stage process using a wide range of data, parameters, and uncertain factors (Sarvari et al., 2014). Multi-stage risk management processes include: (*i*) Risk management planning; (*ii*) Risk identification; (*iii*) Qualitative and quantitative evaluation of risks; (*iv*) Response planning; (*v*) Monitoring and control (PMI, 2017).

Identification and prioritization of risks are essential in later risk management steps and require methods dealing with uncertainty due to the uncertain nature of the risk. Fuzzy theory is one such approach that was first introduced in an article by Zadeh (1965). Fuzzy sets are potent tools for describing phenomena affected by uncertain parameters and creating non-binary logical models. Unlike traditional sets, in fuzzy sets, each member's membership is located in the range of [0,1], which is graded and known as the degree of membership (Zadeh, 1965). Many attempts have been made to generalize fuzzy sets, among which are iv-fuzzy sets, L-fuzzy sets, and IFSs, Vague sets. One of the most important generalizations of fuzzy sets is Intuitionistic fuzzy sets. These sets were first introduced by Atanassov (1986), who showed that membership of a member in the group could be demonstrated using two parameters of the degree of membership $\mu(x)$ and degree of non-membership $\gamma(x)$. Intuitionistic fuzzy sets and logic are used in various scientific fields, and these sets have been extensively used to solve complex and ambiguous problems in uncertain and probability models.

Various studies have investigated the vulnerability of cities during earthquakes. Rashed (2003) surveyed to examine the vulnerably of the state of California against earthquakes using the Analytical Hierarchy Process (AHP) approach in the Geographic Information System (GIS) environment and introduced AHP and Fuzzy approaches as reliable approaches for measuring the vulnerability of cities against earthquakes. Tang and Wen (2009) used artificial intelligence systems in order to evaluate earthquake risk in Deyang city – China. Peng (2015) stated that evaluating the vulnerabilities of various regions is essential for preventing and reducing the damages caused by earthquakes and proposed using different Multi-Criteria Decision Making (MCDM) approaches.

With the rapid advancement of science and technology and the resulting developments, many decisions are affected, especially in complex and ambiguous cases, as well as due to organizational and operational breadth (Sarvari et al., 2021; Dabiri et al., 2021). In such cases, due to the specialization of topics and the specific complexity of the issues, as well as the lack of knowledge, awareness, and individual skills, individual decision-making cannot be used and group interaction should be focused. There are many different ways to make group decisions. One of these methods is the brainstorming technique, which is a group method and a process for creating new ideas. Brainstorming is a collective and common method in which people present their ideas to solve a specific problem or issues and then discuss them in groups and finally reach a general agreement (Besant, 2016). The main challenges in applying the brainstorming technique are due to real-world conditions, ambiguities and doubts caused by human thinking, data and information. This technique is not accurate enough in the face of these challenges, and ultimately no accurate evaluation is done. Intuitionistic fuzzy sets theory covers many of the ambiguities and doubts that arise in decisions.

Previous studies have shown that most researchers use common uncertain and probability approaches for risk assessment while ignoring ambiguities and doubts during the risk management process. Intuitionistic fuzzy logic and sets are powerful tools for solving this problem and considering these ambiguities and uncertainties during risk management. This will then result in higher accuracy of the risk management process. This study uses a hybrid brainstorming and Probability–Impact model and Intuitionistic fuzzy sets to evaluate and prioritize possible risks in worn-out urban fabrics. The earthquake risks extracted from various literature are presented in Table 1.

Please insert Table 1 about here

3. Area of the Study

Kermanshah province is located in the western part of Iran; and its capital is the city of Kermanshah. The city of Kermanshah, with a total population of 946,651, is the ninth most populated city in Iran. This city hosts 48.5% of the total population of Kermanshah province and is divided into eight municipal districts and 136 zones. Among the eight municipal districts, district 3 contains the Jalili zone that was investigated in this study due to its worn-out construction. This district divided into 26 zones. The Jalili zone is one of the oldest zones in Kermanshah, and its population is predicted to reach a total of 1,212 by the end of 2020. This zone covers an area of 136,336 square meters, most of which is made from worn-out buildings of 50 years or older of age. Figure 1 shows the studied region in the city of Kermanshah–Iran.

Please insert Figure 1 about here

Residential buildings in the Jalili zone often have small areas. The building materials used in these buildings often include traditional and low-strength materials. The access situation in this zone is unsuitable, with the width of passages inside the area being less than 8 meters. The zone also lacks open spaces such as parks and a dedicated fire station, emergency service, or medical center. The water and wastewater network is ancient and the most common problem in this network is the fracturing and failure of old cast iron pipes. The gas transfer system, the electrical network, and the telecommunication cables and facilities lack sufficient quality.

4. Research Methodology

This study used the Probability-Impact (P-I) and brainstorming processes while using Intuitionistic fuzzy logic and sets for analysis of the risks in worn-out urban fabrics. The identified risks in previous studies were evaluated and analyzed using the brainstorming approach. The members of the brainstorming team identified the risks after discussing the identified challenges and risks based on a desktop review of previous research studies. During the review at this stage, the experts finally confirmed all the identified risks from reviewing the literature and classifying them as significant earthquake hazards in the dilapidated urban fabrics. With the emphasis of the team experts on the comprehensiveness of the identified risks from the literature review, finally, 19 risks were identified. The information gathered from field studies and documents of relevant organizations (including technical data, photos, census results, etc.) were presented to the brainstorming team members. Then, the experts during brainstorming sessions were asked to determine the variable parameters of Intuitionistic fuzzy sets for these risks (including the degree of accuracy, degree of inaccuracy, and degree of uncertainty). These parameters were used as the basis of Intuitionistic fuzzy set calculations for risk analysis and prioritization. After determining the Intuitionistic fuzzy parameters of the probability of occurrence, and impact of risks, the intensity of risks was calculated, and their upper and lower limits were determined. The numerical interval of the probability of occurrence and impact of risks and unbalanced probability scoring and effects of risks were considered in this study, and the P-I matrix was created. It is generally accepted that the impact of a risk is calculated by the product of its level of severity and likelihood of occurrence (Chan et al, 2011; Sarvari et al., 2014; Tamošaitienė et al., 2021). It is a matrix divided into three regions of high, medium, and low priority. After defuzzification of the numbers, the resulting risks are prioritized according to their scores. Compared to the P-I matrix, risks are classified into 3 categories based on their degree of risk, including high risk (high priority), medium risk (medium priority), and low risk (low priority). This prioritization is the basis of following risk management steps and the following decision-making by managers and urban authorities to provide suitable solutions for the studied region.

4.1. Hybrid brainstorming and Intuitionistic Fuzzy Set approach

In decision-making about specialized topics, personal decisions cannot be used due to the complexity of the case and lack of sufficient knowledge, awareness, and personal skills as it might not be adequate for solving the problem or specialized topic at hand (Chunhua and Guozhen, 2020). Therefore, it is necessary to focus on a group approach. Various methods are used in group decision-making. Brainstorming is one such method that Alex Fackney Osbon first introduced in 1939 as a creative problem-solving method (Sekhar and Lidiya, 2012). Brainstorming includes various rules and specialized techniques that result in the creation of new ideas that might not occur under normal circumstances (Bonnardel and Didier, 2020). The members of the brainstorming team are usually between 5-10 individuals (Sekhar and Lidiya, 2012). The statistical population of the current study were included 15 experts in various urban planning and engineering fields. The experts were included the experienced employees of multiple companies and organizations include the electrical distribution company, the water and wastewater organization, the telecommunication organization, the gas company, the construction engineering council, and the regional municipalities. The use of brainstorming and Intuitionistic fuzzy sets can be divided into 5 stages, including (1) holding brainstorming sessions for risk assessment and determination of Intuitionistic fuzzy risk parameters; (2) data analysis using Intuitionistic fuzzy sets; (3) calculating the severity of risks and upper and lower boundaries; (4) defuzzification of the calculated values and finally (5) prioritization and determination of high-priority risks.

An Intuitionistic fuzzy set A of reference set X is defined as follows:

$A=\{<x, \mu_A(x), \gamma_A(x)> \mid x \in X\}$

The $\mu_A : X \to [0,1]$ and $\gamma_A : X \to [0,1]$ functions with the condition of $0 \leq \mu_A(x) + \gamma_A(x) \leq 1$ are the membership function and real values of $\mu_A(x)$ and $\gamma_A(x)$ in the [0,1] interval and are known as degree of membership and degree of non-membership of X in A, respectively.

Each fuzzy set A' is a special case of Intuitionistic fuzzy sets and can be written as Intuitionistic fuzzy set of $A = \{< x, \mu_A(x), 1 - \mu_A(x) > | x \epsilon X\}$. For every Intuitionistic fuzzy set A of X, $\pi_A(x) = 1 - [\mu_A(x) + \gamma_A(x)]$ is known as the intuitionistic parameter of x in A which is the degree of uncertainty of x in A. Obviously, for every x in X we have $0 \leq \pi_A(x) \leq 1$ (1989).

5. Results and Discussion

5.1. Using proposed method for risk assessment of studied region

During nine brainstorming sessions, experts evaluated and reviewed the information and data regarding the risks, and a consensus was reached regarding the final list of risks based on previous literature. In the next step, experts evaluated and determined Intuitionistic fuzzy parameters of the probability of occurrence and impact of risks on goals (financial and human losses) and selected the values for degree of accuracy, degree of inaccuracy, and degree of uncertainty for every risk. The results obtained from this step are presented in Table 2. They show the Intuitionistic fuzzy parameters of 46 main risks evaluated in this study and their probability and impact on financial and human losses. The degree of accuracy of risks indicates the likelihood of their occurrence and effects on losses, while a degree of inaccuracy is the inverse concept. The Intuitionistic parameter of the degree of uncertainty suggests the amount of uncertainty for each risk assessment. For example, the probability of a particular risk during an earthquake may be high while its impact on losses is low or vice versa. For example, Table 2 indicates that the probability of obstruction in paths with widths of less than 5 meters of 0.9, its impact on financial losses is 0.15 and its effects on human losses is 0.85.

Please insert Table 2 about here

5.2. Prioritization of risks using Intuitionistic fuzzy sets and P–I model

In this stage, the identified risks were evaluated and prioritized using Intuitionistic fuzzy sets. In qualitative risk assessment, to combine the probability and impact dimensions and their estimations, each linguistic variable was assigned a numerical equivalent. Then the risk assessment matrix is formed based on the unbalanced scoring system, and the prioritization limits are determined in the matrix After the Intuitionistic fuzzy calculations of risks and defuzzification of their impacts, the prioritization of the risks are carried out. All numerical comparisons for the probability of occurrence and impact of risks and their numerical range and the risk assessment matrix are specific to this study but can be used in other studies. The following section explains these steps.

5.2.1. Interpretation of linguistic variables of risk dimensions (probability and impact)

The linguistic variables include five level (i.e., very low, low, medium, high, and very high). Numerical values are used for the interpretation of variables Furthermore, to increase the accuracy of comparisons, a numerical range was used for the probability of occurrence and the impact of risks instead of a number (Table 3).

Please insert Table 3 about here

5.2.2. P-I Risk assessment matrix

This matrix is one of the most common methods for showing the combination of probability and impact. The severity of risks is their probability multiplied by their effect, as presented in this matrix. This study uses a 5x5 matrix which includes three zones of red (high priority), orange (medium priority), and green (low priority). Figure 2 shows the probability and impact scores based on the unbalanced scoring system. This scoring is presented in Table 3. According to Figure 2, risks with scores higher than 0.288 are high priority, and risks with scores lower than 0.096 are low priority, with scores between these two values considered a medium priority.

Please insert Figure 2 about here

5.2.3. Determination of upper and lower boundaries and risk severity (P-I scores)

Based on the Intuitionistic fuzzy parameters, the upper and lower boundaries and severities of risks in worn-out urban fabrics investigated in this study were determined using Excel software.

These results are presented in Table 4. The following equations are used for boundary calculations:

L = $\mu_A(x)$*D

U = (1-$\gamma_A(x)$*D

U-L = $\pi_A(x)$ *D

Where $\mu_A(x)$ is degree of accuracy, $\gamma_A(x)$ is degree of inaccuracy, $\pi_A(x)$ is the degree of uncertainty, L is the lower boundary of damage risk, U is the upper boundary of damage risk and D is the impact of the damage caused.

<u>Please insert Table 4 about here</u>

5.2.4. Defuzzification of risk severities

A threshold is defined for defuzzification of risk severities. This threshold is the difference between upper and lower boundaries of risk severities. The following equations are used for defuzzification:

If U-L > M, (U+L) / 2

If U-L < M, U

Where U is the upper boundary of damage, L is the lower boundary, M is the median, and U-L is the difference between upper and lower boundaries. The median of U-L value is calculated using Excel software. This value was equal to 0.02925 for financial damage and 0.008750 for human damage (casualties).

Mf = 0.02925

Mc = 0.00875

Finally, the defuzzification equations and Microsoft Excel software were used to defuzzify risk severities..

5.2.5. Prioritization of individual risks

In this stage, individual risks were prioritized based on their scores and compared using the risk evaluation matrix. First, risks were sorted in descending order according to their scores. Then, the P-I matrix was compared to determine their priority (high, medium, or low). In this matrix, red indicates risks with high priority, orange shows risks with medium priority, and green reveals risks with low priority. Table5 shows the severity of risks and their impact on financial and human losses, respectively.

Please insert Table 5 about here

5.3. Discussion of the analytical results

5.3.1. Effect of risks on financial losses

The results presented in Table 5 show that among 46 risks, 27 risks had high priority (numbers 1 to 27), 6 risks had medium priority (risks 28 to 33) and 13 risks had low priority (risks 34 to 46). Evaluating the risks with high priority shows that vulnerability caused by building's age (51 years and older) with a total score of 0.9262 had the highest, and the vulnerability caused by fracture of water pipes with a score of 0.325 had the lowest scores in this group. Among these 27 high-priority risks, 20 risks had scores higher than 0.5. Only 7 had scores below 0.5 with Vulnerability caused by building's age (51 years and older), Vulnerability caused by several floors (1-2 floors), and Vulnerability caused by a type of structure (other) having first to third highest priorities, respectively. There was a total of 6 risks with medium priority, among which fire hazard with a total score of 0.22 had the highest score, and Vulnerability caused by building quality (new buildings) with a score of 0.105 had the lowest score in this category. Risks with low priority included 13 risks, among which the Obstruction of passages (width of 5-8 meters) had the highest score with 0.085 and flooding of paths and buildings had the lowest score with 0.0075. The highest financial losses are observed for the top 10 risks in the high priority category, with the most apparent damage observed to residential buildings and water and wastewater networks.

5.3.2. Effect of risks on human losses

The prioritization and risk assessment results indicate that among 46 risks, 15 risks had high priority and were very impactful; 3 risks had medium priority, and 28 risks had low priority, which related to urban facilities and secondary risks. The high score of the first 15 risks indicates that the situation of the studied region is very critical in regards to human losses and casualties in case of an earthquake. A brief explanation of investigated risks is as follows: (1) risks of damage to residential buildings and lack of access and obstruction of passages and roads have the highest scores and the most significant effect on casualties. These risks, therefore, have high priority. (2) Risks of worn-out buildings and buildings with the age of higher than 51 years are in the first and second place in Table 5 with a score of 0.8775, and the risk of buildings with 1-2 floors is in the third place with a total score of 0.8415. Given the fact that the majority of buildings in the Jalili zone use other types of building materials (mudbricks and wood, brick and wood, brick and steel, and other traditional building materials), they are significantly vulnerable to earthquakes. Moreover, these buildings lead to high human losses. Therefore, this risk is in the fourth place of the table with a score of 0.8235. (3) Risks of lack of access to fire stations, emergency services, and medical centers also have high priorities in this table, is placed in 5th, 7th, and 8th positions, respectively. The most common problem mentioned is the obstruction of alleyways and roads due to their small width, which will cause issues for relief and rescue efforts. The vulnerability caused by roads with a width of fewer than 5 meters with a total score of 0.7862 and the vulnerability caused by roads with a width of 5 - 8 meters with a score of 0.6187 is in the 6th and 10th positions, respectively; making them high priority risks. (4) Three risks with medium priority in this table include the vulnerability caused by buildings requiring renovation with 0.2062, fire hazard with a score of

0.1925, and vulnerability caused by the age of electrical utilities and network with a total score of 0.1125. (5) Regarding low-priority risks, vulnerability caused by environmental conditions and location had the highest score with 0.075 and flooding. Five vulnerabilities related to telecommunication networks with a score of 0 were in the last places in this table. These results show that these risks have almost zero effect on the number of human losses and casualties.

6. Conclusions and Research Implications

Risk Identification is one of the most critical steps in the risk management process. Any mistakes when identifying risks or the source and impacts of risks can reduce the accuracy of risk management. Therefore, the use of scientific and systematic processes is essential for risk identification. The aim of this study was to recommend an innovative combined method based on the Probability-Impact (P-I) approach and intuitionistic fuzzy set theory to identify and prioritize the earthquake risks associated with worn-out urban fabrics. For this purpose, the main earthquake risks in the worn-out urban fabrics were extracted by reviewing the research literature, then it was confirmed by 15 experts during brainstorming sessions. Finally, 19 critical earthquake risks in the worn-out urban fabrics were identified. The researcher-made questionnaire was developed based on 19 identified risks based on 5-point Likert measurement scale. Then the probability of risks and the effect of identified risks were solicited and determined. The P-I approach and brainstorming and Intuitionistic fuzzy sets were used to investigate the impact of risks on objectives (financial and human losses and damages) during an earthquake in worn-out urban fabrics. Analyzing the top 10 priority risks regarding financial losses indicated that the unfavorable situation of buildings and water and wastewater facilities in this zone and their vulnerability to earthquakes is due to the age of the structures. Prioritization in terms of human losses (casualties) also indicates the high casualties in this zone due to the destruction of buildings. In addition, prioritization based on human losses indicates that obstructions of passages and roads, and lack of access to emergency service, fire stations, and medical centers for timely relief and rescue during earthquakes.

In terms of the theoretical implications, this study helps to better manage safety in worn-out urban fabrics by identifying and assessing the critical earthquake risks in these areas by a novel quantitative hybrid method - which, according to the authors' knowledge, has not been studied before. In terms of the practical implications related to the results of this study, in order to reduce earthquake risks in worn-out urban fabrics, it is recommended to determine the relevant risk response strategies in advance and also to set standards and protocols by organizations. A structured definition of risk and safety management in worn-out urban fabrics dramatically increases the chance of improving disaster resilience of these areas in the built environment. In particular, it demonstrates that the renovation of dilapidated buildings, reinforcement and improvement of buildings and electrical and mechanical facilities, and expansion of access roads as well as proper risk management planning of processes, allow urban managers to help improve their effectiveness and productivity in disaster management. To succeed in disaster management, urban managers need proper organization, improvement of environmental and building conditions. Hence, some of the possible future research directions for deepening the identified findings are highlighted as follows: What are the specific managerial and environmental capabilities that allow urban managers to perform better in the field of disaster management in worn-out urban fabrics? What are the risk reduction strategies that can be adopted for worn-out urban fabrics? Moreover, as suggested by Sarvari et al. (2020) and Khosravi et al. (2020), it will also be valuable to compare the critical earthquake risks of worn-out urban fabrics with other urban spaces in order to identify any similarities and differences. Finally, the hybrid approach proposed in this study can not only be adopted for other urban worn-out fabrics in Iran and other developing countries for generalization but can also be applied in other studies in the field of risk management.

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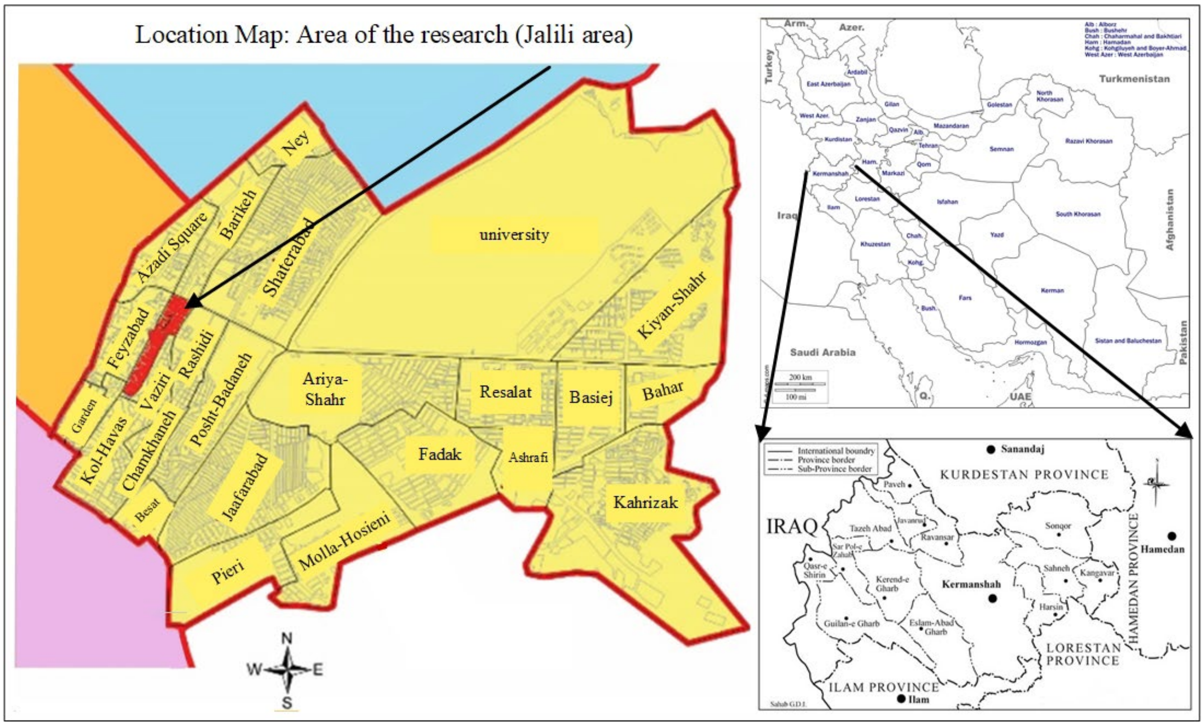

Figure 1. Location map of the studied region

Probability	Threat				
0.99	0.0594	0.1188	0.2376	0.4752	0.9504
0.70	0.042	0.084	0.168	0.336	0.672
0.50	0.030	0.06	0.12	0.24	0.48
0.30	0.018	0.036	0.072	0.144	0.288
0.10	0.006	0.012	0.024	0.048	0.096
Impact	0.06	0.12	0.24	0.48	0.96

Low priority	Medium priority	High priority

Figure 2. The probability and impact (P-I) matrix used for this study

Table 1. Risks caused by earthquakes in an area based on the literature review

Risk area	No.	Risks	Sources
Demolition and vulnerability of residential buildings	1	Vulnerability caused by type of structure	FEMA (2010); Kiani et al. (2017); Salvati et al. (2019)
	2	Vulnerability caused by structure's quality	Kiani et al. (2017); Shieh et al. (2014); Salvati et al. (2019)
	3	Vulnerability caused due to building's age	Kiani et al. (2017); Tsai and Chen (2012); Salvati et al. (2019)
	4	Vulnerability caused due to number of floors	Kiani et al. (2017); Shieh et al. (2014); Salvati et al. (2019)
	5	Vulnerability caused due to substandard materials	FEMA (2010); Tsai and Chen (2012)
	6	Vulnerability caused by environmental conditions of worn-out urban fabrics	FEMA (2010)
Infrastructural vulnerabilities	7	Vulnerability of water and wastewater infrastructures	Cirianni et al. (2012)
	8	Vulnerability of gas infrastructures	Cirianni et al. (2012)
	9	Vulnerability of electrical infrastructures and network	Sadeghi et al. (2021)
	10	Vulnerability of telecommunication infrastructure and network	Cirianni et al. (2012)
Obstructions and lack of access	11	Obstruction of passages (roads and alleyways)	Ioan Ianos (2017); Salvati et al. (2019)
	12	Lack of access to open space	Shieh et al. (2014); Ioan Ianos (2017); Salvati et al. (2019)
	13	Lack of accessibility for relief forces	Shieh et al. (2014); Ioan Ianos (2017); Salvati et al. (2019)
	14	Lack of access to fire stations	Shieh et al. (2014); Ioan Ianos (2017); Salvati et al. (2019)
	15	Lack of access to medical centers	Shieh et al. (2014); Ioan Ianos (2017); Salvati et al. (2019)
Secondary risks (secondary risks for buildings)	16	Fire hazard for buildings	Sadeghi et al. (2021)
	17	Explosion hazard	Sadeghi et al. (2021)
	18	Flooding	Ruiter et al. (2017)
	19	Damage to buildings due to aftershocks	Sadeghi et al. (2021)

Table 2. Intuitionistic fuzzy parameters of risks

Main risk area	Risks	Type	Code	Probability of occurrence and impact	Degree of accuracy	Degree of inaccuracy	Degree of uncertainty
Demolition and vulnerability of residential buildings	Vulnerability caused by type of structure	Metal skeleton	R_1	Probability of occurrence	0.75	0.15	0.10
				Financial impact	0.70	0.20	0.10
				Human loss	0.80	0.15	0.05
		Concrete skeleton	R_2	Probability of occurrence	0.5	0.35	0.15
				Financial impact	0.65	0.30	0.05
				Human loss	0.70	0.25	0.05
		Other (brick and steel, brick and wood, mudbrick and wood, etc.)	R_3	Probability of occurrence	0.90	0.07	0.03
				Financial impact	0.95	0.02	0.03
				Human loss	0.90	0.05	0.05
	Vulnerability caused by structure's quality	New buildings	R_4	Probability of occurrence	0.55	0.30	0.15
				Financial impact	0.15	0.70	0.15
				Human loss	0.05	0.90	0.05
		Acceptable	R_5	Probability of occurrence	0.65	0.25	0.10
				Financial impact	0.25	0.60	0.15
				Human loss	0.10	0.80	0.1
		Requiring renovation	R_6	Probability of occurrence	0.80	0.15	0.05
				Financial impact	0.60	0.30	0.10
				Human loss	0.25	0.65	0.10
		Requiring reconstruction	R_7	Probability of occurrence	0.95	0	0.05
				Financial impact	0.85	0.10	0.05
				Human loss	0.90	0.05	0.05
Demolition and vulnerability of residential buildings	Vulnerability caused by building's age	1-10 years	R_8	Probability of occurrence	0.15	0.75	0.10
				Financial impact	0.20	0.70	0.10
				Human loss	0.05	0.90	0.05
		11 – 30 years	R_9	Probability of occurrence	0.55	0.35	0.10
				Financial impact	0.95	0.30	0.05
				Human loss	0.70	0.25	0.05
		31 – 50 years	R_{10}	Probability of occurrence	0.85	0.10	0.05
				Financial impact	0.80	0.15	0.05
				Human loss	0.70	0.20	0.05
		Older than 51 years	R_{11}	Probability of occurrence	0.95	0	0.05
				Financial impact	0.95	0.05	0
				Human loss	0.90	0.05	0.05
	Vulnerability caused due to number of floors	1 – 2 floors	R_{12}	Probability of occurrence	0.90	0.03	0.07
				Financial impact	0.95	0	0.05
				Human loss	0.90	0.05	0.05
		3 – 5 floors	R_{13}	Probability of occurrence	0.30	0.65	0.05
				Financial impact	0.40	0.55	0.05
				Human loss	0.20	0.70	0.05

Main risk area	Risks	Type	Code	Probability of occurrence and impact	Degree of accuracy	Degree of inaccuracy	Degree of uncertainty
	Vulnerability caused due to substandard materials	--	R_{14}	Probability of occurrence	0.80	0.15	0.05
				Financial impact	0.90	0.05	0.05
				Human loss	0.70	0.25	0.05
	Vulnerability caused by environmental conditions of worn-out urban fabrics	--	R_{15}	Probability of occurrence	0.10	0.45	0.10
				Financial impact	0.30	0.65	0.05
				Human loss	0.15	0.75	0.10
Obstructions and lack of access	Obstruction of passages (roads and alleyways)	Width of less than 5 meters	R_{16}	Probability of occurrence	0.90	0.05	0.05
				Financial impact	0.15	0.80	0.05
				Human loss	0.85	0.10	0.05
		Width of 5 – 8 meters	R_{17}	Probability of occurrence	0.80	0.15	0.05
				Financial impact	0.10	0.80	0.10
				Human loss	0.75	0.15	0.10
		Width of higher than 8 meters	R_{18}	Probability of occurrence	0.20	0.75	0.05
				Financial impact	0.05	0.90	0.05
				Human loss	0.10	0.82	0.05
	Lack of access to open space	--	R_{19}	Probability of occurrence	0.85	0.10	0.05
				Financial impact	0.05	0.90	0.05
				Human loss	0.70	0.20	0.10
	Lack of accessibility for relief forces	--	R_{20}	Probability of occurrence	0.90	0.05	0.05
				Financial impact	0.05	0.85	0.10
				Human loss	0.85	0.10	0.05
	Lack of access to fire stations	--	R_{21}	Probability of occurrence	0.85	0.10	0.05
				Financial impact	0.80	0.15	0.05
				Human loss	0.90	0.05	0.05
	Lack of access to medical centers	--	R_{22}	Probability of occurrence	0.80	0.15	0.05
				Financial impact	0.80	0.15	0.05
				Human loss	0.05	0.85	0.10
Secondary risks (secondary risks for buildings)	Fire hazard	--	R_{23}	Probability of occurrence	0.50	0.40	0.10
				Financial impact	0.40	0.55	0.05
				Human loss	0.35	0.55	0.10
	Explosion hazard	--	R_{24}	Probability of occurrence	0.10	0.85	0.05
				Financial impact	0.15	0.80	0.05
				Human loss	0.10	0.80	0.10
	Flooding	--	R_{25}	Probability of occurrence	0.05	0.85	0.10
				Financial impact	0.05	0.90	0.05
				Human loss	0	0.95	0.05
	Damage to buildings due to aftershocks	--	R_{26}	Probability of occurrence	0.20	0.70	0.10
				Financial impact	0.15	0.80	0.05
				Human loss	0.05	0.90	0.05
Urban infrastructural and	Vulnerability of water and wastewater infrastructures	Type of materials used in water distribution networks	R_{27}	Probability of occurrence	0.75	0.10	0.15
				Financial impact	0.90	0.05	0.05
				Human loss	0.05	0.90	0.05

Main risk area	Risks	Type	Code	Probability of occurrence and impact	Degree of accuracy	Degree of inaccuracy	Degree of uncertainty
		Quality of water distribution network	R_{28}	Probability of occurrence	0.60	0.35	0.05
				Financial impact	0.50	0.40	0.10
				Human loss	0.03	0.90	0.07
		The age of water distribution network	R_{29}	Probability of occurrence	0.95	0.03	0.02
				Financial impact	0.80	0.10	0.10
				Human loss	0.05	0.90	0.05
		Fracture of water distribution pipes	R_{30}	Probability of occurrence	0.60	0.30	0.10
				Financial impact	0.50	0.45	0.05
				Human loss	0.02	0.95	0.03
		Type of materials used in wastewater networks	R_{31}	Probability of occurrence	0.90	0.05	0.05
				Financial impact	0.85	0.05	0.10
				Human loss	0.03	0.90	0.07
		Quality of wastewater network	R_{32}	Probability of occurrence	0.95	0.03	0.02
				Financial impact	0.90	0.05	0.05
				Human loss	0.02	0.95	0.03
		The age of wastewater network	R_{33}	Probability of occurrence	0.95	0.03	0.02
				Financial impact	0.90	0.05	0.05
				Human loss	0.02	0.95	0.05
		Fracture of wastewater pipes	R_{34}	Probability of occurrence	0.90	0.05	0.05
				Financial impact	0.85	0.10	0.05
				Human loss	0.02	0.95	0.05
	Vulnerability of gas infrastructures	Type of materials used	R_{35}	Probability of occurrence	0.15	0.80	0.05
				Financial impact	0.20	0.70	0.10
				Human loss	0.03	0.90	0.07
		The quality of network and utilities	R_{36}	Probability of occurrence	0.05	0.90	0.05
				Financial impact	0.10	0.85	0.05
				Human loss	0.02	0.90	0.08
		The age of network and utilities	R_{37}	Probability of occurrence	0.10	0.85	0.05
				Financial impact	0.15	0.80	0.05
				Human loss	0.02	0.95	0.03
		Fracture of gas transfer pipes	R_{38}	Probability of occurrence	0.05	0.90	0.05
				Financial impact	0.1	0.85	0.05
				Human loss	0.10	0.95	0.04
	Vulnerability of electrical infrastructures and network	Type of materials used	R_{39}	Probability of occurrence	0.60	0.30	0.10
				Financial impact	0.95	0.03	0.02
				Human loss	0.10	0.85	0.05
		The quality of network and utilities	R_{40}	Probability of occurrence	0.65	0.25	0.10
				Financial impact	0.85	0.10	0.05
				Human loss	0.10	0.85	0.05
		The age of network and utilities	R_{41}	Probability of occurrence	0.70	0.25	0.05
				Financial impact	0.93	0.05	0.02
				Human loss	0.15	0.75	0.10

Main risk area	Risks	Type	Code	Probability of occurrence and impact	Degree of accuracy	Degree of inaccuracy	Degree of uncertainty
		Vulnerability of aboveground and underground networks	R_{42}	Probability of occurrence	0.60	0.30	0.10
				Financial impact	0.95	0.05	0
				Human loss	0.10	0.85	0.05
	Vulnerability of telecommunication infrastructure and network	Type of materials used in networks and utilities	R_{43}	Probability of occurrence	0.70	0.25	0.05
				Financial impact	0.96	0	0.04
				Human loss	0	0.95	0.05
		The quality of telecommunication networks and utilities	R_{44}	Probability of occurrence	0.05	0.45	0.05
				Financial impact	0.95	0	0.05
				Human loss	0	0.95	0.05
		The age of telecommunication network and utilities	R_{45}	Probability of occurrence	0.65	0.25	0.10
				Financial impact	0.96	0	0.04
				Human loss	0.05	0.95	0
		Damage to central cables	R_{46}	Probability of occurrence	0.30	0.65	0.05
				Financial impact	0.20	0.70	0.10
				Human loss	0	0.95	0.05

Table 3. The numerical range for probability linguistic variables

Scale (linguistic variables)	Numerical range for probability	Probability score	Numerical range for impact	Impact score
Very low	1-10%	0.1	1-6%	0.6
Low	11-30%	0.3	7-12%	0.12
Medium	31-50%	0.5	13-24%	0.24
High	51-70%	0.7	25-48%	0.48
Very high	71-99%	0.99	49-96%	0.96

Table 4. The results of calculations for Intuitionistic fuzzy parameters for risks associated with worn-out urban fabrics in Jalili zone

Code	Lf	Uf	Uf-Lf	Lc	Uc	Uc-Lc
R_1	0.525	0.595	0.07	0.6	0.68	0.08
R_2	0.325	0.4225	0.0975	0.35	0.455	0.105
R_3	0.855	0.8835	0.0285	0.81	0.837	0.027
R_4	0.0825	0.105	0.0225	0.0275	0.035	0.0075
R_5	0.1625	0.1875	0.025	0.065	0.075	0.01
R_6	0.48	0.51	0.03	0.2	0.2125	0.0125
R_7	0.8075	0.85	0.0425	0.855	0.9	0.045
R_8	0.03	0.05	0.02	0.0075	0.0125	0.005
R_9	0.3575	0.4225	0.065	0.385	0.455	0.07
R_{10}	0.68	0.72	0.04	0.595	0.63	0.035

Code	Lf	Uf	Uf-Lf	Lc	Uc	Uc-Lc
R_{11}	0.925	0.95	0.0475	0.855	0.9	0.045
R_{12}	0.855	0.9215	0.0665	0.81	0.873	0.063
R_{13}	0.12	0.14	0.02	0.06	0.07	0.01
R_{14}	0.72	0.765	0.045	0.56	0.595	0.035
R_{15}	0.135	0.165	0.03	0.0675	0.0825	0.015
R_{16}	0.135	0.1425	0.0075	0.765	0.8075	0.0425
R_{17}	0.08	0.085	0.005	0.6	0.6375	0.0375
R_{18}	0.01	0.0125	0.0025	0.02	0.025	0.005
R_{19}	0.425	0.45	0.025	0.595	0.63	0.035
R_{20}	0.045	0.0475	0.0025	0.765	0.8075	0.0425
R_{21}	0.68	0.72	0.04	0.765	0.81	0.045
R_{22}	0.04	0.0425	0.0025	0.72	0.765	0.045
R_{23}	0.2	0.24	0.04	0.175	0.21	0.035
R_{24}	0.015	0.0225	0.0075	0.01	0.015	0.005
R_{25}	0.0025	0.0075	0.005	0	0	0
R_{26}	0.03	0.045	0.015	0.01	0.015	0.005
R_{27}	0.675	0.81	0.135	0.0375	0.045	0.0075
R_{28}	0.3	0.325	0.025	0.018	0.0195	0.0015
R_{29}	0.76	0.776	0.016	0.0475	0.0485	0.001
R_{30}	0.3	0.35	0.05	0.012	0.014	0.002
R_{31}	0.765	0.8075	0.0425	0.027	0.0285	0.0015
R_{32}	0.855	0.873	0.018	0.019	0.0194	0.0004
R_{33}	0.855	0.873	0.018	0.019	0.0194	0.0004
R_{34}	0.765	0.8075	0.0425	0.045	0.0475	0.0025
R_{35}	0.03	0.04	0.01	0.0045	0.006	0.0015
R_{36}	0.005	0.01	0.005	0.001	0.002	0.001
R_{37}	0.015	0.0225	0.0075	0.002	0.003	0.001
R_{38}	0.005	0.01	0.005	0.0005	0.001	0.0005
R_{39}	0.57	0.665	0.095	0.06	0.07	0.01
R_{40}	0.5525	0.6375	0.085	0.065	0.075	0.01
R_{41}	0.651	0.6975	0.0465	0.105	0.1125	0.0075
R_{42}	0.57	0.665	0.095	0.06	0.07	0.01
R_{43}	0.672	0.72	0.048	0	0	0
R_{44}	0.475	0.5225	0.0475	0	0	0
R_{45}	0.624	0.72	0.096	0	0	0
R_{46}	0.06	0.07	0.01	0	0	0

Lf: lower boundary of financial damage; Lc lower boundary of casualties, Uf: upper boundary of financial damage; Uc upper boundary of casualties, Df: impact of financial damage; Dc impact of casualties

Table 5. Risk prioritization based on human and financial losses based on P-I matrix

Code	Prioritization (defuzzied financial risk values)	Rank (financial losses)	Prioritization (defuzzied human risk values)	Rank (human losses)
R_1	0.5600	20	0.6400	9
R_2	0.3738	25	0.4025	15
R_3	0.8835	3	0.8235	4

Code	Prioritization (defuzzied financial risk values)	Rank (financial losses)	Prioritization (defuzzied human risk values)	Rank (human losses)
R_4	0.1050	33	0.0350	28
R_5	0.1875	29	0.0700	20
R_6	0.4950	22	0.2062	16
R_7	0.8288	6	0.8775	1
R_8	0.0500	36	0.0125	37
R_9	0.3900	24	0.4200	14
R_{10}	0.7000	12	0.6125	11
R_{11}	0.9262	1	0.8775	2
R_{12}	0.8820	2	0.8415	3
R_{13}	0.1400	32	0.0650	22
R_{14}	0.7425	10	0.5775	13
R_{15}	0.1500	30	0.0750	19
R_{16}	0.1425	31	0.7862	6
R_{17}	0.0850	34	0.6178	10
R_{18}	0.0125	43	0.0250	30
R_{19}	0.4500	23	0.6125	12
R_{20}	0.0475	37	0.7862	7
R_{21}	0.7000	13	0.7875	5
R_{22}	0.0425	39	0.7425	8
R_{23}	0.2200	28	0.1925	17
R_{24}	0.0225	41	0.0150	34
R_{25}	0.0075	46	0	42
R_{26}	0.0450	38	0.0150	35
R_{27}	0.7425	11	0.0450	27
R_{28}	0.3250	26	0.0485	25
R_{29}	0.7760	9	0.0195	31
R_{30}	0.3250	27	0.0140	36
R_{31}	0.7862	7	0.0285	29
R_{32}	0.8730	4	0.0194	32
R_{33}	0.8730	5	0.0194	33
R_{34}	0.7862	8	0.0475	26
R_{35}	0.0400	40	0.0060	38
R_{36}	0.0100	44	0.0020	40
R_{37}	0.0225	42	0.0030	39
R_{38}	0.0100	45	0.0010	41
R_{39}	0.6175	17	0.0650	23
R_{40}	0.5950	19	0.0700	21
R_{41}	0.6742	15	0.1125	18
R_{42}	0.6175	18	0.0650	24
R_{43}	0.6960	14	0	43
R_{44}	0.4988	21	0	44
R_{45}	0.6720	16	0	45
R_{46}	0.0700	35	0	46