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Assessment of Risk Caused By Earthquake in Region 1 of Tehran Using the Combination of RADIUS, TOPSIS and AHP Models

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ORIGINAL ARTICLE

ABSTRACT: Tehran, one of the important cities of Iran, is in great risk against earthquakes because several active faults are located into or around it. The significance of this metropolis from the economic and political point of view, high population and risks of possible earthquake has drawn the attention of urban managers to this problem. On this basis, to confront the probable risks and reduce the negative effects of this phenomenon, it is indispensible and of important objectives of Tehran urban management to investigate the seismic vulnerability of the city. With respect to this important issue, region 1 of Tehran municipality was selected as the study area because of its proximity to the active faults at north of Tehran. The study method and the analysis of the gathered data were performed using the methods based on information database, RADIUS, TOPSIS and AHP models, and the software based on the Geographical Information System. Variables such as the buildings location in proportion to faults, type of materials, oldness of the buildings, number of floors, population density, soil type, slope of the region, and pathway network were used for the research and the region vulnerability using 3 probable earthquake scenarios were investigated. Results indicated that region 1 of Tehran municipality is vulnerable against earthquakes.

Keywords: Earthquake vulnerability, Region 1 of Tehran Municipality, RADIUS, TOPSIS, AHP.

INTRODUCTION

Earthquakes are natural phenomena ignoring of which may have disastrous consequences. Strong earthquakes have made humans think of compiling fundamental plans for reducing their disastrous damages and perilous consequences. Geological features of the country have made earthquake the most devastating cause of human casualties. Historical studies reveal that several parts of Iran have been financially and physically damaged with this catastrophic incident. According to UN reports, Iran held the top position among the countries with the highest number of earthquakes of over 5.5 Richter magnitude scale in 2003 and it also is one of the highest vulnerable countries of the world from the casualty point of view [1].

The peculiar groups of structures of public buildings without reinforced masonry materials, crowded old buildings in urban centers, urban decays, residential buildings and concrete structures with weak designs and poor materials from the 1960s, 70s, and 80s, have brought high vulnerability to Iran. Cities are the centers of population and environmental and economic loadings and this mandates a new look toward reducing the risk of earthquakes.

Earthquake is a natural phenomenon that may bring disasters only if the target community neglects its risks. Tehran as the capital city is the most populated urban area in Iran and its geological features and geographic location on some active faults and the rich history of their activity clearly prove a very strong quake before long and this risk increases in the first region of Tehran municipality for the large number of its active faults. Another reason for the high risk in this region is the common feature of this type of urban areas and that is the rate of decay buildings and unplanned structures with low resistance against seismic loadings. Moreover, low and poor level of planning has made it so hard to aid the residents in cases of emergency and this augments the danger of a human tragedy. Thus, there is a vital need for a suitable model that has the capacity to receive the spatial and non-spatial data and analyze them in proper geographic information systems (GIS) and multi-criteria decision making systems in order to evaluate and estimate the earthquake risk in Tehran and provide a systematic process of crisis management and prepare the community against this phenomenon.

Several analyses and estimations have been conducted regarding earthquake risk. One of the first attempts to estimate the physical vulnerability of the buildings in Iran was made by the Tavakolis [2]. They provided three failure curves for three different types of buildings in the 1990 Manjil-Rudbar earthquake. They

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investigated the damages on the villages near Manjil and derived an equation for the maximum ground acceleration and damages in the buildings [2]. They divided buildings in their study into three main types:

1. Engineered Structures (iron and concrete)
2. Quasi-engineered structures (masonry and wood)
3. Unengineered structures (adobe)

A similar study was conducted by Japan International Cooperation Agency (JICA) in Tehran. They evaluated Tehran's vulnerability from physical and human points of view and analyzed the failure curves provided by the Tavakolis [3]. Amini [4] used RISK_UE and TOPSIS Fuzzy models, GIS, spatial and non-spatial criteria and expert views to study vulnerability of the 9th region of Tehran municipality to earthquake and investigated the region's resistance against different magnitudes of quake and found that this region is vulnerable to potential earthquakes [4]. Azizi and Akbari [5] applied urban criteria and used AHP and GIS to evaluate the vulnerability of the city to earthquakes and found that as the parameters like slope of the land, population density, building density, building age, and the distance between buildings and open spaces increase, vulnerability goes up. However, the increase in parameters like distance from active faults, wide paths and the balance between neighboring buildings' applications decreases the vulnerability [5].

Ahad-Nezhad [6] modeled vulnerability of Zanjan through AHP and RISK_UE models and estimated human, economic and social damages earthquakes of different magnitudes may have in this city in northwestern Iran [6]. Giovinazzi [7] first investigated vulnerability models like RISK_UE and different damage scenarios and then used it to study one of the vulnerable areas in Italy named Liguria [7]. Lantada et al. [8] modeled vulnerability of Barcelona, Spain through RISK_UE model and applied other models to estimate human and economic damages Barcelona may experience in case of earthquake [8]. Tang and Wen [9] utilized an artificial intelligence system based on GIS and artificial networks to estimate the earthquake risk in the city of Diang in China. This system is generally used for identification of quake risk of structures in pre-earthquake conditions, quick estimation of earthquake damages, and preparation of immediate public and state responding conditions during the earthquake and after that [9].

Considering the above-mentioned points, the present study aims to investigate and estimate vulnerability of the first region of Tehran municipality in earthquakes using RADIUS, TOPSIS and AHP models in three different probable earthquake scenarios. Fig. 1 gives an overall picture of the whole research trend.

DATA AND METHODOLOGY

The Region under Study

The first region of Tehran municipality in northernmost part of Tehran was chosen to be investigated in this study. This region in the southern edge of the Alborz mountain range in longitude 534272.5 east and 546670.5 west and latitude 3964923.5 north and 3959463.5 south. In the north its height is 1800 meters and the southern limits are Chamran, Babaei, and Modares expressways. In the east it reaches Lashgarak road and Ghoochak forest park and in the west it ends in the Darakeh River. The first region municipality has 10 districts and 26 quarters and its population according to 2006 census is 339334. Fig. 2 shows the map of the region with its 10 districts.

Data Used

The criteria used in this study are the position of the building and the faults, number of floors, population density, soil type, slope of the region, paths network. Moreover, ArcGIS, IDRISI and RADIUS programs were utilized.

Models Used

RADIUS: RADIUS protocol was first used in 1996 to provide an earthquake scenario and compile a road map for cities in danger of earthquakes in developing countries. The major aim followed by the managers of the project sponsored by the UN was promotion of awareness and creation of a scientific and applicable tool for decreasing earthquake risk in urban areas. This protocol with its modifications was later used as a program to estimate damages and create an earthquake scenario. This model could help all those involved in urban issues. The major goals RADIUS follows are [10].

1. Designing a tool for managing earthquake risk that could fulfill the needs of earth-quake prone cities
2. Conducting comparative studies for a better understanding of the earthquake risk in different parts of the world
3. Exchanging information for reducing the earthquake risk in urban levels
4. Preparing a promotion program for the existing urban structure including reinforcing buildings and vulnerable infrastructures and securing outdoor areas and emergency exits
5. Providing rescue equipment, fire extinguishers and emergency transportation

RADIUS works in Excel environment and the operator has to enter data on the limits of the region under study from the networking, population, number of the buildings and their structure type, soil type and information on life lines, type of earthquake scenario and its parameters into the software. Then, the program analyzes the data entered and outputs the following information:

1. Earthquake magnitude in the form of PGA and MMI magnitude
2. Damages on the Buildings
3. Damages on life lines
4. Casualties including the deceased and the injured
5. Figures and tables displaying results thematically

One of the major goals of this project was developing an experimental tool for urban risk management. In the whole process of building destruction, RADIUS considers earthquake scenario, calculation of attenuation using function, calculation of augmentation induced by local soil condition through soil map, conversion of PGA into modified Mercalli intensity scale, utilizing vulnerability function for all types of buildings, utilizing vulnerability function for all infrastructures, and utilizing vulnerability function for casualties [10]. The whole process of damage estimation is represented in fig. 3.

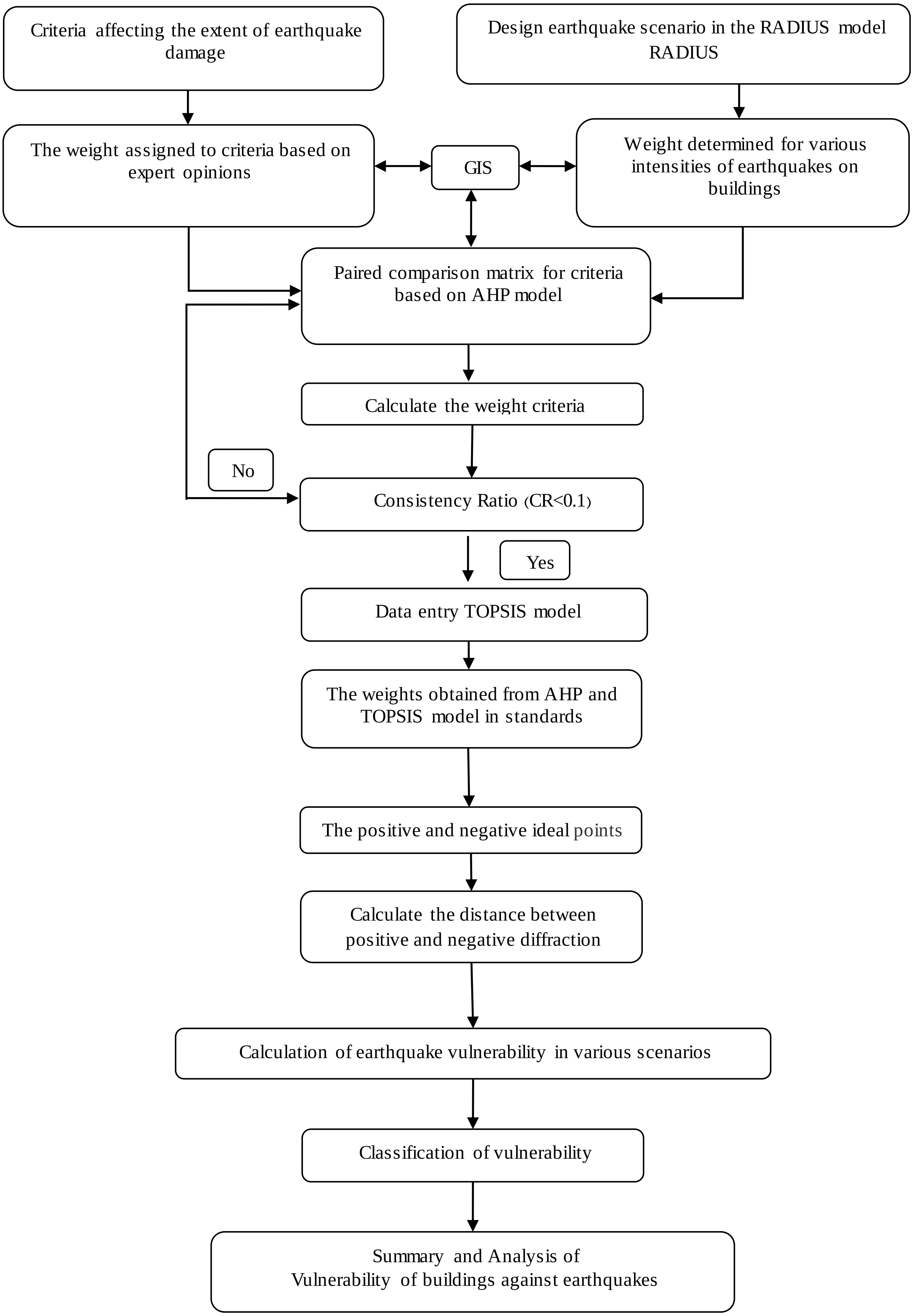

Figure 1. View of research

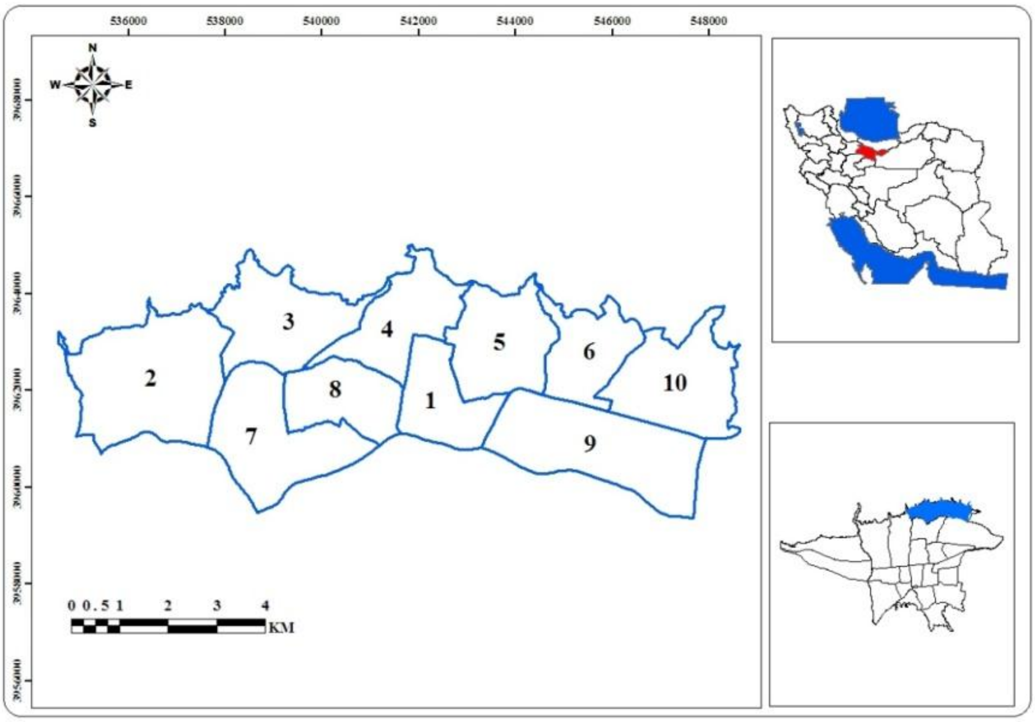

Figure 2. Location of study area

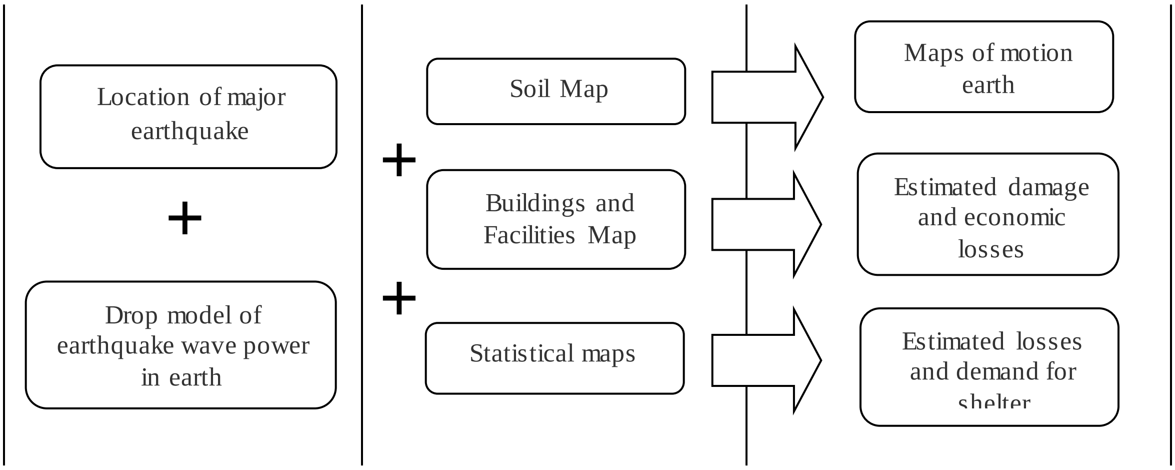

Figure 3. Damage estimates in the application process RADIUS [11].

Analytic Hierarchy Process (AHP) Model

In order to analyze complex fuzzy problems, this method was proposed by Thomas Saaty based on the analyses in human brain [12]. Analytic hierarchy model is one of the most comprehensive models designed for multi-criteria decision making for it provides a hierarchical formulation for problems and lets qualitative and quantitative criteria be considered in the problem. It includes different alternatives in decision making and analyzes the sensitivity on the criteria and sub-criteria [13]. AHP is generally used for estimating large numbers of criteria and solving multi-criteria problems. It enables decision makers use the testability of this model in solving different problems regardless of any group they are from [14]. Since AHP does not work based on probability, the results are transparent. On the other hand, paired comparisons facilitate evaluation of several alternatives with various criteria from different groups as an integrated part of this process [15].

AHP is based on paired comparisons and facilitates judgment and calculation. It also displays the compatibility and incompatibility of a decision as a vital advantage for this multi-criteria decision making technique founded on powerful theoretical frameworks [13]. All comparisons in this hierarchical analysis process are done in pairs thus decision makers may have the opportunity to compare verbal judgments so that if element *i* is compared to element *j*, the decision maker may decide on the importance of *i* over *j* according to table 1 offered by Thomas Saaty [16].

When the priority of the criteria over each other is defined, the consistency ratio of the system (CR) should not exceed 0.1 where CR is obtained from dividing compatibility index (CI) by average consistency ratio index (RI) i.e. CR= CI/ RI where RI is provided by Saaty in 1991 for different sizes and CI is obtained from eq. 1

Equation 1. $CI = \lambda_{\max} - {}^{n}\!/_{n-1}$

Where n i the number of criteria, λ_{max} is the maximum Eigen value. Revision on the weights will be necessary in case the CR exceeds 0.1 [12].

Table 1. The Fundamental Scale for Making Judgments [9]

Definition	Intensity of relative importance
Extremely Preferred	9
Very strongly Preferred	7
strongly Preferred	5
Moderately Preferred	3
Equally Preferred	1
intermediate values between	2,4,6,8

TOPSIS Model

TOPSIS was first proposed by Hwang and Yoon (1981). It is one of the mostly used multi-criteria decision making. Not only does it consider the distance from an ideal point, but also it takes the distance from a negative ideal point. In other words, the selected alternative must have the minimum distance form positive ideal and maximum distance from the negative ideal point. Fundamental considerations in this model are:

1. Desirability of any index must be uniformly increasing (or decreasing) so that the best value of any index will represent the positive ideal and the worst value will represent the negative ideal.
2. The distance of an alternative from a positive (or negative) ideal may be calculated with the Euclidean distance (from the second power) or in the form of sum of absolute values from linear distances (city block distances) [12].

In the TOPSIS model, considering features and criteria, two positive and negative ideal points are selected and the best alternative is the one that is closest to the positive ideal point and the furthest from the negative ideal point. Ideal point methods prioritize alternatives according to their distance from an ideal point. This ideal point may be a hypothetical point and is the point in which resultant of all criteria is calculated. The fundamental concept of TOPSIS is that all alternatives must be closest to the positive ideal point and furthest from the negative ideal point [17]. In the present study, the positive ideal point is the point with the highest earthquake vulnerability and the negative ideal point is the one with the lowest earthquake vulnerability. Utilizing the distance index, the equation for making decision based on the ideal point could be obtained from eq. 2.

Equation 2 $$S_{i^+} = \left[\sum_j^n W_j^p \left(V_{ij} - V_{j^+}\right)^P\right]^{\frac{1}{P}}$$

Where S_{i+} is the distance from the i^{th} alternative from the ideal point for the j^{th} feature, W_j is the weight of the j^{th} alternative, V_{ij} the standard value of the j^{th} alternative for the i^{th} alternative, V_j is the positive ideal value for the j_{th} feature and p is the parameter that can vary between 1 and indefinite. Similarly, the distance between points and negative ideal point is obtained from eq. 3.

Equation 3. $$S_{i^-} = \left[\sum_j^n W_j^p \left(V_{ij} - V_{j^-}\right)^P\right]^{\frac{1}{P}}$$

In the above equation, S_{i-} is the distance between the i^{th} alternative and the negative ideal point for the j^{th} feature and V_{j-} is the negative ideal point for the j^{th} feature. Later on, the value of C_{i*} is calculated through eq. 4.

Equation 4 $$C_{i^*} = \frac{S_{i^-}}{S_{i^*} + S_{i^-}}$$

C_{i*} is a value between 0 and 1 and when the value is closer to 1, that alternative is closer to the ideal condition .[18] In the present study, the closer the value is to 1, the more vulnerable those limits are and the closer they are to 0, the less vulnerability these limits will have.

Earthquake Scenario

In order to estimate the damages an earthquake may have in the first region of Tehran municipality, RADIUS model was first used to design an earthquake scenario and to calculate the its magnitude. Earthquake scenario is the magnitude, intensity and other parameters of any earthquake that the software takes as a probable quake in the region. The input parameters for compiling the earthquake scenario include: position of the earthquake, depth of the quake, its magnitude and its time. Since different regions of different cities may have different characteristics of soil type, its condition and buildings application along with several other statistical data. The first region of Tehran municipality was divided into 123 equal networks of 600* 600 meters and the data for each of these networks were entered into the program separately. The networking was done in ArcGIS software considering the borders and distribution of the buildings in them. The networking is displayed in fig. 4.

Among several active faults in the region, the following ones are supposed to be the most dangerous:

- Masha fault (length: about 200 km)
- North of Tehran fault (length: about 90 km)
- South of Ray fault (length: about 20 km)

Consequently, 3 models were designed for RADIUS features of which are demonstrated in table 2. Then, according to the scenarios, the intensity of each earthquake was calculated for each different district and considering these intensities and expert views, the desired weight (table 6) was loaded on its buildings. Table 3 shows the average earthquake intensity in different districts of the region.

RESULTS

In order to estimate the damages induced by a probable earthquake in the first region of Tehran municipality using RADIUS, AHP, TOPSIS and their theoretical framework, the applied criteria including position of the buildings and the faults, materials, age of the buildings, number of the floors, population density, soil type, the slope of the region, and paths' network were entered. The priority of these criteria was compared through AHP and expert views and their weight and importance was calculated via IDRISI computer program. The results of these calculations are represented in table 4. As it can be seen, the value of CR is 0.03 that is less than 0.1 and therefore it is acceptable. Any of these parameters had their own criteria then a specific weight was attributed to them according to expert views. These weights can be found in table 6 where the weights are between 0 and one

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i.e. the closer they are to zero the less vulnerable they were and the closer they were to 1 the more vulnerability they had. These parameters were then put in TOPSIS model and the positive and negative ideal points were combined according to equations 2, 3 and 4. The obtained values for the vulnerability of each building are a number between 0 and 1. After that, the values were grouped like table 5 and each building goes into one of these groups of vulnerability.

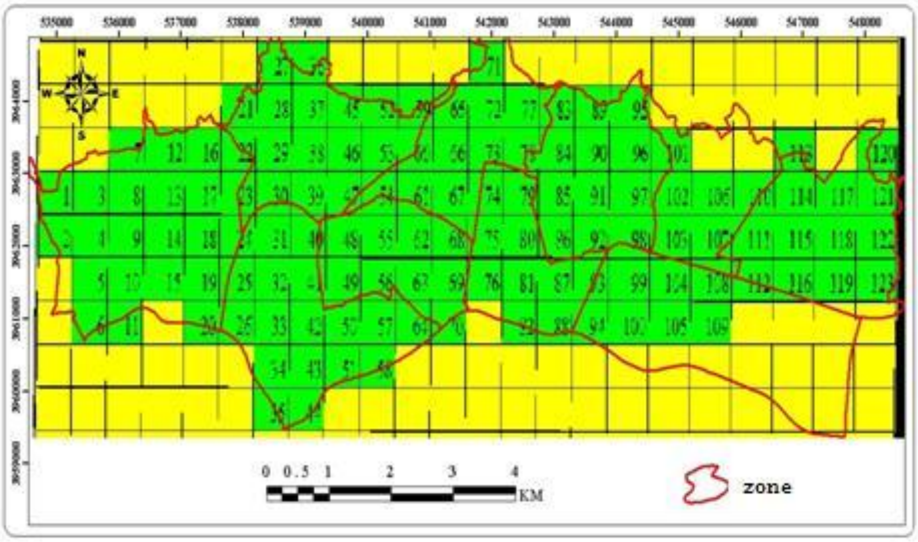

Figure 4. The lattice of region with RADIUS model

Table 2. Specifications models scenario earthquake

Specifications	Mosha fault scenario	North Tehran fault scenario	Ray fault scenario
Length	68 Km	58 Km	26 Km
Width	30 Km	27 Km	16 Km
Position relative to region	Northeast	North	South
Earthquake intensity	7.2 Richter	7.2 Richter	6.7 Richter
Depth of the earthquake	5 Km	5 Km	5 Km
Earthquake intensity in different parts of region	7 to 8 Richter 8 to 9 Richter	8 to 9 Richter 9 to 10 Richter	6 to 7 Richter 7 to 8 Richter

Table 3. The average intensity of an earthquake (MMI), which is felt in each of the areas

District	Mosha fault scenario	North Tehran fault scenario	Ray fault scenario
1	9.3	7.3	8.3
2	8.8	6.9	7.6
3	8.9	6.8	7.8
4	9.3	7.1	8.2
5	9	7	8.1
6	9	7	8.1
7	9	7	7.7
8	9.3	7.3	8.1
9	9.1	7.1	8.1
10	8.5	6.7	8

Table 4. Criteria used to compare paired

Preference Matrix	Position of the fault	Type of material	Old building	Number of Floors	Population density	Soil Type	Slope	Street network	Criteria weight
Position of the fault	1	2	2	4	4	5	8	9	0.2725
Type of material	1.2	1	5	4	4	5	8	8	0.2231
Old building	1.2	1.5	1	2	2	4	7	8	0.1719
Number of Floors	1.4	1.4	1.2	1	2	3	6	6	0.1324
Population density	1.4	1.4	1.2	1.2	1	3	6	5	0.0903
Soil Type	1.5	1.5	1.4	1.3	1.3	1	4	4	0.0588
slope	1.8	1.8	1.7	1.6	1.6	1.4	1	3	0.0307
Street network	1.9	1.8	1.8	1.6	1.5	1.4	1.3	1	0.0203

Table 5. Rating of damage to buildings (Coburn Andrew, Spence, Robin, 2002)

Degree of damage	Range	Description
D0	0	None of damage
D1	0-0.2	Little of damage
D2	0.2-0.4	Moderate of damage
D3	0.4-0.6	Considerable damage to the heavy
D4	0.6	Very heavy of damage to complete destruction

Table 6. Weighting the criteria used by the expert opinions

Vulnerability factors	Type	The proposed weight
Soil Type	Alluvium New Testament	1
	Kahrizak alluvium	0.75
	Conglomerates and alluvial deposits	0.125
slope	0 to 15 degrees	0.25
	16 to 30 degrees	0.75
	More than 30 degrees	1
Street network	6 meter wide and less than 6 meters	1
	Within 6 to 10 meters	0.75
	Within 10 to 15 meters	0.375
	Width of 15 meter	0.125
Old building	1 to 10 years	0.25
	10 to 20 years	0.75
	More than 20 years	1
Number of Floors	1 and 2 floors	0.25
	3 and 4 and 5 floors	0.75
	6 floors and more	0.56
Population density	Low	0.25
	Average	0.625
	High	1
Type of material	Clay Skeleton	1
	Brick structure	0.75
	Metal structure	0.375
	Concrete structure	0.25
Position of the fault	6 to 7 Richter	0.5
	7 to 8 Richter	0.7
	8 to 9 Richter	0.85
	9 to 10 Richter	1

Table 7. The ideal criteria used in TOPSIS model

Criterion	Ideal points		Criterion	Ideal points	
Type of material	Positive	0.2231	Street network	Positive	0.0203
	Negative	0.0588		Negative	0.00253
Old building	Positive	0.1719	slope	Positive	0.0307
	Negative	0.0429		Negative	0.0077
Number of Floors	Positive	0.0993	Mosha fault	Positive	0.2316
	Negative	0.0331		Negative	0.1907
Population density	Positive	0.0903	Shomal fault	Positive	0.2725
	Negative	0.0225		Negative	0.2316
Soil Type	Positive	0.0588	Ray fault	Positive	0.1907
	Negative	0.0073		Negative	0.1362

Estimating Buildings' Vulnerability and Its Distribution According to the Scenarios

The overall condition of vulnerability of the buildings in the region is represented in table 8. As it can be seen from the table, in the scenario of Masha fault 30.38%, in the scenario of north of Tehran fault 42.61% and in the scenario of south of Ray fault 20.05 of the buildings will experience severe damages some of which will destroy. The table shows that the highest vulnerability is for the north of Tehran fault and the lowest one is for the South of Ray fault. Figures 5, 6 and 7 show the vulnerability of region in different scenarios. Figures clearly show that the region is vulnerable because of the north fault but it should be noted that the whole region is at risk although the risk of the north fault is higher. According to the findings, the highest damage will be from the north fault and the lowest risk will be from the Ray fault. The reason for this may be the short and far distances of north and Ray faults from the region respectively. According to the findings about several districts of this region it is concluded that districts number 5, 8 and 7 are highly vulnerable in all scenarios in this study i.e. they are the most vulnerable areas for the magnitude of earthquake in these districts are high and most of the buildings are made of bricks. Moreover, buildings in districts 7 and 8 are generally old. The buildings in districts 9 and 10 are the least vulnerable for they are generally steel or concrete structures and thus they are not very old.

Table 8. Statistical distribution of the overall vulnerability of a housing area on the desired scenario

	Range of Vulnerability	Statistical distribution of the vulnerability of buildings in the area(Percent)										Percent in the region
		1	2	3	4	5	6	7	8	9	10	
Mosha fault scenario	Little of damage	0.95	3.15	0.93	1.40	0.00	1.03	0.00	0.00	0.00	17.26	2.10
	Moderate of damage	56.55	51.54	31.01	46.93	42.26	72.05	52.41	35.77	75.76	78.49	49.89
	Considerable damage to the heavy	3.97	28.76	38.05	37.81	5.44	9.52	7.09	8.31	17.73	4.25	17.63
	Very heavy of damage to complete destruction	38.53	16.55	30.01	13.86	52.30	17.40	40.50	55.92	6.51	0.00	30.38
North Tehran fault scenario	Little of damage	0.05	0.30	0.12	0.22	0.00	0.14	0.00	0.00	0.00	5.24	0.46
	Moderate of damage	54.81	50.69	26.67	44.46	34.87	68.64	43.52	33.04	60.88	61.74	44.38
	Considerable damage to the heavy	6.17	8.08	14.39	6.43	10.99	7.67	14.16	9.51	26.24	33.02	12.55
	Very heavy of damage to complete destruction	38.97	40.93	58.82	48.89	54.15	23.56	42.32	57.45	12.87	0.00	42.61
Ray fault scenario	Little of damage	0.04	3.14	0.93	0.58	0.07	0.33	0.00	0.02	0.00	17.73	1.94
	Moderate of damage	60.90	55.68	40.33	49.66	46.64	78.22	53.15	38.25	84.12	81.22	53.93
	Considerable damage to the heavy	24.02	36.68	48.48	48.76	26.84	15.64	7.86	6.49	12.09	1.05	24.07
	Very heavy of damage to complete destruction	15.04	4.50	10.26	1.00	26.44	5.81	38.99	55.24	3.78	0.00	20.05

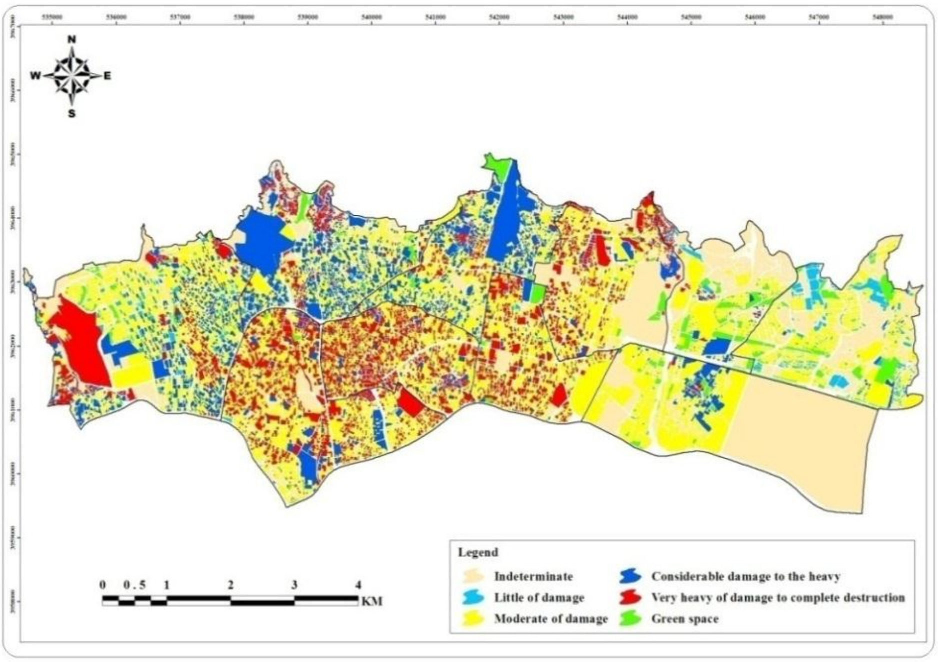

Figure 5. Distribution map of buildings destroyed by Mosha fault scenario

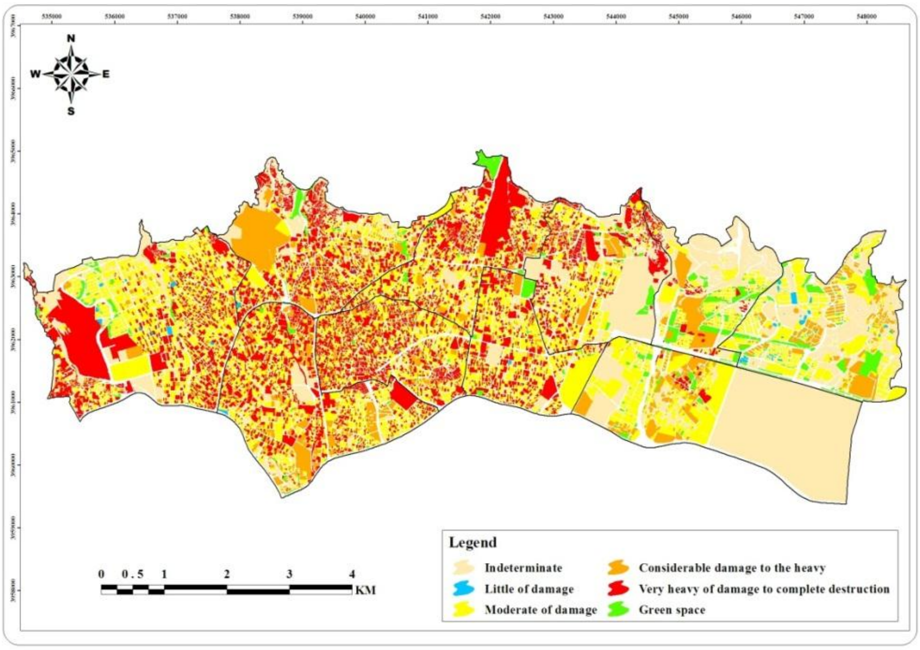

Figure 6. Distribution map of destroyed buildings on the North Tehran fault scenario

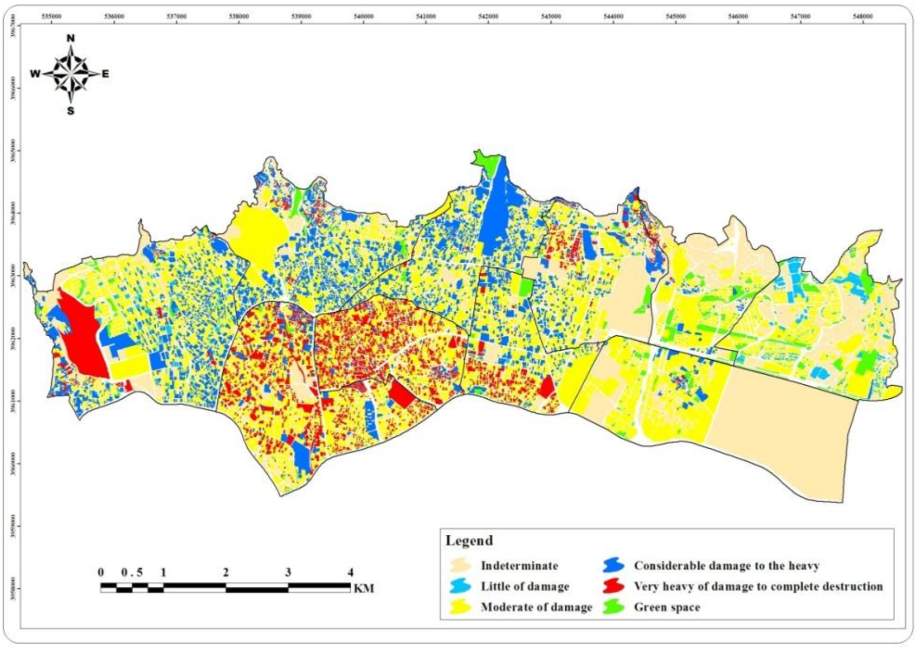

Figure 7. Distribution map of buildings destroyed on the Ray fault scenario

CONCLUSION

Several models for analysis and estimation of the earthquake induced damages have been developed and various studies have been conducted in and out of Iran. The studies conducted in Iran have chosen a limited area as their field e.g. JICA project [3] that investigated vulnerability through statistical domains. Another point worth mentioning is that vulnerability of regions is a reflection of human behavior or management in that specific region for construction strategies and engineering principles must be observed under thought and supervision of humans. Thus, any study conducted in the field must observe different conditions in the area under study. In the JICA project for Tehran, this point was not seen since they used the failure curves [2] had produced for Rudbar-Manjil earthquake in the case of Tehran [18]. Expert views in the field of construction, urban planning and earthquakes are also connected and in the case of defining the criteria and prioritizing them they are of great influence i.e. they can ensure precision of the results. These points had been neglected in the studies conducted to earthquakes. Another important point is that magnitude of the earthquake must be investigated considering the faults in the area and this also has been ignored in many of the domestic studies conducted in Iran.

The present study aimed to take all above-mentioned considerations into account and the vulnerability estimation was obtained specifically for any specific building. On the other hand it attempted to consider faults in different earthquake magnitudes. In order to evaluate the compatibility of the model with the region under study, expert views were considered in prioritizing the criteria. Results revealed that the first region of Tehran municipality is highly vulnerable to earthquake. In other words, districts 5, 7 and 8 in this region are highly vulnerable and districts 9 and 10 are the least vulnerable to the potential earthquake scenarios.

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