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IDENTIFICATION AND PRIORITIZATION OF SEISMIC RISKS IN URBAN WORN-OUT TEXTURES USING FUZZY DELPHI METHOD

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Abstract

Earthquake is a random natural phenomenon, which can occur at any time and location in a given seismic zone with any magnitude. The earthquake vulnerability in buildings and urban infrastructures is a key issue for crisis management. Therefore, an assessment model should be developed to identify and prioritize the significant seismic risks involved. In risk management, several numerical and descriptive phrases are used for risk identification and assessment. These phrases are estimative by nature and the accuracy of the estimations is vital in future decision-making in risk management. Fuzzy sets are a reliable tool in solving such problems and result in high level of accuracy through creating multiple-value logical models. The purpose of this study is to identify and prioritize the major risks associated with earthquakes in urban worn-out textures through the Delphi survey technique and fuzzy sets approach. The experts' opinions were collected using a fuzzy Delphi questionnaire with a five-point Likert scale of measurement method. Participants in the Delphi panel consist of 15 experts in the field of engineering. Important risks were determined and prioritized in the two phases of fuzzy Delphi method. According to the results, among the 19 identified major risks, road blockage and flood with defuzzification values of 0.917 and 0.583, respectively, have the highest and lowest risk potential respectively in Jalili Neighborhood's worn-out textures. It is expected that, because of the simplicity and the high accuracy for identification of the most vulnerable parts, this study provides scientific and useful guidance to urban managers and planners in decision-making and adopting the most appropriate strategies for mitigating damages and potential risks of earthquakes in urban worn-out textures.

Keywords: Fuzzy Delphi method, Iran, seismic risk management, urban risk management, urban worn-out texture

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1. Introduction

Urban texture is a dynamic and changing quantity that shows how cities have evolved and expanded over the time. The texture of each city determines the urban physical space and distance between the urban elements (Kropf, 1996; Kong and Qian, 2019). Urban worn-out textures are parts of the urban context that have gradually lost their physical and functional quality (Nakhi et al., 2016). The recession of an area of the city will initiate a process of wear and tear, and sooner or later, it will affect the urban textures depending on their characteristics. The urban worn-out texture usually involves old and unstable buildings in textures with narrow pathways. The residents of these buildings are of low-income and socially-deprived class, who do not normally receive adequate service and attention after an unfortunate event such as earthquake. The main characteristics of worn-out textures consists of age (Kiani et al., 2017; Varesi et al., 2012), small size, low number of floors (Kiani et al., 2017; Shieh et al., 2014), lack of proper

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accessibility (Lee et al., 2007; Shieh et al., 2014; Taylor et al., 2006), deterioration (wear and tear), vulnerability of urban infrastructure to obsolescence and deterioration (Cirianni et al., 2012; Kongar et al., 2017), and use of traditional and non-standard materials in their construction processes (FEMA, 2010; Varesi et al., 2012). Typically, these buildings lack the neccesary structural systems. These systems are categorized based on the construction materials (e.g., steel, concrete, masonry, wood, or iron-wood) (FEMA, 2010; Kiani et al., 2017; Varesi et al., 2012). In worn-out structures, infrastructure such as electricity networks, communications structures, gas networks, sewage and water systems etc. are often obsolete and out of date. Earthquake causes widespread damages to such dilapidated and old structures, making providing service very difficult at the time of emergencies (Cirianni et al., 2012; Kongar et al., 2017). Such structures are also vulnerable to secondary risks.

The existence of a large number of buildings which have been built using traditional materials as well as old and unreliable infrastructures increases the possibility of fire and explosion (Mondal, 2019; Trevlopoulos et al., 2019; Zhen-dong Zhao et al., 2008). There is also the possibility of flooding (de Ruiter et al., 2017). Due to their unique characteristics, these structures play a critical role in the vulnerability of the city to natural disasters especially when constituting a high percentage of the total building count, and therefore should be taken into account in selecting an appropriate strategy to mitigate the devastating effects of earthquakes (Huang et al., 2012; Liu et al., 2019; Nyimbili et al., 2018; Yucesan and Kahraman, 2019). Over 70,000 hectares of Iranian cities include worn-out urban structures (Asgari et al., 2015). The city of Isfahan with more than 40% of worn-out structure was ranked first in Iran (Saghaei, 2017). In most large cities of Iran, such as Tehran (capital of Iran), Shiraz and Kermanshah, about 5% (Asgari et al., 2015), 15% (Varesi et al., 2012) and 12% (Mosavi et al., 2014) of the total area of the city are made of worn-out structures, respectively. One of the main goals of urban planning is to reduce the vulnerability of the city to earthquakes and minimize the human life and economic losses after such event (Nazmfar et al., 2019).

Urban worn-out textures are at a greater risk due to the incompatibility of their structural design with building standard codes, lack of proper communication network, and worn-out facilities and equipment (Nakhi et al., 2016). Urban worn-out textures are usually one of the most densely occupied parts of the city and because of the quality of the materials used in their buildings and their greater age, a special care should be given to their vulnerability in crisis management (Tsai and Chen, 2010). In this context, it is important to identify the potential risk factors and determine their corresponding probability of occurrence. Risk assessment provides important and essential information on prioritizing risk and employing effective techniques to mitigate the consequences (Garcia et al., 2014). Due to the challenges in the urban worn-out textures, the main objective of risk management is to eliminate ambiguity of the situation and provide the management team with a detailed plan to approach this issue. In order to identify and prioritize the potential risks, common popular methods such as document investigation, data collection approaches such as brainstorming, Delphi method, interview, etc. have been used in the majority of risk management studies. In all these methods, several descriptive and numerical phrases are used to estimate the probability of risks. These estimates are not accurate and need to be examined by newer methods to increase te accuracy of the estimates.

The purpose of this study is to identify the risks in the urban worn-out texture followed by an earthquake event and prioritize them according to the Fuzzy Delphi method in order to mitigate the destructive consequences efficiently.

2. Material and methods

2.1. Research background

2.1.1. General context

Iranian plateau is located on the Alpine-Himalayan seismic belt. The convergent movement of the Eurasian-Saudi tectonic plates has made Iran as one of the most active seismic zones in the world. From a statistical point of view, 8% of the world's earthquakes and 17% of the world's largest earthquakes have occurred in Iran (Zare and Kamranzad, 2015). This plateau has been defined as a young continental collision except for the Makran area in the south-eastern coast of Iran (Byrne et al., 1992; Masson et al., 2007). The majority of seismic activities occur near the political borders of Iran (Walker and Jackson, 2004). The city of Kermanshah, the capital of Kermanshah Province, is located in the western part of Iran and in Zagros tectonic seismic zone. The seismic activity of this region is categorized as very high and is one of the most earthquake-prone areas in Iran (BHRC-PN, 2018). The city is surrounded by major seismic faults including the Recent Testament fault (Main recent fault), which runs northwest-southeast and forms the northeast boundary of the Zagros mountain range. This fault is actually a series of strike-slip faults including Doroud Fault, Nahavand Fault, Garon Fault, Sahneh Fault, and Pearl Fault, which range from 33 to 35 degrees north latitude from the southeast to the northwest. Each year a large number of earthquakes happen in Kermanshsah province. For example, Sare-pol Zahab earthquake of 2017 with a magnitude of 7.3 caused many casualties and total destruction of the city.

Given the seismic record and the existence of important and active faults in Kermanshah province, the issue of protecting cities and rural areas in the province against the effects and consequences of earthquakes seems necessary. The presence of worn-out textures in various parts of Kermanshah city such as Jalili, Feyzabad, Bazar, Sarcheshmeh, Azadi Square, and etc. indicates the vulnerability of the region to seismic events. Worn-out urban textures are a major part of the city's urban area in Iran (Isfahan 40%, Shiraz 22%, Kermanshah 12%), which require rehabilitation in order to maintain their functionality and in some cases, they should be reconstructed due to severe degradation (Nakhi et al., 2016). Masonry is one of the main construction materials used in different buildings of the worn-out texture of the city such as residential buildings, historic and cultural heritage buildings. It is important to conduct surveys to assess the vulnerability of these buildings to earthquake. These surveys will eventually help in adopting appropriate strategies to deal with potential risks (Ferreira et al., 2013). Preventive approaches have recently attracted the attention of many experts and specialists in the field, and many studies were aimed at reducing earthquake risk and assess potential disaster scenarios (Kegyes-Brassai, 2014).

Ianoş et al. (2017) have signified the need for reconstruction and strengthening of worn-out buildings as well as other necessary measures regarding ancient and historical textures, schools, and religious places. It was shown that the interplay between urban planning and earthquake risk management is critical in vulnerability assessment of structures. These results can be used to formulate strategies and programs for dealing with earthquake impacts (Barbat et al., 2010). Seismic performance assessment of buildings can be considered as an important step in reducing earthquake risk, which provides important data for the government, authorities, and officials (Kegyes - Brassai, 2014). Earthquake risk management is a multi-stage process consisting of a range of data, variables, and probabilistic factors (Vahdat et al., 2014). Multi-stage risk management processes include risk identification, qualitative and quantitative risk assessment, risk planning and response, monitoring, and control. The risk is an uncertain event, which can have a positive or a negative impact on the project objectives (PMI, 2004). Identifying and prioritizing these risks is essential in risk management, and the uncertainties may have a huge effect in prioritization of these uncertain events. One of the methods for identification and prioritization of risks is the Fuzzy set theory which was introduced by Zadeh in 1965. The classical sets assign zero and one to each proposition in the fuzzy set of each member; however, the fuzzy set of each member actually belongs to the interval [0, 1] (Zadeh, 1965). Fuzzy set is a powerful tool in describing phenomena affected by uncertain parameters. In this theory, the concept of membership degrees $\mu: X \rightarrow [0, 1]$ is fundamental (Bustince and Burillo, 1996). Rashed (2003) explored the vulnerability of California city to earthquakes and found that combining the Analytic Hierarchy Process (AHP) and Fuzzy methods leads to a more reliable evaluation of vulnerability of the city to earthquakes. Combination of the Fuzzy and AHP model were used by many researchers for risk evaluation and prevention in natural hazards (Huang et al., 2012; Nyimbili et al., 2018; Yucesan and Kahraman, 2019). Tang and Wen (2009) used an artificial intelligence (AI) system to investigate earthquake risk in Diang city, China. Peng (2015) has considered the importance of assessing regional vulnerability to prevent and mitigate earthquake effects, and used different Multi-Criteria Decision Making (MCDM) methods to evaluate the criteria. Finally, the TOPSIS method was shown to be the safest and most accurate in prioritization of risks. Imani et al (2016) developed strategies for organizing and reducing the vulnerability of worn-out textures (Case Study of Imamzadeh Hasan district in Tehran) using Strength Weakness Opportunity Threat (SWOT) model and Quantitative Strategic Planning Matrix (QSPM) matrices. After studying the internal factors, i.e., strengths and weaknesses, and the external factors, i.e., opportunities and threats of the region, Delphi method was used to complete the information. In a study carried out by Nayeri et al. (2018) on urban worn-out texture (case study of Abdulabad neighbourhood of Tehran), the resistance of worn-out texture to earthquake was studied. Fuzzy method and AHP were used to investigate the main factors in resistance. In addition, verbal expressions expressed in triangular fuzzy numbers was used to eliminate the human error. It was shown that managerial and economic factors and participation of residents in recreation and resuscitation process were the most important among the studied parameters. Li et al. (2017) identified and evaluated the risks of the historic buildings based on AHP and entropy weight method.

Identifying the risks is the first step in the risk management process. The purpose of risk identification is to collect information about the details of as many uncertain events as possible prior to their occurrence, in order to have previous preparation to deal with them when they occur. An effective risk management focuses only on dealing with the risks, i.e., it is important to identify and eliminate the non-risk items. In this study, a number of risks were identified in order to assess the subjectivism of potential risks in the studied worn-out texture, based on documentary studies and field investigations, as well as the experts' opinions in the relevant field. The identified risks are presented in Table 1.

2.1.2. Case study investigation

Kermanshah city is located at Kermanshah province with GPS coordinates of 33 °: 36' to 35°: 15' north latitude and 45°: 24' to 48°: 30' east latitude. The worn-out texture of Jalili district in Kermanshah, Iran, was selected as the case study in this investigation (Fig. 1). It is confined to the Barekeh district from the north, to Waziri and Kale Hawas district from the south, to Faizabad district from the west, and to the Rashidi and Waziri district from the east. Based on the results of the 2016 population and housing census of Kermanshah, Jalili district is one of the oldest districts of Kermanshah with a population of 1244 people in 2019. Most of the buildings located in this district are worn and are estimated to be over 50 years old. The materials used in buildings are mostly traditional and masonry materials, but less than 15% of buildings with new materials are found at some places. Residential buildings in this study were categorized based on their total area including building with area less than 75 m^2 (147 cases), 76-100 m^2 (152 cases), 101-200 m^2 (80 cases), and 201-500 m^2 (10 cases). 97.4% of these buildings had a total area of less than 200 square meters (MPO, 2018). The majority of the houses in this neighbourhood were not built according to new construction methods such as 3D Sandwich Panel, Prefabricated Reinforced Concrete Systems, Insulating Concrete Formwork (ICF), Hot Rolled Steel Structures, etc., and it should be mentioned that the Iranian code of practice for seismic resistant design of buildings (Standard No. 2800) has not been observed in the construction process of nearly all of them.

The most common building materials used are brick, iron, wood, adobe which are traditional construction materials. According to the recent investigation, only 56 building blocks were constructed by reinforced concrete and steel. Regarding building materials this study includes 53 steel structures, 3 reinforced concrete structures, 136 iron and brick buildings, 167 brick and wood buildings, 5 adobe buildings, and 4 building made from other materials (MPO, 2018).

Poor accessibility is another significant issue in these parts of the city. In fact, the only one or two main street are acceptable as far as their width is concerned. Next main issue is the total lack of open areas, recreational facilities and centers, leisure parks, and other conveniences. Equally important is also the absence of fire stations, medical centers, clinics, and relief centers.

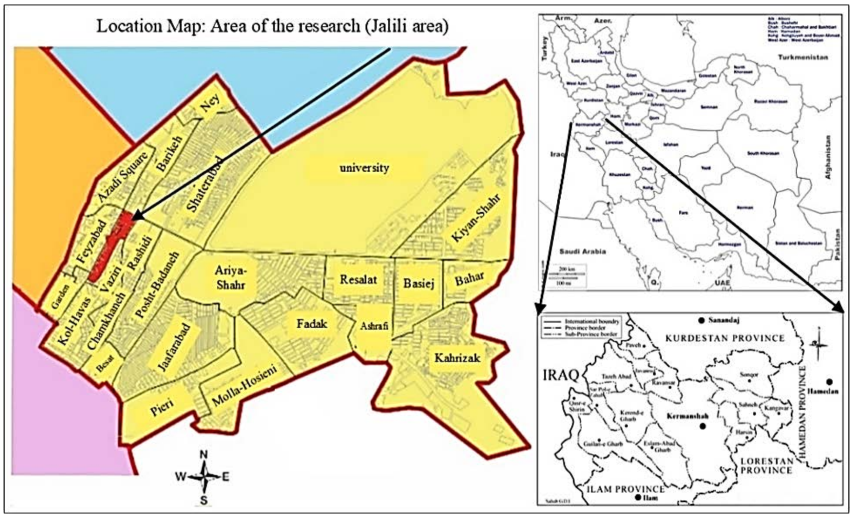

Fig. 1. Area of the case study (Jalili, Kermanshah, Iran)

Table 1. Identified risks in urban worn-out textures from literature review

Source of risk	***Risk NO.***	***Risk factors***	***Reference***
Demolition and vulnerability of residential buildings	1	Type of structural systems	FEMA (2010); Kiani et al. (2017); Varesi et al. (2012)
	2	Quality of the building	Kiani et al. (2017); Shieh et al. (2014)
	3	Antiquity of buildings	Kiani et al. (2017); Varesi et al. (2012)
	4	Number of floors in a building	Kiani et al. (2017); Shieh et al. (2014)
	5	Non-compliance with materials standards	FEMA (2010); Varesi et al. (2012)
	6	Environmental and structural conditions of the worn-out texture neighborhood	BHRC-PN (2018); FEMA (2010)
Infrastructure vulnerability	7	Sewage and water networks and installations	Cirianni et al. (2012)
	8	Gas networks and installation	Cirianni et al. (2012)
	9	Electricity networks and utilities	Kongar et al. (2017)
	10	Telecommunication networks and installation	Cirianni et al. (2012)
Blockages and accessibilities	11	Roadblocks (Alleyways and Streets)	Taylor et al. (2006)
	12	Outdoor unavailability	Shieh et al (2014)
	13	Unavailability of rescue centers	Shieh et al. (2014)
	14	Unavailability of fire station	Shieh et al. (2014)
	15	Unavailability of health centers	Shieh et al. (2014)
Secondary risks (Secondary risk exposure of buildings)	16	Fire	Mondal (2019)
	17	Explosion	Zhao et al. (2008)
	18	Flood	Quigley and Duffy, (2020)
	19	Aftershocks	Trevlopoulos et al. (2019)

2.2. Research methodology

There are different approaches for collecting the required information for identification of the variables involved in a given problem. The widely used Delphi method collects information from professional respondents who are asked to give opinions in their area of expertise. The method is based on reaching a consensus by taking into account the opinions of all members of the group (Hsu and Sandford, 2007; Khoshfetrat et al., 2020). Participants who are included in the Delphi method form a specialized and expert group, and are the main reason behind its success. However, this success is dependent upon the number of experts and their qualifications (Powell, 2003). Based on the resources and the scope of the problems, the number of panel experts is changeable (Delbecq et al., 1975; Fink et al., 1984). The larger number of panel experts, the higher the susceptibility of the judgement (Murphy et al., 1998).

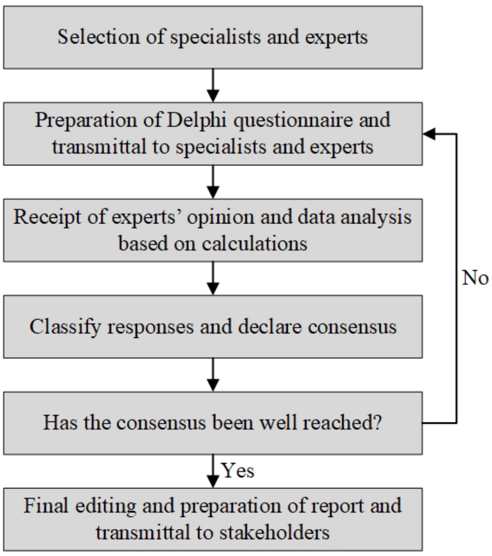

Fig. 2. Flowchart of Delphi technique in qualitative research

The Delphi method is still evolving. One of the advantages of the Delphi method is its ease of use; because it does not require advanced mathematical, execution and analysis skills, but requires a person familiar with the Delphi method and creativity in project design (Dabiri et al., 2020). This method has always been faced with expert opinions with low convergence and high implementation costs. Important ideas and ideas may also be removed by analysts during the Delphi process. Therefore, the concept of combining the traditional Delphi method and fuzzy theory was introduced by Murray et al. in 1985, in order to remove the ambiguity and inconsistency of the Delphi method (Sarvari et al., 2019a). In the fuzzy Delphi method, as the name suggests the information obtained from the experts is analyzed through a fuzzy scheme (Chen, 2012). The fuzzy Delphi methodis the basis for decision-makers to screen ineffective factors and to avoid the influence of geometric mean final values. In addition to reducing the costs and time, it allows to evaluate the fuzziness of the decision-making process and to achieve a better factor selection (Sanaei et al., 2011).

In order to identify the potential risks in the worn-out urban textures, first a questionnaire was prepared based on the studies of past earthquake events in Iran and the world, as well as interviews with relevant field experts. Experts were asked to amend any other source of risk to this questionnaire if they were not included. Reliability assessment at each stage was based on Cronbach's alpha calculation of the questionnaire completed by the experts. Microsoft Excel and SPSS software were used for calculation. The flowchart for applying the Delphi technique in qualitative decision-making is shown in Fig. 2.

2.3. Method

2.3.1. Triangular fuzzy number

Fuzzy number is a fuzzy set with the following three conditions:

- Being normalized
- Be convex
- Its supporting set is bounded

Triangular fuzzy number (TFN) is a fuzzy number, which is displayed with three number (F=l, m, u). The upper limit is denoted by u; lower limit is denoted by l and m is the most probable value of a fuzzy number. The membership function of a triangular fuzzy number is given by (Habibi et al., 2015), (Eq. 1):

$$u_f(x) = \begin{cases} \dfrac{x-1}{m-1} & l < x < m \\ \dfrac{u-x}{u-m} & m < x < u \\ 0 & otherwise \end{cases} \tag{1}$$

Triangular fuzzy number F= (l, m, u) is displayed geometrically in Fig. 3.

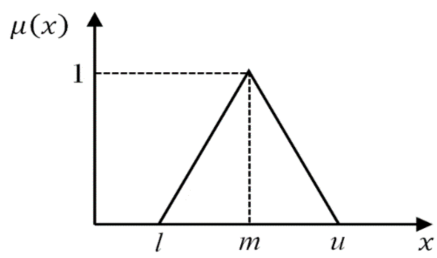

Fig. 3. The geometrical image of the triangular fuzzy number (Habibi et al., 2015)

The fuzzy Delphi method consists of the following essential steps (Habibi et al., 2015): *(i)* Identify and select the appropriate spectrum to fuzzify the linguistic expressions of the responders, *(ii)* Fuzzy aggregation of fuzzification values, *(iii)* Defuzzification of values, *(iv)* Selecting of threshold and screening criteria. In the algorithm of implementation of fuzzy Delphi method, the triangular fuzzy numbers are in 5-point Likert scale of measurement according to Table 2 and Fig. 4.

Table 2. Triangular fuzzy number of five-point Likert scale

Triangular fuzzy number (l, m, u)	***Fuzzy number***	***Linguistic Variable***
(0,0,0.25)	1	Very Unimportant (VU)
(0,0.25,0.5)	2	Unimportant (U)
(0.25,0.5,0.75)	3	Moderately Important (MI)
(0.5,0.75,1)	4	Important (I)
(0.75,1,1)	5	Very Important (VI)

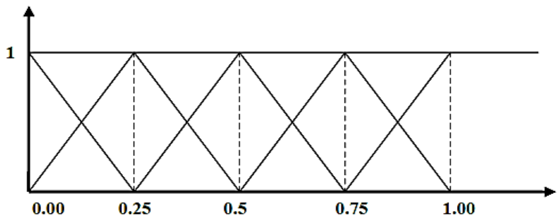

Fig. 4. Triangular fuzzy numbers equivalent to the five-point Likert spectrum (Habibi et al., 2015)

In this study, the fuzzy average method was used to aggregate the experts' opinions. Each expert's viewpoint can be presented by a triangular fuzzy number (l, m, u) (Eq. 2), and the fuzzy average can be calculated by the following expression (Eq. 3) (Habibi et al., 2015):

$$F_i = (l_i, m_i, u_i) \tag{2}$$

$$f_{ave} = \frac{\sum l}{n}, \frac{\sum m}{n}, \frac{\sum u}{n} \tag{3}$$

where n is the total number of experts. The defuzzification of values obtained is based on the following equations Eqs.(4-5):

$$F = (l, m, u) \tag{4}$$

$$X = \frac{l+m+u}{3} \tag{5}$$

Table 3 shows the defuzzification of triangular fuzzy numbers for a five-point scale of measurement calculated using (Eq. 5).

2.3.2. Lawshe method

The Lawshe method (Lawshe, 1975) was used to validate the content of the questionnaire. The number of participants involved in the validation of the method was 10 experts from different fields to provide a more accurate judgment. Quantifying panel member votes is done by calculating the content validity ratio (CVR) (Lawshe, 1975). The following formula (Eq. 6) is used for this purpose:

$$CVR = \frac{ne - \frac{n}{2}}{\frac{n}{2}} \tag{6}$$

where: *ne* is the number of group members who consider the questionnaire necessary and *n* is the total number of group members.

Note that, the minimum acceptable CVR for the 10-member panel is 0.62. To determine the mean value of panel members' judgments, the following transformations were performed in the questionnaire: *(i)* Replacement with number 3 if the parameter is considerred as necessary, *(ii)* Replacement with number 2 if the parameter is considerred as useful but unnecessary, *(iii)* Replacement with number 1 if the parameter is considerred as unnecessary. The results for the average score of panel judgement and CVR value for each question and the results of acceptance and rejection of questions are given in Table 4.

According to the results, all the potential risks identified in the survey questionnaire were approved and confirmed by the experts. The statistical population of this study consisted of 15 experts in various technical and engineering fields. These experts are among the most experienced and highly qualified industrial practitioners in their fields selected from the public and private sectors and governmental organizations. Table 5 shows the demographic characteristics of the experts who attended the Delphi process. The Fuzzy Delphi questionnaire includes the 19 risk factor related.

3. Results and discussion

In Fuzzy Delphi technique the analysis of experts' opinions is done in several phases. If in two successive phases the average experts' opinions seems reasonable the process stops. Rejection or acceptance of criterion is done through a specific threshold. This threshold is normally 0.7, but based on the type of research and also the viewpoints of experts it can be different. If the criterion is higher than the threshold it is accepted, and if not it is rejected (Cheng and Lin, 2002; Habibi et al., 2015).

Table 3. Defuzzification numbers for a five-point Likert scale

Very Important (VI)	***Important (I)***	***Moderately Important (MI)***	***Unimportant (U)***	***Very Unimportant (VU)***
0.92	0.75	0.5	0.25	0.083

Table 4. CVR value, numerical average of judgment and results of accepting and rejecting questions

Source of risk	*NO.*	*Question*	*Experts' opinions*			*CVR*	*Numerical mean of judgments*	*Minimum acceptable CVR for 10 experts*	*Accept query efficiency*
			Unnecessary	*Abstain*	*Necessary*				
Demolition and vulnerability of residential buildings	1	Type of structural systems	0	1	9	0.8	2.9	0.62	accept
	2	Quality of the building	1		9	0.8	2.8	0.62	accept
	3	Antiquity of buildings	0	0	10	1	3	0.62	accept
	4	Number of floors in a building	0	1	9	0.8	2.9	0.62	accept
	5	Non-compliance with materials standards	0	0	10	1	3	0.62	accept
	6	Environmental and structural conditions of the worn-out texture neighborhood	0	0	10	1	3	0.62	accept
Infrastructure vulnerability	7	Sewage and water networks and installations	0	0	10	1	3	0.62	accept
	8	Gas networks and installation	0	0	10	1	3	0.62	accept
	9	Electricity network and utilities	0	0	10	1	3	0.62	accept
	10	Telecommunication networks and installation	0	1	9	0.8	2.9	0.62	accept
Blockages and accessibilities	11	Roadblocks (Alleyways and Streets)	0	0	10	1	3	0.62	accept
	12	Outdoor unavailability	0	1	9	0.8	2.9	0.62	accept
	13	unavailability of rescue centers	0	1	9	0.8	2.9	0.62	accept
	14	Unavailability of fire station	0	0	10	1	3	0.62	accept
	15	Unavailability of health centers	0	1	9	0.8	2.9	0.62	accept
Secondary risks (Secondary risk exposure of buildings)	16	Fire	0	0	10	1	3	0.62	accept
	17	Explosion	0	1	9	0.8	2.9	0.62	accept
	18	Flood	0	1	9	0.8	2.9	0.62	accept
	19	Aftershocks	0	1	9	0.8	2.9	0.62	accept

Table 5. Personal characteristics of Delphi panel of experts

Background	*Respond*	*Frequency (%)*
Education level	Bachelor	7 (47)
	Master	5 (33)
	PhD	3 (20)
Working experience	Below 10 years	3 (20)
	11 - 20 years	7(47)
	Over 21 years	5 (33)
Working Sector	Public	7 (47)
	Private	6 (40)
	Academic	2 (13)
Position	Senior manager	4 (27)
	Project coordinator	2 (13.3)
	Civil engineer	3 (20)
	Financial manager	2 (13.3)
	Project manager	2 (13.3)
	Faculty member	2 (13.3)

3.1. First phase of the fuzzy Delphi method

The fuzzy Delphi questionnaire was designed according to the previous studies. The questionnaire consists of 4 sources of risks and 19 questions. Fuzzy Delphi Analysis of collected data was performed with Microsoft Excel software program. Fuzzy average method is used for aggregation of experts' opinions Eqs. (1- 2). Defuzzification of opinions is done using Eqs. (3-4). The threshold is set to 0.25. The average experts' opinions after first survey are presented in Table 6. Given that in the first step of the Fuzzy Delphi method, none of the responses are less than the threshold (0.25), thus none of them were removed in the continuation of the Fuzzy Delphi process (Cheng and Lin, 2002; Habibi et al., 2015).

3.2. Second phase of fuzzy Delphi method

In this phase, the results of the first phase and the extent of their disagreement with the views of other experts were given to the members of the group along with a new questionnaire and they were asked to comment on it. Polls stopped if the difference between the two polls was below 0.1 (Cheng and Lin, 2002). The analysis results of the second phase and the difference between the first and second survey are presented in Table 7. As it can be observed, the average defuzzification difference in the two steps was less than 0.1, and thus the convergence was achieved, implying that a third phase was not necessary (Cheng and Lin, 2002).

3.3. Prioritization of the risks of urban worn-out textures

To prioritize the risk factors considered in the questionnaire, the defuzzification averages obtained from the second phase of the fuzzy Delphi method (Table 7) were compared to the Defuzzification numbers of the five-point Likert scale shown in Table 3.

For example, type of structural system, where the average is 0.817 and is classified VI. As shown in Table 8, risks are classified based on their significance (Habibi et al., 2015).

Table 6. Average experts' opinions after the first phase survey of Delphi method

Source of Risk	***Risk No.***	***Risk factors***	***Triangular fuzzy mean with experts' opinions***			***Average defuzzification after first phase survey***
			u	***m***	***l***	
Demolition and Vulnerability of Residential Buildings	1	Type of structural systems	0.967	0.883	0.633	0.828
	2	Quality of the building	0.933	0.817	0.567	0.772
	3	Antiquity of buildings	1.000	0.967	0.717	0.894
	4	Number of floors in a building	0.967	0.850	0.600	0.806
	5	Non-compliance with materials standards	1.000	0.983	0.733	0.906
	6	Environmental and structural conditions of the worn-out texture neighborhood	0.950	0.883	0.633	0.822
Infrastructure vulnerability and urban Installation	7	Sewage and water networks and installations	0.983	0.850	0.600	0.811
	8	Gas networks and installation	0.983	0.950	0.700	0.878
	9	Electricity network and utilities	0.967	0.800	0.550	0.722
	10	Telecommunication networks and installation	0.850	0.650	0.400	0.633
Blockages and accessibilities	11	Roadblocks (Alleyways and Streets)	1.000	1.000	0.750	0.917
	12	Outdoor unavailability	0.933	0.817	0.583	0.778
	13	Unavailability of rescue centers	0.983	0.883	0.633	0.833
	14	Unavailability of fire station	0.983	0.967	0.717	0.889
	15	Unavailability of health centers	0.983	0.933	0.683	0.867
Secondary risks	16	Fire	1.000	0.967	0.717	0.894
	17	Explosion	0.900	0.750	0.517	0.722
	18	Flood	0.783	0.583	0.350	0.572
	19	Aftershocks	0.867	0.767	0.533	0.722

Table 7. Average expert's opinions after the second phase survey of Delphi method

Source of Risk	***Risk NO.***	***Risk factors***	***Triangular fuzzy Average with experts' opinions***			***Defuzzification Average of specialists in the 2th stage of Delphi method***	***Defuzzification Average of specialists in the 1th stage of Delphi method***	***Difference of Defuzzification Average of specialists in the 1th and 2th stage of Delphi method***
			u	***m***	***l***			
Demolition and vulnerability of residential buildings	1	Type of structural systems	0.967	0.867	0.617	0.817	0.828	-0.011
	2	Quality of the building	0.950	0.833	0.583	0.789	0.772	0.017
	3	Antiquity of buildings	1.000	0.967	0.717	0.894	0.894	0.000
	4	Number of floors in a building	0.983	0.867	0.617	0.822	0.806	0.017
	5	Non-compliance with materials standards	1.000	0.983	0.733	0.906	0.906	0.000
	6	Environmental and structural conditions of the worn-out texture neighborhood	0.950	0.867	0.617	0.811	0.822	-0.011
Infrastructure and urban Installation vulnerability	7	Sewage and water networks and installations	0.100	0.850	0.600	0.817	0.811	0.006
	8	Gas networks and installation	0.100	0.950	0.700	0.883	0.878	0.005
	9	Electricity network and utilities	0.983	0.817	0.567	0.789	0.772	0.017
	10	Telecommunication networks and installation	0.883	0.667	0.417	0.656	0.633	0.023
Blockages and accessibilities	11	Roadblocks (Alleyways and Streets)	1.000	1.000	0.750	0.917	0.917	0.000
	12	Outdoor unavailability	0.933	0.800	0.567	0.767	0.778	-0.011
	13	Unavailability of rescue centers	0.983	0.867	0.617	0.822	0.833	-0.011
	14	Unavailability of fire station	0.983	0.967	0.717	0.889	0.889	0.000
	15	Unavailability of health centers	0.983	0.933	0.683	0.867	0.867	0.000
Secondary risks	16	Fire	1.000	0.967	0.717	0.894	0.894	0.000
	17	Explosion	0.900	0.733	0.500	0.711	0.722	-0.011
	18	Flood	0.783	0.600	0.367	0.583	0.572	0.011
	19	Aftershocks	0.850	0.733	0.500	0.694	0.722	-0.028

Table 8. Prioritization of the risks of urban worn-out textures

Risk Priority No.	*Risk factors*	*Risk Score*	*The degree of risk relevance*
1	Road blocks (Alleyways and Streets)	0.917	VI
2	Non-compliance with materials standards	0.906	VI
3	Antiquity of buildings	0.894	VI
4	Fire	0.894	VI
5	Unavailability of fire station	0.889	VI
6	Gas networks and installation	0.883	VI
7	Unavailability of health centers	0.867	VI
8	Number of floors in a building	0.822	VI
9	Unavailability of rescue centers	0.822	VI
10	Type of structural systems	0.817	VI
11	Sewage and water networks and installations	0.817	VI
12	Environmental and structural	0.811	VI
13	Quality of the building	0.789	VI
14	Electricity network and utilities	0.789	VI
15	Outdoor unavailability	0.767	VI
16	Explosion	0.711	I
17	Aftershocks	0.694	I
18	Telecommunication networks and installation	0.656	I
19	Flood	0.583	I

According to Table 8, the risk of blockages with 0.917 defuzzification number due to the narrow internal passages of the studied worn-out texture has the highest risk potential in this area. This risk has a direct impact on the accessibility of the neighbourhood. Due to narrow pathways in the studied area, the rescue operation becomes challenging which increases the vulnerability of the area to earthquakes. Furthermore, due to the unavailability of fire stations as well as the lack of health centres, the risk of the aforementioned items is determined as "very important".

Most of the buildings in the area are made of traditional and weak materials such as adobe, adobe and brick, brick and wood, brick and iron, which are over 50 years old. Most of the buildings suffer high degree of degradation and they have not been retrofitted or renewed over the years, making them less resistant to earthquakes. In addition, the materials used in the construction of the buildings do not comply with the available government standards. The risks of Non-compliance with materials standards and Antiquity of buildings, with score of 0.906 and 0.894, respectively, confirms this issue.

The unavailability of fire station with a score of 0.889 is ranked in the top 5 among the considered risks in this study. This greatly increased their importance in buildings where 96% of them are single and double floor, lack earthquake resistant structural systems or are not built in accordance with technical and engineering principles and specifications. In this prioritization, the flood risk with a score of 0.583 has the lowest score in Table 8, but it is still characterized as important risk factor.

These risks are of vital importance both in crisis management plans and in worn-out texture renovation so that earthquake hazard and vulnerability are significantly decreased (Narimisa and Basri, 2019; Sarvari et al., 2019b).

3.4. Prioritization of the source of risk in the urban worn-out context

This prioritization is based on the defuzzification average of the total number of questions (i.e. risk factors) in each domain. The results are presented in Table 9. In this prioritization, the 'Blockages and accessibilities'' risk source was ranked first with a score of 0.852. This indicates the importance of this area of risk in the worn-out texture. The area of risk of demolition and vulnerability of residential buildings was rated with a score of 0.840. This area is also very important in terms of financial loss and casualties. Areas of infrastructures vulnerability and urban installations and secondary risk areas ranked third and fourth respectively with scores of 0.786 and 0.721.

Table 9. Prioritization of the source of risk of urban worn-out textures

Priority	*Source of Risk*	*Defuzzification average in experts' opinions*
1	Blockages and accessibilities	0.852
2	Demolition and Vulnerability of Residential Buildings	0.840
3	Infrastructure and urban Installation vulnerability	0.786
4	Secondary risk	0.721

4. Conclusions

Risk management consists of identification and prioritization of important risks. In most international standards such as Project Management Institute (PMI), Association for Project Management (APM), International Analysis and Management (ISO), etc., several numerical and descriptive phrases are used for identification and assessment of risks. These phrases are estimative by nature and the accuracy of the estimation is vital in future risk management in decision-making. Fuzzy sets, as a vague set, are a reliable tool in solving problems and result in high level of accuracy through creating multiple-value logical models.

In this research, these sets are used in risk analysis. Due to limited resources in the majority of cities all around the world, it is necessary to prioritize the sources of risks based on their importance. This study presents the results of identification and prioritization of seismic risks in worn-out textures of Jalili neighbourhood located in Kermanshah city, Kermanshah, Iran. The risk identification process indicated 19 potential risks, which were prioritized based on the experts' opinions using fuzzy Delphi method. The 5-point Likert spectrum and the triangular fuzzy numbers corresponding to each of the 19 risk areas were used to prioritize the risks. In this prioritization, the risk of road blockages, Non-compliance with materials standards, and Antiquity of buildings with a score of 0.917, 0.906, and 0.894, respectively, were ranked as top three significant risks. In this ranking, flood risk with defuzzification number of 0.583 has the lowest risk potential but is still characterized of high importance.

Prioritization of the different areas of risk indicates the high importance of accessibility of the area during and after an earthquake event. Since a large portion of worn-out textures throughout Iran share similar characteristics, identifying and prioritizing the risks in the worn-out texture of the case study can provide useful information and valuable insights for city managers and government authorities to make better informed decisions when encountering the potential hazards in the area.

It is concluded that the fuzzy Delphi method is effective in determination and prioritization of the risks in urban worn-out textures subjected to seismic hazards. New risk analysis with Fuzzy method was conducted to increase its validity, but future research studies can be envisaged to increase the accuracy of these estimates using other novel statistical approaches and more advanced analytical methods.

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