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Seismic vulnerability assessment of urban buildings and traffic networks using fuzzy ordered weighted average

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Abstract: Urban buildings and urban traffic network are considered as the vital arteries of cities which have particular effects especially after the crisis in the search and rescue operations. The aim of this study is to determine the vulnerability of urban areas especially, buildings and traffic networks using multi-criteria geographic information systems and decision-making methods. As there are many effective criteria on the seismic vulnerability that they have uncertain and vague properties, the method of this paper is applying fuzzy ordered weighted average (OWA) to model the seismic vulnerability of urban buildings and traffic networks in the most optimistic and pessimistic states. The study area is district 6 of Tehran that is affected by the four major faults, and thus will be threatened by the earthquakes. The achieved results illustrated the vulnerability with different degrees of risk levels including very high, high, medium, low and very low. The results show that in the most optimistic case 14% and in the pessimistic case 1% of buildings tolerate in very low vulnerability. The vulnerability of urban street network also indicates that in the optimistic case 12% and in the pessimistic case at most 9% of the area are in appropriate condition and the North and North-East of the study area are more vulnerable than South of it.

Keywords: Earthquake; Vulnerability Assessment; Urban buildings; Traffic network; Multi-Criteria Decision Analysis (MCDA); Fuzzy-OWA.

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Introduction

Natural hazards are the issues that most human settlements, especially in the big cities of the world are encountered (Alexander 2002; Newman 2017). According to the United Nations report in 2010, Iran has the highest number of main earthquakes in the world (https://en.wikipedia.org/wiki/International_rankings_of_Iran 2018; Avaz and Jaafari 2006) and it has the second highest number of casualties due to earthquakes per one million residents (https://en.wikipedia.org/wiki/International_rankings_of_Iran 2018). In this regard, the buildings of the city as one of the most important physical elements, especially in the field of life security and the prevention of economic losses, are very important. On the other hand, the settled population of these buildings is an important factor for vulnerability of these regions (Pitilakis 2013; Bahadori et al. 2017). Also, the role of the traffic network as the oldest vital artery is unforgivable (Tzeng and Chen 1998). In the twentieth century over 1100 devastating earthquake occurred in different parts of the globe in which more than 1.5 million people have lost their lives, 90% of these casualties were the result of the fall of non-resistance buildings that were created due to the neglect and absurd construction (Coburn and Spence 2002; Lantada et al. 2009) which lead to irreversible tragedies that its effects remain for many years. So the vulnerability assessment of traffic networks and buildings in order to plan and reduce these harms seems necessary (Rezaie and Panahi 2015).

Many studies have been done about the vulnerability of urban buildings and traffic network (Guettiche et al. 2017; Karapetrou et al. 2017 ; Riedel et al. 2015; Sheikhian 2015; Riedel et al. 2014; Gueguen 2013; Khamespanah et al. 2013; Yang and Qian 2012; Alinia and Delavar 2011; Amiri et al. 2007; Taylor et al. 2006; Aghataher et al. 2005; Lang 2002). There are two different strategies to model the vulnerability assessment of urban buildings (Pitilakis 2013): The first one concentrates on the physical characteristics of the buildings and evaluates the single building structure (Mouroux et al. 2004; Goda and Hong 2008; Gueguen 2013; Guettiche and Mimoune 2014; Guettiche et al. 2017; Karapetrou et al. 2017). These models perform detailed individual analysis of all buildings and are considered as large scale analysis. The second strategy focusses on all aspects of the urban life including the population of each building, the slope of the region, the topology of buildings, and so on (Pitilakis 2013; Bahadori et al. 2017; Banica et al. 2017). This paper applies the second approach and reviews the related researches as follows. Molina et al. (2010) applied logic tree for seismic risk assessment. They developed software that was able to estimate buildings damage and Casualties. Luping and Dalian (2012) introduced an analysis for the vulnerability assessment of traffic network, based on vulnerability understanding and analysis of traffic network model. Nagae et al. (2012) offered a framework to find ways of strengthening anti-earthquake for transportation and urban street network. They tested the efficiency of calculations and rationality of method in Kobe in Japan and its suburbs. Rahman et al. (2015) and Bahadori et al. (2017) developed an integrated model for seismic vulnerability assessment of residential buildings in Iran based on the Analytical Hierarchy Process (AHP) in GIS. They applied five main criteria – geotechnical and seismological, social, distance to hazardous facilities, and access to vital services – with their related sub-parameters (Rahman et al. 2015; Bahadori et al. 2017).

The main objective of this study is the vulnerability assessment of the urban buildings and traffic networks considering different scenarios as well as identifying the priority level of vulnerability. In this way, the rate of building vulnerability through different Fuzzy-OWA quantifiers and operators are computed. The main contributions of this paper are vulnerability assessment of urban buildings in most optimistic and pessimistic states and vulnerability assessment of urban traffic networks. The study area is district 6 of Tehran that is affected by the four major faults. This paper utilizes from combining Fuzzy and OWA methods. Based on this model, decision-making problems under uncertainty condition have been resolved and decisions have been made with great flexibility so that output maps meet an acceptable level of objectives and criteria for decision makers and experts.

The rest of the paper is structured into five sections. Section 2 describes the material and proposed method. Section 3 implements methodology and depicts the results. Section 4 discusses the achieved results and section 5 described the conclusions of the research in study area.

1 Materials and Methods

This section basically reveals to describe the proposed method and its preliminaries. In this regards first the study area is explained and then proposed method and its elements are described.

1.1 The study area

District 6 is one of the old and densely populated regions that are located in the central part of Tehran (Figure 1), and it is extremely vulnerable to natural disasters such as an earthquake. District 6 is surrounded by different faults including North Tehran fault (Mosha-Fasham), South of Tehran Fault (Ray fault), Mahmudiyah fault, Davudieh fault, Xi'an fault and etc. These faults are effective on seismic hazards and vulnerability of buildings and traffic networks. One of the main physical characteristics of the district 6 is the existence of the most important administrative-service functions with trans-regional, municipal and even national scale performance.

1.2 Proposed method

In this study, at first, the effective vulnerability criteria of buildings and urban street network are determined. In the second phase, criteria and layers are weighted using a direct vote of experts. Then the criteria were weighted by integration of Analytical Hierarchy Process (AHP) method (Saaty 1994) and the opinions of the specialists to produce a map for each criterion. According to this procedure, 13 criteria map are derived (8 maps for the vulnerability of buildings and 5 maps for streets network vulnerability). At the end, these maps are combined using the Ordered Weighted Average (OWA) method and fuzzy conceptual quantifiers and provide 8 final vulnerability maps in various scenarios with different degrees of risk. Summary of the research method is shown in Figure 2.

1.2.1 Ordered Weighted Average (OWA)

The OWA is a risk-based hybrid multi-criteria decision analysis (MCDA). This method has been developed based on the fuzzy sets theory, but its application is not restricted to fuzzy sets (Malczewski et al. 2013). In this approach, a new notion for the development of Boolean decision rules and linear weighted composition is introduced at several risk levels that is familiarized by Yager (1988). The OWA operator is defined by Equation (1).

$$OWA_j = \sum_{i=1}^{n} \left(\frac{U_i V_i}{\sum_{i=1}^{n} U_i V_i} \right) Z_{ij} \qquad (1)$$

Where U_i is the weight of ordered i^{th} criteria (W_i), V_i is an element of order weight, V= [V₁,

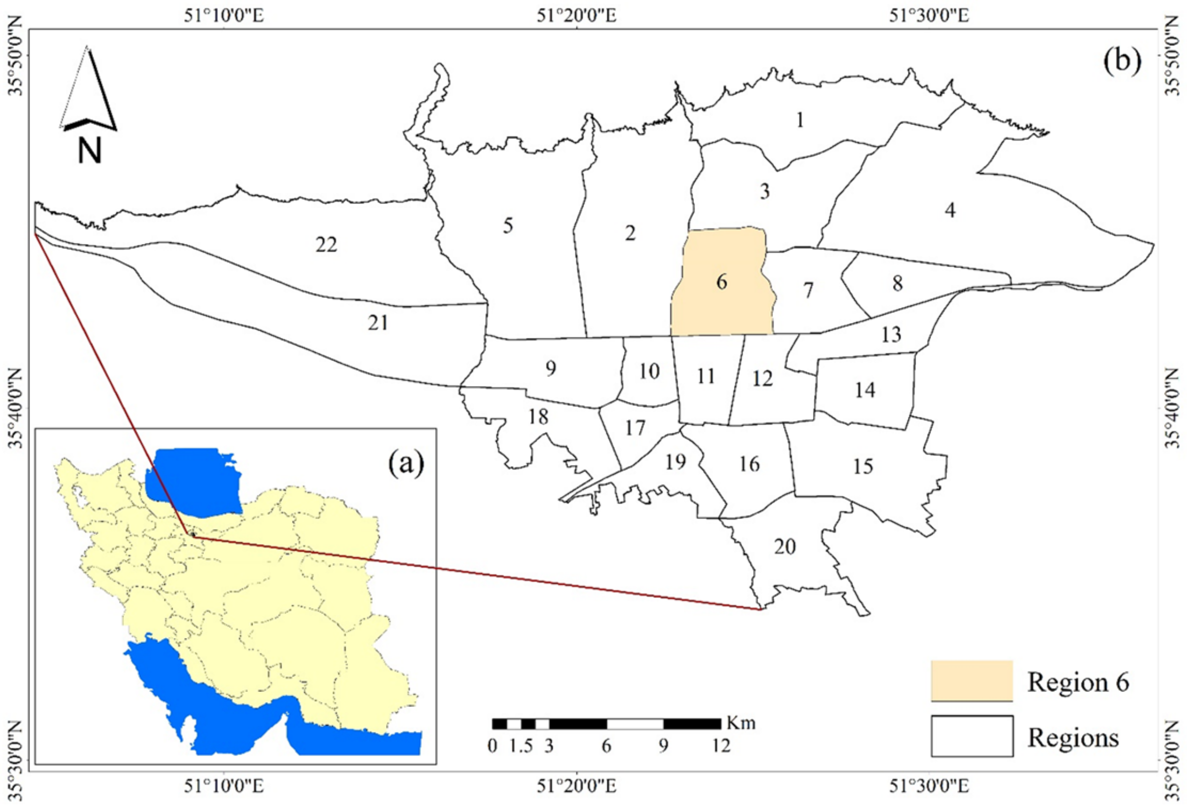

Figure 1 Case study area; (a) Location of the Iran; (b) Tehran City.

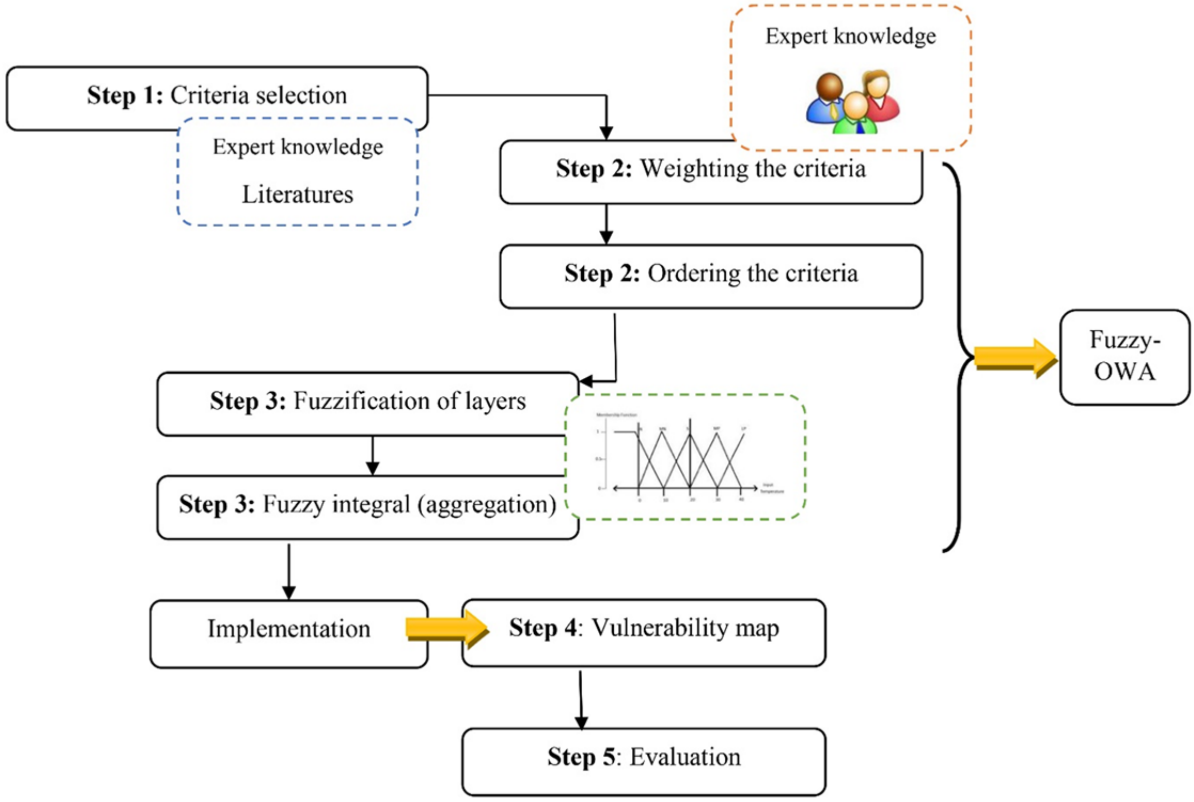

Figure 2 Flowchart of the proposed method.

$V_2 ... V_n]$; $V_i \in [0, 1] \sum (i = 1, n)$; $V_i = 1$ $Z_{1j} \geq Z_{2j} \geq ... \geq Z_{nj}$ that are obtained by reordering of criteria with $X_{ij}.X_{2j}.X_{nj}$values (Boroushaki and Malczewski 2008).

Figure 3 shows the degree of risk-taking position of OWA operator in relations between (AND minimum) and (OR maximum). This degree reflects the amount of emphasis by the decision-maker on better or worse values of a set of criteria and or the same risk-taking and risk-aversion of decision-maker. The degree of ORness is defined as

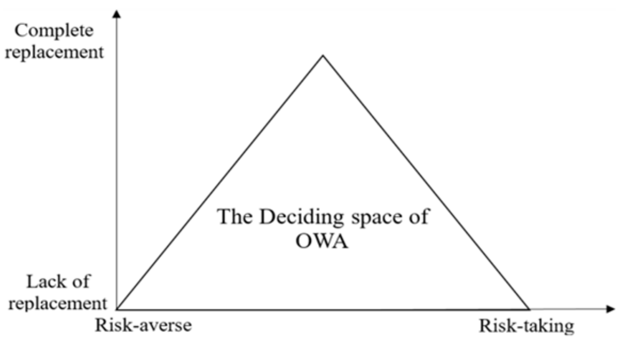

Figure 3 the Deciding space in OWA method (Romano et al. 2015).

Equation (2).

$$\text{ORness} = \frac{1}{n=1} \sum_{i=1}^{n} (n - i).\text{W1} \ , 0 \leq \text{ORness} \leq 1 \quad (2)$$

The higher ORness value means the greater risk potential or optimism of decision-maker and less ORness, means the pessimism and risk aversion of decision-maker. In general, the degree of ORness can be interpreted in the context of the behavioral theory of multi-criteria decision making. OWA operator with a higher risk degree from 0.5 represents a risky and optimistic decision, risk degree of 0.5 indicates a neutral decision maker, and degree risk less than 0.5 represents a decision-maker will be risk-averse and pessimistic. As mentioned, ORness ranges from 0 to 1. The value indicates the position of the OWA operator on a continuum between the Boolean 'AND' or 'OR' combination rules. It shows the degree to which the OWA operator is similar to the logical 'OR' in terms of its combination behavior. With different ORness values (or parameter) one can generate different sets of the OWA weights and, in turn variety of GIS-based map combination strategies ranging from minimum-type (logical AND) combination through all intermediate types (including the conventional weighted overlay) to a maximum-type (logical 'OR') combination (Malczewski et al. 2003; Boroushaki and Malczewski 2008; Gorsevski and Jankowski 2010; Al-Yahyai et al. 2012; Mendas and Delali 2012) (see Table 1).

As mentioned OWA is one of the multi-criteria combination methods, in fact, this method is an extension of two fundamental categories of decision rules in GIS that includes Boolean overlap operators and weighted linear combination. On the other hand, OWA can be within a continuous range from "All" qualifier to "at least one" qualifier (Malczewski 2006b). To identify the location of OWA operator in this range ORness can be used (Yager 1996).

1.2.2 Fuzzy set theory

Fuzzy set (Zadeh 1983) in a universe U is defined as a mapping A from U to [0, 1], representing a vague conception. For A in U, μ (A) is called the membership degree of A that is between 0 and 1. If A and B are fuzzy sets in the similar universe U, A is called a fuzzy subset of B, written $A \subseteq B$, if f $\mu(A) \leq \mu(B)$ in U (Zadeh 1983).

For every β in [0, 1], $A\beta$ point to the subset of U represented by (Zadeh 1983). The $A\beta$ is defined as Equation (3)

$$A\beta = \{u \mid u \in U \wedge \mu(A(u)) \geq \beta\} \quad (3)$$

$A\beta$ is termed the β-level set of the fuzzy set A. particularly; $A1$ is the set of elements from U which are completely companionable with the vague scheme modeled by $\mu(A)$. If A1≠Ø, the fuzzy set A is termed normalized and elements from $A1$ are depicted as modal values of A (Zadeh 1983). The support supp (A) of A is the set of elements from U which is owned by A to a firmly positive degree (Zadeh 1983). The Supp (A) is defined as Equation (4).

$$\text{Supp}(A) = \{u \mid u \in U \wedge \mu(A(u)) > 0\} \quad (4)$$

1.2.3 Fuzzy-OWA

To combine fuzzy sets there are three basic operators: a) Intersection operator, b) Union operator, and c) Averaging operator. Yeager (1988) provided a combining technique based on OWA operators which is a combination of three types of hybrid functions mentioned above. (Malczewski 1999). In this paper, a method of Fuzzy-OWA has been used to assess the vulnerability of urban buildings and traffic network. Traditional OWA methods have limited effectiveness when assessment criteria are too numerous. In this case, combining the criteria in a way that takes into

Table 1 Buildings vulnerability criterions, classes and rates

Row	Index	Class	Score	Row	Index	Class	Score
1	Building density (%)	< 50	1	4	Building age (years)	< 5	1
		50-100	2			5-15	2
		100-150	3			16-25	3
		150-200	4			> 25	4
		200-250	5	5	Building materials	Steel and concrete	1
		250-300	6			Brick and iron	2
		300-350	7			Cement block	3
		350-400	8			Other	4
		400-450	9	6	Number of floors	1-2	1
		450-500	10			3-5	2
		> 500	11			6-10	3
2	Street width (m)	> 45	1			11-15	4
		40-45	2			> 15	5
		35-40	3	7	Buildings quality	Maintainable	1
		30-35	4			Restoration	2
		24-30	5			Destruct	3
		20-24	6			Other	4
		15-20	7	8	Population density (/ha)	< 25	1
		12-15	8			25-50	2
		< 12	9			50-75	3
3	Building area (m²)	> 500	1			75-100	4
		200-500	2			100-125	5
		< 200	3			125-150	6
						> 150	7

account the assumptions of the decision maker regarding the relationship between the criteria will be very difficult (Malczewski et al. 2003). In such cases the key aspects of the decision issue can be expressed on the basis of fuzzy conceptual quantities such as "the majority of criteria must be met" or "80 percent of the criteria must be met". This requires a change in the methods of making a multi-criteria decision so that it corresponds to the status of these fuzzy quantities. This method includes 3 main stages that are: 1) Identification of the fuzzy conceptual quantifiers 2) Creation a set of ordinal weights related to fuzzy conceptual quantifiers 3) Calculation of the position of each cells using a combination function (Boroushaki and Malczewski 2008).

1.2.4 Fuzzy conceptual quantifiers

According to the fuzzy logic principals, each member belong to fuzzy set in the interval [0, 1] (Zadeh 1983). When the fuzzy conceptual quantifiers measure the suitability of sets, "zero" represents 0% and "one" means "100%" suitability. So if Q is a conceptual quantifier, it can be presented as a Q fuzzy set of the unit interval [0, 1] where for each Pϵ [0, 1], Q (p) indicates the degree of compatibility with the concept expressed by Q (Malczewski 2006b). One of the simplest approaches for defining parameterized subset on the unit interval is using Equation 5 (Yager 1996).

$$Q(P) = p^\alpha \quad , \alpha > 0 \tag{5}$$

Whenever 'α' is changed, different types of quantifiers and their operators are obtained. If 'α' equals to '1', Q (p) will be proportional to the identity quantifier. If α equals to '0' the quantifier Q (p) gets its extreme mode of at least one that matches to the 'MAX' operator. If α inclines to infinity, the quantifier Q (p) gets its extreme mode of all that matches to the 'MIN' operator.

1.2.5 Criteria of buildings vulnerability

After describing the proposed approach for decision making, it is obvious that the effective criteria should be defined. These criteria are obtained through investigation of related researches (Sandi et al. 2007; Lumantarna et al. 2014; Rezaie and Panahi 2015; Sheikhian et al. 2015; Delavar et al. 2017; Bahadori et al. 2017; Boukri et al. 2018) and also the experts' knowledge through interviewing and questionnaire completion by related experts. In this regard, 15 different experts in seismic vulnerability assessment confirmed the driven criteria from the literatures and also modified some of them. Finally, the effective criteria are defined as follows:

Buildings quality: This criterion indicates the possibility of building strength. Usually, new buildings are stronger than impaired buildings.

Street width: The lower the width of the street, the higher vulnerability will be caused, according to the blockage of the streets.

Building area: The vulnerability of smaller buildings due to the fragmentation of open space and the loss of useful and secure space for helping is more than large buildings.

The number of floors: This criterion is equivalent to the height of the building. The tall buildings that are constructed without considering safety rules will raise vulnerability because in this case evacuations, search, relief operations will be difficult.

Building age: Practically old buildings have a greater risk of damage.

Population density: the higher population density will cause a greater number of casualties during an earthquake, relief operations will be more difficult and evacuation of buildings will take a longer time.

Building materials: This criterion has a significant impact on the sustainability of buildings. If there are resistant materials, the vulnerability will be decreased.

Building density: With increasing building density, the possibility of demolition and vulnerability will be increased.

1.2.6 Criteria of vulnerability for urban street network

The vulnerability of urban traffic networks will be assessed according to the following criteria:

Proximity to a fault: Since the occurrence of most earthquakes is caused by active faults, distance from faults indicator have a significant role on vulnerability estimation.

Slope: Slope is also an important criterion of vulnerability.

Height: With increasing height, the slope also increases; accordingly the traffic network vulnerability will increase.

Aspect: Aspect is also an effective criterion.

Slopes that receive more sun light and also have a better flow of air are less vulnerable.

Soil type: In relation to the amount of rainwater infiltration and the degree of its resistance against the stagnation of urban streets, buildings, building facilities and floors are very important.

2 Results

This section reveals the implementation stages. First, the required data are presented. Then the details of implementation including the procedures of methodology execution and used software are explained. Then vulnerability maps and the experimental results are described.

2.1 The required data

The used data in this study, including maps and information layers related to criteria (Tables 1 and 2). The huge layers that have been used in this study have been provided from Municipality, Roads and Urban Development Geological Survey, of Iran and Statistical Center of Iran. To assess the vulnerability of urban buildings, parcels of a cadastral map of the 6th region of Tehran were used, which included 29050 parcels. Of the entire existing parcels, only 28,228 units that have building were used. The prepared results are illustrated in Figures 4 and 5.

2.2 Details of implementation

In calculating the primary weights of buildings and urban street network criteria, AHP is used. This method performed in Expert Choice 12 software and the results are illustrated in Table 3. All the weights are calculated using pairwise comparison and AHP formulations (Saaty 1994).

Then, the archived maps were combined using fuzzy-OWA (with different α) and vulnerability map with different degrees of risk and in several scenarios was extracted. The values of ordered weights and OWA operator value in various scenarios are obtained using the Table 4. The results of these calculations are shown in Table 5. Figures 6 and 7 show vulnerability maps of urban buildings and traffic network in 4 different scenarios according to the different value of ‘α’.

The first scenario considered α=0 (fuzzy conceptual quantifiers “at least one”) and second scenario considered α=0.3 (Figures 6 and 7) that are related to very optimistic and optimistic states

Table 2 Urban traffic networks vulnerability criterions, classes and rates

Row	Criteria	Classes	Score
1	Distance to fault (m)	< 400	11
		400-1000	10
		1000-1500	9
		1500-2000	7
		2000-2500	6
		3000-3500	5
		3500-4000	4
		4000-4500	3
		4500-5000	2
		> 5000	1
2	Type of soil	Inceptions	2
		Rock	1
3	Slope(°)	> 15	3
		5-15	2
		< 5	1
4	Elevation (m)	> 1400	4
		1300-1400	3
		1200-1300	2
		< 1200	1
5	Aspect	North	9
		North West	8
		North East	7
		West	6
		Flat	5
		East	4
		South East	3
		South West	2
		South	1

Table 3 The final weight of each vulnerability criteria

Building		Streets	
Criteria	Final weight	Criteria	Final weight
Building quality	0.345	Distance to fault	0.556
Population density	0.230	Type of soil	0.197
Street width	0.179	Slope	0.114
Building density	0.103	Elevation	0.084
Building age	0.064	Aspect	0.049
Building materials	0.041		
Number of floors	0.021	Inconsistency factor: 0/07	
Building area	0.017		
Inconsistency factor: 0/06			

Table 4 Types of decision-making scenarios in Ordered Weighted Average (OWA) method

Scenarios	α	Risk potential
Very optimistic	0	1
Optimistic	0.3	0.75
Average	1	0.5
Pessimistic	3	0.25

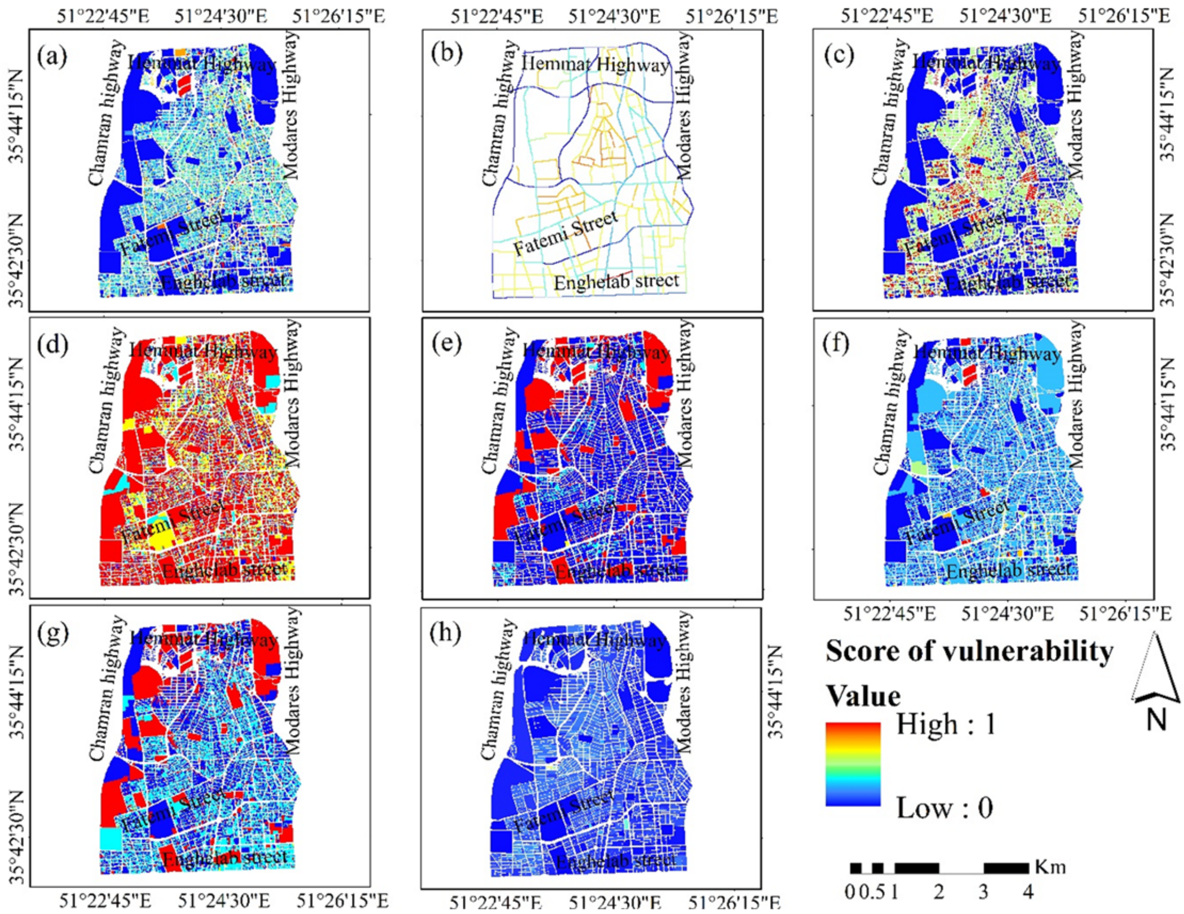

Figure 4 Classification maps of buildings according to each criterion. a)Building density, b)street width, c)building area, d) Building age, e)Building materials, f)number of floors, g) Buildings quality, h)Population density.

according to the Table 4. The very optimistic scenario has a high potential for risk in determining the vulnerability of buildings and urban traffic network, this approach is similar to the OR (equivalent to the MIN operator) Boolean operator. In the third scenario, the alpha value is considered equal to 1 (fuzzy conceptual quantifiers "Half") which based on decision-making rules is called the neutral scenario. The result of OWA operator for α = 1 produces weighted linear combination. Figures 6 and 7 shows the vulnerability map of two spatial decision-making scenarios with values α = 3 (fuzzy conceptual qua ntifiers "Almost all"). As can be seen, with increasing α parameter the amount of risk in spatial decision making is reduced. Figures 6 and 7 show the vulnerability of spatial options according to fuzzy conceptual quantifiers in 4 scenarios.

According to the Table 4, it is clear that when the degree of potential risk equals to '0.25', the fuzzy conceptual quantifier is "Almost all", and in

Table 5 Ordered weights for criteria with respect to different degrees of risk potential

Weight	Criteria	Risk potential			
		0.25	0.5	0.75	1
1	Buildings quality	0.041	0.345	0.726	1.000
2	Population density	0.149	0.230	0.121	0.000
3	Street width	0.238	0.179	0.017	0.000
4	Building density	0.194	0.100	0.035	0.000
5	Building age	0.159	0.067	0.023	0.000
6	Building materials	0.019	0.041	0.012	0.000
7	Number of floors	0.059	0.021	0.006	0.000
8	Building area	0.051	0.017	0.017	0.000
9	Distance to fault	0.171	0.556	0.475	0.000
10	Type of soil	0.091	0.084	0.036	0.000
11	Slope	0.065	0.049	0.02	0.000
12	Elevation	0.19	0.114	0.042	0.000
13	Aspect	0.483	0.197	0.064	0.000

most pessimistic state or in a risk-averse decision (logical operator AND). It means that in our case study area 5 percent of the buildings are very vulnerable and 14 percent of them having very little vulnerability.

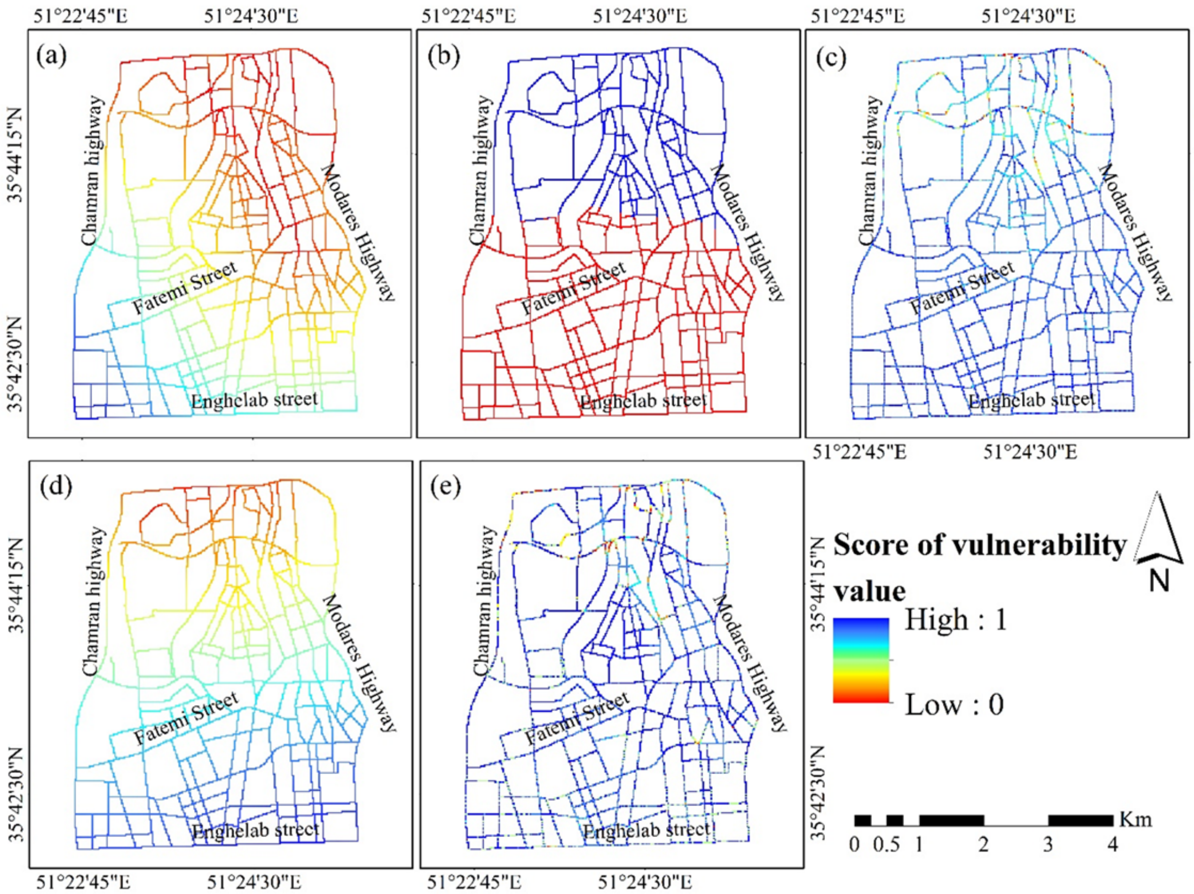

Figure 5 the 6th Tehran urban street network classification maps according to each criteria. a) distance to fault, b) type of soil, c) slope, d) elevation, e) aspect.

When the degree of potential risk is equal to '0.5' or fuzzy conceptual quantifier is "Half", the potential of risk or in a neutral state, show that 3 percent of the buildings are in very high vulnerability and 17 percent of the buildings have very little vulnerability. In a relatively optimistic state, means decision making with high-risk potential, or risk potential of '0.75', only 1 percent of the buildings are highly vulnerable and 12 percent of the buildings have a very low vulnerability.

Also in decision making when the degree of risk potential equals to 1 or when fuzzy conceptual quantifier is "at least one" that is in the most optimistic state and we are in risky decision (logical operator OR), 27 percent of the buildings have a very high vulnerability and only 1 percent of the buildings have a very low vulnerability. Finally, spatial options based on points obtained for each option and according to different degrees of risk potential demonstrate the vulnerability.

2.3 The final indicator of the vulnerability of the urban street network

According to the results of different scenarios with different degrees of risk potential, the final output of the average vulnerability was estimated at '0.55', which indicates high vulnerability in the region. This means that according to the results of different scenarios with different degrees of risk potential on average, more than half of the regional street network is vulnerable. The final indicator obtained for the vulnerability of urban streets in various scenarios with different degrees of risk potential is shown in Figures 6 and 7. As seen in different scenarios relatively vulnerability in the northern region has more inappropriate situation rather than the South and South-West region.

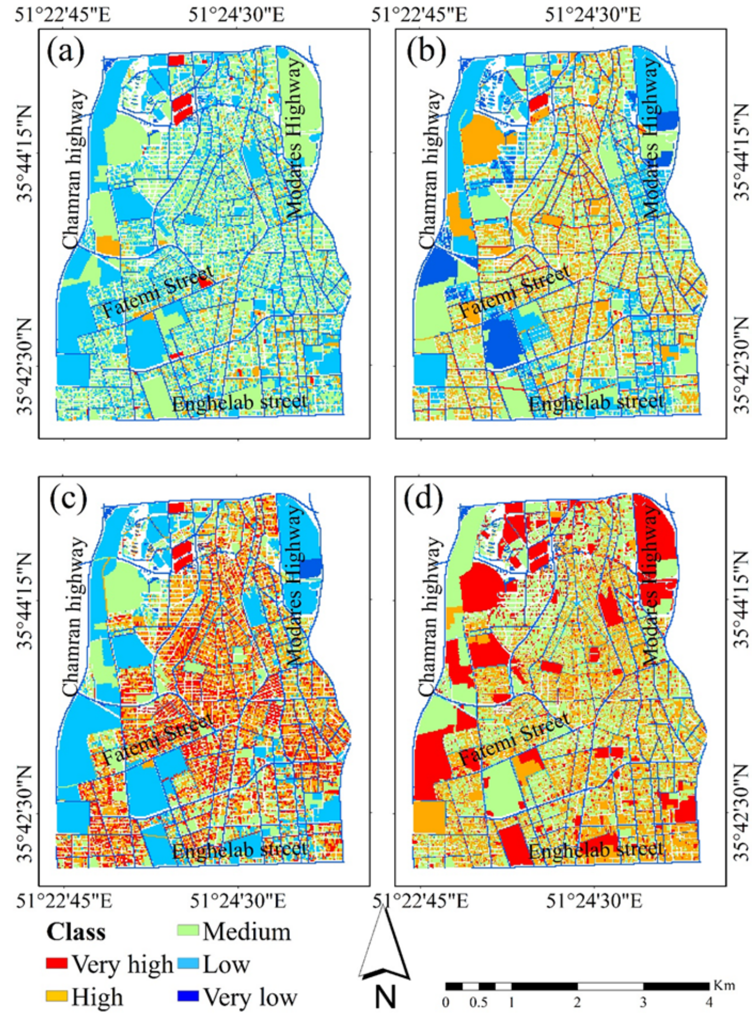

Figure 6 Map of the vulnerability of buildings with different degrees of risk. a) The vulnerability map with the degree of risk 0.25, b) The vulnerability map with the degree of risk 0.5, c)The vulnerability map with the degree of risk 0.75 d) The vulnerability map with the degree of risk 1.

3 Discussion

In this research the effective criteria on urban buildings and traffic network are weighted and aggregated using Fuzzy-OWA method. First, the primary weighting process is done by the AHP and then the final weights are calculated by fuzzy numbers through OWA approach. The results suggest that values of criteria layers in moderate vulnerability scenario (α =1) obtained from OWA method are equal to values of the weighted linear combination of layers method in AHP. And by selecting other values of α we can model some operators such as 'OR' and 'AND' also their unity interface. OWA method added to the combination of layers and spatial decision-making, in cases such as weighted overlay or Boolean 'AND', 'OR' operators provide the ability of weighting in other states with risk potential and balance. High vulnerability areas mainly are urban centers with the administrative and political application and important urban facilities or buildings with a low build quality. This fact shows the lack of attention to construction, overload age and restoration quality of these buildings. Also, the main reason for the high vulnerability of street network of this is proximity to the fault, soil type and slope of an area. Therefore, planning by managers and analysts and providing basic solutions are essential for reducing vulnerability. In some decision-making processes, decision-makers can not accurately assess because their knowledge is ambiguous and inaccurate. In this study, the Fuzzy-OWA method was evaluated and a uniform framework for uncertainty was considered. Comparing to the other method for risk assessment like logic tree, Fuzzy-OWA could model the different degree of seismic vulnerability from most optimistic to most pessimistic situations, however both of them are able to model the uncertainty.

4 Conclusions

This paper used Fuzzy-OWA analysis to conduct vulnerability assessment of urban traffic network according to the 13 criteria in various scenarios. The results show that in the most pessimistic condition, only 14% of street network have a high vulnerability. In most optimistic condition, 36% of the area has high vulnerability. Based on the results of the vulnerability of urban street network in the most optimistic mode 12% and in the most pessimistic condition, 9% of the streets are in safe state. Also, the results of the vulnerability of the building in four scenarios with different degrees of risk potential show that in the most pessimistic mode 5% of the buildings have a very high vulnerability and 14% of them have the

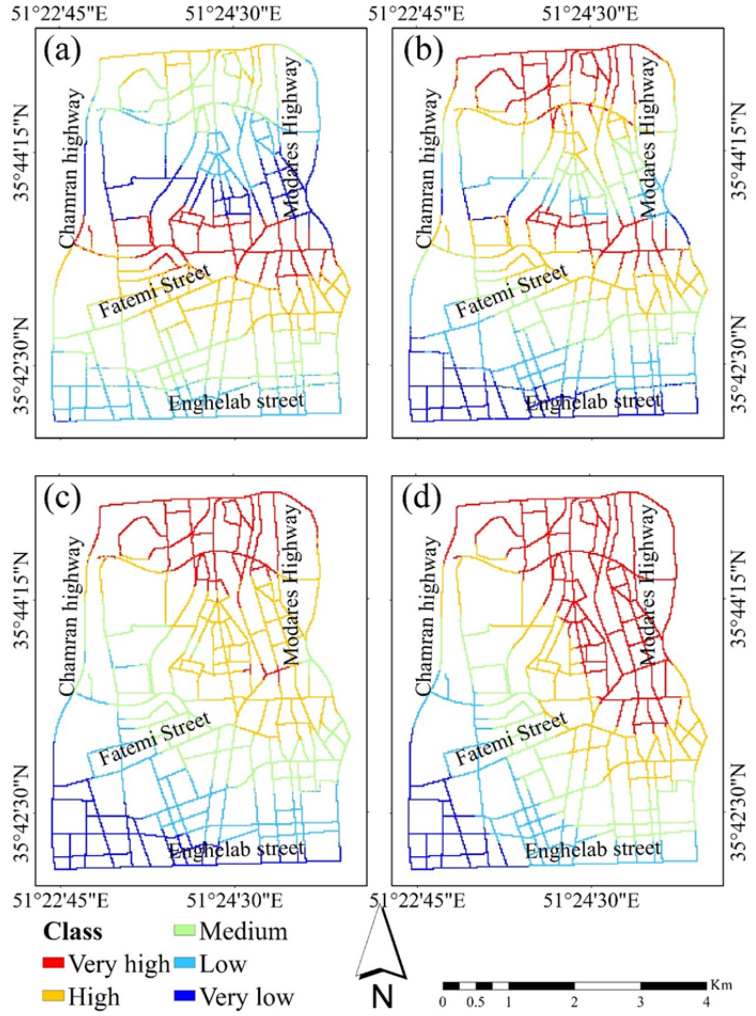

Figure 7 Map of the vulnerability of street network with different degrees of risk. a) vulnerability map of street network ORness 0.25, b) vulnerability map of street network ORness 0.5, c)vulnerability map of street network ORness, 0.75 d) vulnerability map of street network ORness 1.

very low vulnerability. In the most optimistic mode, 27% of buildings have very high vulnerability and only 1% of the buildings have very low vulnerability. The concentration of buildings with high vulnerability was in the areas that have very old texture and low building quality. The type of materials is also a very important factor in increasing vulnerability, since a high percentage of vulnerable buildings have been applied poor materials. The height of buildings without considering the 'anti-destruction laws based on earthquakes' also have an important role in increasing the buildings vulnerability.

In addition to the vulnerability zoning of the case study area, the proposed method has some specific advantages. First, Fuzzy-OWA is a new integration method, flexible enough and a decision maker can decide according to their interests and actual needs. Second it integrates intuitive fuzzy information and semi-mathematical information, so it can manage the uncertainty of experts' knowledge. Finally it extends different risk scenarios and helps the relief and rescue managers to get ready for responding the more damaged area after earthquake. Also it helps the urban decision makers to retrofit the more vulnerable buildings to reduce the possible risk. On the other hand, this method depends on the experts' knowledge and it could be act as a drawback, however the fuzzy logic could remove the uncertainties effect in OWA approach to a large extent. The proposed method has the ability to implement in the other cities.

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