ORIGINAL PAPER

Assessment and mapping of the seismic vulnerability of Tabriz city using the Fuzzy logic

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ABSTRACT

The present study aimed to investigate and zonate Tabriz city, Iran in terms of vulnerability to earthquake hazard using the GIS software. Due to the geographical location of Tabriz over the North Tabriz Fault as an active and seismic fault from the north of the city, the necessity of this issue is highlighted. Based on the 10 most important influential factors in the vulnerability of cities to earthquake (geological and environmental factors), the seismic vulnerability zoning maps were developed by the ARC GIS software using the Fuzzy logic. By the integration of the layers using the Fuzzy method, the final map of the vulnerability of Tabriz City in equilibrium earthquakes was prepared in five zones with very high, high, moderate, low, and very low vulnerability. According to the zoning maps, Tabriz is not well positioned in terms of the occurrence of earthquakes, and most of the populated areas (especially the northern and central parts of the city) have higher vulnerability.

Keywords: Zoning, North Tabriz fault, Earthquake, Vulnerability, Fuzzy logic, GIS

Introduction

Natural disasters are an important issue in the world's major cities.[1] As a risk factor, natural disasters are beyond the scope of access and control in urban environments.[2] Earthquake is considered to be the foremost natural disaster in the world due to its vastness, frequency of occurrence, and the extent and severity of the subsequent damages.[3] Although earthquakes may not lead to adverse consequences, unpreparedness to deal with this natural phenomenon could cause significant damages.[4]

Extensive research has been focused on the degree of vulnerability and zoning of the risk of earthquakes with differences in the methodology and procedures.[3,5-8] In a study conducted by Guo and Kapucu, the social vulnerability of Hanzhong City (China) to earthquakes was assessed using rough analytic hierarchy process method, and the influential factors were identified based on the opinion of experts, derived from the AHP model, and evaluated after weighting.[9] In another study by Jena *et al*., the same model was used to assess the risk of earthquake in Aceh province (Indonesia), and the obtained results indicated that the southeastern regions of the city were at the moderate to very high risk of earthquake, while the other areas were reported to be at low and very low risk of earthquake. The findings of the mentioned study could contribute to government agencies and decision-makers in estimating the dimensions of the risk of earthquake and preparedness for the disaster.[2]

In Iran, Yariyan *et al.* assessed the risk of earthquake using the AHP model in Sanandaj City. In the mentioned research, a new hybrid model of AHP (FAHP-ANN) was designed and used in earthquake risk assessment in Sanandaj. By identifying the criteria of earthquake vulnerability (demographic,

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environmental, and physical), considering the earthquake background in the region, and weighting the model, the vulnerability of the region to earthquakes was assessed.[3]

The geological structure of the Iranian plateau and its margins is related to the folded belt system of the Cenozoic era, which is a potential and positive factor in terms of mineral and economic reserves and a negative factor in terms of seismic evolution.[10] As Iran is located in the Himalayan Alpine orogenic belt, the deformations are not over yet, and the final balance has not been established.[11] Saudi Arabia, India, and Siberia are exerting pressure on Iran respectively from the southwest, east, and southeast/northeast, and Iran's resistance to the pressures has led to numerous faults and fractures.[12] The activity of these faults has made Iran one of the most important earthquake-prone regions in the world. The energy caused by these pressures is stored in faulty areas, and after release in the form of destructive waves, the subsequent earthquake causes the destruction of cities.

Recent earthquakes have shown that Iran is a seismic country, and none of its regions are safe from earthquakes.[13] In the report of the United Nations Planning Office, Iran has been ranked first among other countries regarding the number of the earthquakes with the magnitude of 5.5 per year, while also having the highest ranks in terms of vulnerability to earthquakes and the number of the casualties.[14] The same report has also shown that in Iran, earthquakes are the predominant factor in various natural disasters.[15]

Tabriz is one of the metropolises of Iran, which is considered to be in a very-high-risk zoning position.[16] Vicinity to the North Tabriz Fault, the population of 1,733,033 (2016 census), and huge industrial, cultural, and historical assets have rendered Tabriz as the most dangerous city in terms of earthquake risk. The North Tabriz Fault is one of the most hazardous faults in Iran, which has been the source of numerous devastating earthquakes throughout history.[11]

According to the latest estimates until 2011, 400,000-500,000 citizens of Tabriz live in these areas. Dry and inflexible urban planning regulations and the lack of proper financial capacity, authoritative management, and strategies in this regard have proved that worn-out tissues will swallow Tabriz with time. Therefore, it is essential to reduce the possible damages to this historical city. Due to the high seismic risk in Tabriz City, principled and correct seismic vulnerability zoning should be performed considering geological, human, and urban factors.

In order for the proper management of the mentioned crisis in Tabriz City, the present study aimed to zone the seismic vulnerability of various areas in Tabriz during a destructive earthquake by the Fuzzy logic system using the appropriate criteria in the GIS environment based on geological, human, and urban factors.

Geographical location of the study area

Tabriz City is located in the northwest of Iran and is the capital of East Azarbaijan Province (Fig. 1). The geographical coordinates of Tabriz are 38° and 36′N, and 46° and 49′E, with the approximate altitude of 1,348 meters above the sea level. As the largest city in the northwest of Iran covering an area of 23,745 hectares with the altitude of 1,350 meters above the sea level, Tabriz is located in Tabriz Plain. Tabriz City is limited by the Einali Mountains from the north to the heights of Sahand Mountain from the south, Basmanj agricultural lands from the east, and Tabriz Plain from the west. According to the 2016 census, the population of this city is 1,733,033.

The plateau of Azarbaijan Province is situated between the plateau of Iran from the east, plateau of Armenia from the north, and plateau of Anatolia from the west. Tabriz Plain is located at the center of the plateau of Azarbaijan on the eastern side of the shores of Lake Urmia and is considered to be part of the large plain along Lake Urmia.

Materials and Methods

This was an applied, developmental research in terms of the design and a descriptive-analytical research in terms of the methodology. The methodology was based on the analysis and overlap of the information layers in the ArcGIS software and preparation of a Fuzzy map, Fuzzy layers, and their integration using a simple Fuzzy inference method to present the final vulnerability map of Tabriz.

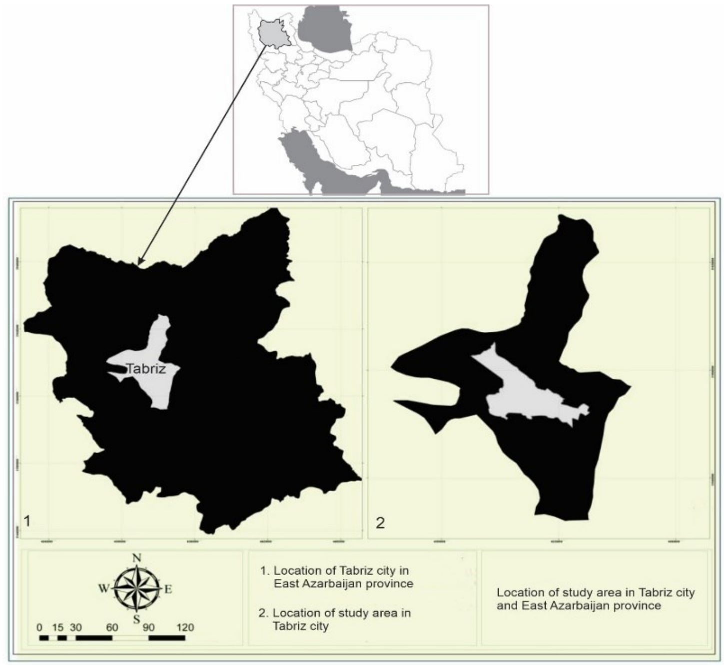

Fig. 1. Location of study area

Initially, library studies were carried out using the related texts and maps, and the previous studies in this regard were also reviewed to identify the influential factors in seismic vulnerability. Based on the comprehensive and systematic approach of the research, both the geological and environmental factors were studied. The natural factors included distance from the fault, slope of the ground, material of bedrock, and groundwater level of the area. The environmental factors were population density, building density, access to relief and hospital centers, green space, parks and open spaces, and distance from hazardous sources.

At the next stage, the maps obtained from the municipal, road, and urban development organizations were used, and in some cases, field surveys and the information layers related to the selected factors were prepared. To provide the required data, the 1:100,000 geological map of Tabriz was initially prepared by a geological survey, and the mineral exploration of Iran was scanned to be converted into a georeference and digitized using the ArcGIS software. After digitization, the digital elevation model (DEM) of the region was prepared, and the region slope information layer was prepared. After the conversion of the information layers into the raster form, the features of lithology, slope, geomorphology, and fault location were determined.

The next stage involved the identification of various applications of urban lands. For this purpose, we collected the available qualitative information in organizations such as Tabriz Municipality, Iran Water and Wastewater Engineering Company, Geological Survey and Mineral Exploration of Iran, and Statistical Center of Iran, and the zoning maps were drawn. Finally, the information layers were combined in the GIS, and the scores of each layer were used to develop the final zoning map of earthquake vulnerability in Tabriz City by the Fuzzy logic.

Fuzzy logic

A Fuzzy set is a class of elements or phenomena without a clear and precise range, which indicates whether the phenomena belong to the class, and in this case, whether the complications to some extent belong to multiple sets. The Fuzzy logic is an approach to the modeling of the complex systems that are impossible or very difficult to model by mathematics and classical modeling techniques in a simple and flexible manner. The Fuzzy logic considers numbers between zero and one and measures accuracy with a number whose value is within the range of 0-1. For instance, if the black color is zero and the white color is one, the gray color will be close to zero.

The theory of Fuzzy sets and the Fuzzy logic was introduced by Zadeh[17] with the purpose of developing a more efficient model to describe the processing of natural languages at the time. He also introduced concepts such as Fuzzy sets, Fuzzy events, Fuzzy numbers, and Fuzzy construction into mathematics and engineering.

Results and Discussion

The influential factors in earthquake vulnerability

Various criteria are used to assess the earthquake vulnerability crisis depending on the method and regional location. In the present study, 10 important influential factors in determining earthquake vulnerability by the Fuzzy method were selected, and the reasons for their importance are shown in Table 1.

Table 1. Correlations between factors and vulnerability

Number	Criteria	Reasoning
1	Distance from the fault	If the distance from the fault is large, the vulnerability is reduced
2	Land slope	If the slope is low, the vulnerability is reduced.
3	Material of bedrock	Vulnerability is reduced if the bedrock material is suitable.
4	Groundwater level of the area	If the groundwater level is low, the vulnerability is reduced.
5	population density	If population density is low, vulnerability is reduced.
6	Distance from relief and medical centers	Vulnerability is reduced if the distance from relief and treatment centers is short.
7	Access to open spaces and streets	Vulnerability is reduced if access to open spaces and streets is high and better.
8	Distance from dangerous centers	If the distance from the risk centers is long, the vulnerability is reduced.
9	Building Density	If the building density is low in an area, the vulnerability is reduced.
10	Access to green spaces and parks	Vulnerability is reduced if access to green spaces and parks is high.

Ranking of the layers

To rank the influential factors in seismic vulnerability, they were considered as layers. After identifying the layers affecting vulnerability, each layer was rated and ranked to obtain the characteristics of each point of the study area, and the rates were used to prepare the base maps of each layer.

Fault layer

Faults are an important risk factor for earthquakes. The buildings that are known for their earthquake resistance are often far from faults as increased distance from faults is associated with the decreased impact of vulnerability on buildings.[18] In the study by Martins *et al*., the layer was investigated as an important factor.[19] The North Tabriz Fault is one of the most hazardous faults in Iran, and we investigated the seismic vulnerability zoning based on the distance from the North Tabriz Fault using the Fuzzy method. Table 2 shows the distance from the fault as divided into 500-m distances.

Table 2. Vulnerability and its ranking based on distance from North Tabriz Fault

Rank	Vulnerability	Interval of distance from fault (m)
5	Very much	0-500
4	Much	500-1000
3	Medium	1000-1500
2	Low	1500-2000
1	Relatively low	2000 ≤

After ranking the distance from the fault layer, the estimated distance map from the North Tabriz Fault was obtained using the Fuzzy method (Fig. 2). As can be seen in Fig. 2, based on the distance from the fault, all the northern and eastern regions of Tabriz are located on the fault zone and are in a very high and catastrophic range in terms of vulnerability. In terms of the municipal division, these areas include areas one, two, five, six, nine, and 10, as well as the northern parts of area four. In simpler terms, Valiasr, Golpark, Golkar, Abbasi, Baghmisheh, Vali Amr, Rushdieh, Idelu, Yousefabad, and Baranj towns are in the range of vulnerability caused by the fault layer.

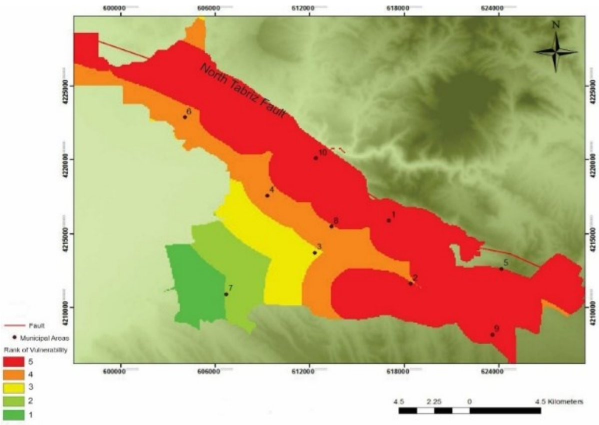

Fig. 2. Seismic vulnerability map of Tabriz City based on distance from North Tabriz Fault zone

Slope

Slopes play a key role in disaster mapping, such as earthquakes and landslides as they provide sufficient information about fault slip.[20] In addition, this layer provides information about the topography of cities. The slope of the study area was considered as another influential factor in the preparation of the vulnerability map. Degradation increases dramatically on the lands with steep topography, especially on ridges and peaks. As such, the areas with steep slopes are more vulnerable to earthquakes and landslides. In the study by Jena *et al.* regarding the assessment of the risk of earthquake in Aceh province (Indonesia), slope was considered to be an influential factor.[21] Table 3 shows the grading of the slope layer based on the criteria.

After combining the basic slope map of Tabriz with the slope rank of each point, the valuation map of Tabriz was obtained based on the slope layer (Fig. 3).

Table 3. Vulnerability and its ranking based on slope range

Rank	Vulnerability	Range of slope
5	Very low	0-5
4	Low	5-10
3	Medium	10-15
2	Much	15-20
1	Very much	20 ≤

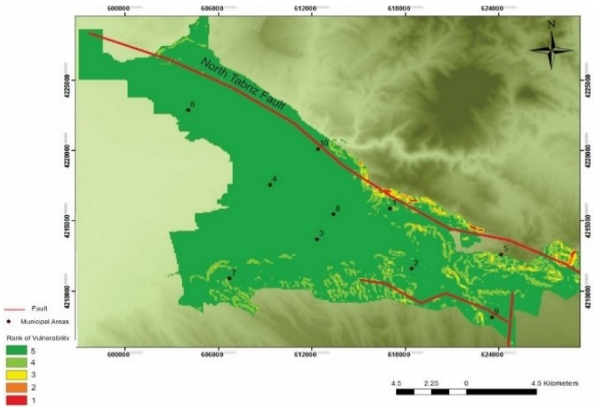

Fig. 3. Seismic vulnerability map of Tabriz city based on slope layer

As is observed in Fig. 3, Tabriz City has a better status in terms of slope, while some of the northern areas are considered to be high-risk and vulnerable zone, and the others are in a good position with the slope of less than 15 degrees.

Groundwater level

If the groundwater level is high in an area, loose sandy sediments have a high liquefaction potential, so that liquefaction during an earthquake could damage urban buildings and increase the effects of earthquake, which in turn increase the vulnerability and vice versa. Table 4 shows vulnerability and its ranking based on the groundwater level ranges.

After the ranking, the vulnerability map of Tabriz was obtained based on the groundwater level (Fig. 4).

As is depicted in Fig. 4, it could be concluded that based on the groundwater level layer, the central parts of Tabriz are very high-risk zones in terms of vulnerability to earthquake.

Table 4. Groundwater level layer vulnerability ranking

Rank	Vulnerability	Range of groundwater level (m)
5	Very much	0-5
4	Much	5-11
3	Medium	11-20
2	Low	20-30
1	Very low	30 ≤

Bedrock material

Lithological conditions in terms of behavior against seismic waves are important natural and environmental parameters in vulnerability against earthquake as harder geological series are associated with lower earthquake wave transmission capacity and decreased destructive power of an earthquake. According to the information in Table 5, conglomerates and sandstone have low vulnerability due to their high hardness, while young alluvium is highly vulnerable due to their low stability.

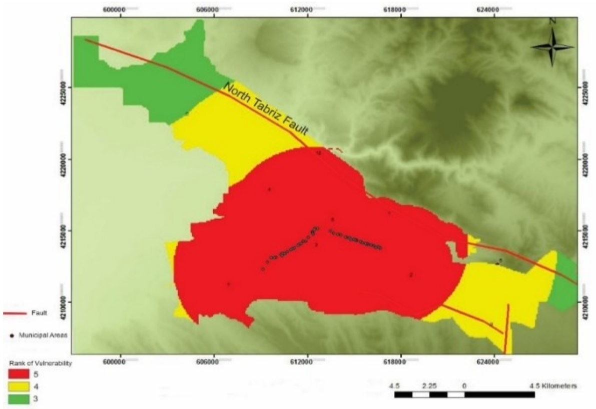

Fig. 4. Seismic vulnerability map of Tabriz city based on groundwater level (Points show groundwater level sampling points)

Table 5. Vulnerability ranking of different parts of Tabriz based on type of bedrock

Range	Vulnerability	Rank	Compatibility
Conglomerate and sand	Very low	1	Very compatible
Tuff and conglomerate	Low	2	Compatible
Gypsum and marl	Medium	3	Medium compatibility
Alluvial barracks	Much	4	Inconsistent
Alluvium of the present covenant	Very much	5	Very Inconsistent

After compiling and ranking the 1:100,000 geological map of Tabriz, the vulnerability map of the city was obtained based on the type of bedrock and lithology (Fig. 5).

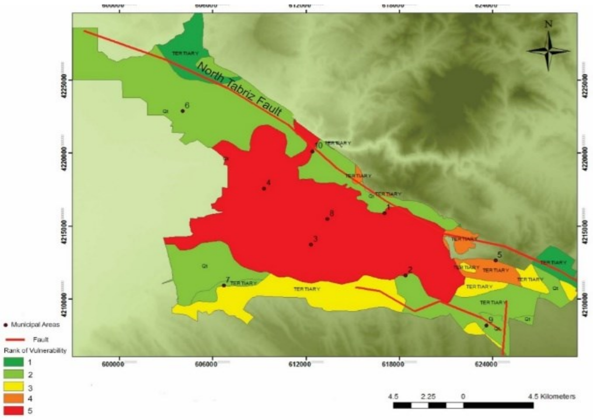

Fig. 5. Seismic vulnerability map of Tabriz city based on lithology and bedrock material

According to the information in Table 5, young sediments were highly incompatible, while the conglomerates and sandstones were highly compatible. According to the map (Fig. 5), most areas of Tabriz city are in a very incompatible and incompatible range.

Distance from relief and treatment centers

To minimize the damage caused by earthquakes, the distance from medical centers should be minimal, and the distance from medical centers is considered to be an influential factor in the preparation vulnerability maps. The increased distance from these centers is associated with higher vulnerability after an earthquake. Table 6 shows the range of the distance from medical centers and hospitals.

Fig. 6 depicts the vulnerability map of Tabriz city based on the distance from relief and treatment centers.

As is observed in Fig. 6, most of the relief and hospital centers in Tabriz are in the city center, and the areas with very high vulnerability have a small proportion of these centers. In general, it could be stated that in terms of access to medical centers, Tabriz city has a favorable status.

Table 6. Vulnerability and its ranking based on range access to relief and treatment centers

Rank	Vulnerability	Range of distance with relief and treatment centers (m)
5	Very low	0-500
4	Low	500-1000
3	Medium	1000-1500
2	Much	1500-2000
1	Very much	2000 ≤

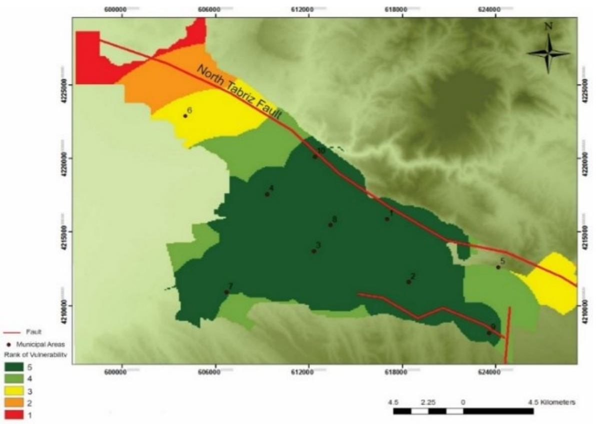

Fig. 6. Vulnerability map of Tabriz city based on distance from relief and treatment centers

Building density

Considering the characteristics of the earthquake phenomenon and knowledge of the associated damages to human settlements, it could be stated that higher building density leads to the increased resident population in each piece of land, which in turn causes the relative reduction of open spaces, difficulty in evacuation during accidents, intensification of the earthquake due to the increased height and impact of the adjacent buildings on each other, increased volume of debris after the earthquake, and difficulty in post-disaster rescue operations. The construction of buildings with low height and equal distance from each other through a proper development program could reduce earthquake vulnerability.[20] Furthermore, the reinforcement of old buildings may be effective in reducing the damages caused by earthquakes in the future.[22] Therefore, it could be inferred that with the increased density of buildings in an area, the vulnerability also increases. Table 7 shows the ranking of vulnerability based on the building density layer. Fig. 7. shows the evaluated map of Tabriz city based on the density of the buildings.

Table 7. Vulnerability and its ranking based on building density

Rank	Vulnerability	Range (unit)
1	Very low	0-200
2	Low	200-400
3	Medium	400-600
4	Much	600-800
5	Very much	800 ≤

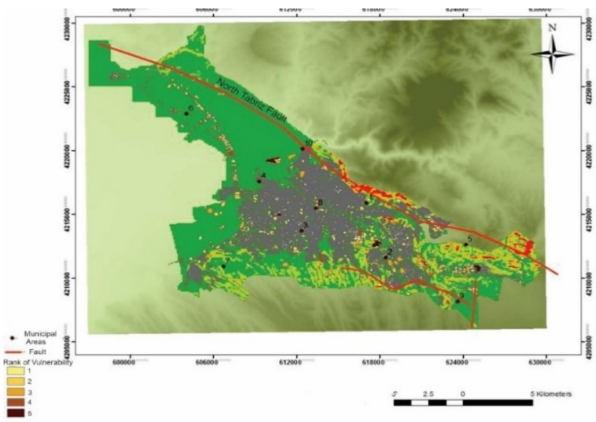

Fig. 7. Vulnerability map of Tabriz city based on building density

The lack of green color in the guide section is due to the lack of construction in those areas, and the areas with the green color are mostly gardens and green spaces. As is depicted in Fig. 7, the buildings in Tabriz city (commercial, residential, service, relief, cultural, educational) are often concentrated in the north, south, and center of the city, and the points in Fig. 7 marked with crimson color have extremely high vulnerability.

Population density

Population density is another influential factor in the seismic vulnerability of cities, and densely populated areas are more vulnerable.[19] Since the chronological order of the effects of earthquake is in the form of severe earthquakes, agitation, and casualties, the importance of population density in the last stage of the earthquake crisis could be decisive. In terms of population density, 80%

of the population of Tabriz lives in 1% of the city's land, and the average gross density of the mostly residential areas of Tabriz is estimated at 120 people per hectare and up to 170 people per hectare in older neighborhoods. According to the average gross population density of cities (100-200 people per hectare), Tabriz is considered to be a city with medium population density. Evidently, this density varies in different places. In the slums and suburbs, the density was estimated to be far more than 200 people per hectare, and during 1956-2011, the population density decreased from 247 people per hectare in 1956 to approximately 100 people in 2011. In fact, the faster trend, physical expansion of the city relative to the population, and continuation of its horizontal expansion at a relatively high speed have reduced the density to 100 people. Population density is directly correlated with the degree of vulnerability to earthquake, so that with increased density, the vulnerability of the area and mortality rate would also increase and vice versa. Table 8 shows the population density intervals and vulnerability ranking. Fig. 8 shows the vulnerability map of Tabriz city based on the population density.

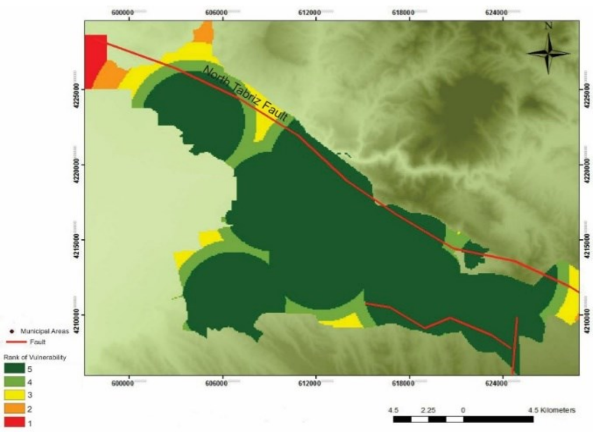

Fig. 8. Vulnerability map of Tabriz city based on population density layer

As is depicted in Fig. 8, the population density of Tabriz in the marginal regions (especially the northwestern region) is in the high vulnerability zone, and the areas marked with dark green and light colors are more acceptable according to Table 8.

Table 8. Vulnerability and its ranking based on population density

Rank	Vulnerability	Range
1	Very low	1-28700
2	Low	28700-94897
3	Medium	94897-169047
4	Much	169047-243400
5	Very much	243400-316136

Distance from hazardous centers

Hazardous facilities and centers include nuclear power plants, power transmission plants, refineries, and gas stations, which are associated with hazardous materials and could cause secondary hazards (e.g., fire and explosion).[2] According to the information in Table 9, the degree of earthquake vulnerability was inversely correlated with the distance from these centers, and the increased distance from hazardous centers was associated with the lower vulnerability of the area and vice versa. Fig. 9 shows the vulnerability map of Tabriz city based on the layer of distance from hazardous areas.

Table 9. Vulnerability and its ranking based on distance from hazardous centers

Rank	Vulnerability	Range (m)
5	Very much	0-200
4	Much	201-400
3	Medium	401-600
2	Low	601-800
1	Very low	801 ≤

As is shown in Fig. 9, Tabriz city is not in a good situation, and most areas of the city are in a zone with high earthquake vulnerability.

Outdoor and street access

Open spaces in cities and the usability of these spaces play a key role in reducing the damage and casualties caused by earthquakes. In the event of an earthquake, having a list of the locations of these spaces could minimize or prevent the damages caused by severe crises, and these spaces could be used as primary evacuation open spaces and temporary housing construction sites.[23] The shorter distance from open spaces and streets during an earthquake results in less damage and vulnerability, while difficult and remote access is associated with higher vulnerability. Table 10 shows vulnerability and its ranking based on the distance from the open spaces and streets in Tabriz. Fig. 10 shows the final valued map of Tabriz based on the distance from the streets.

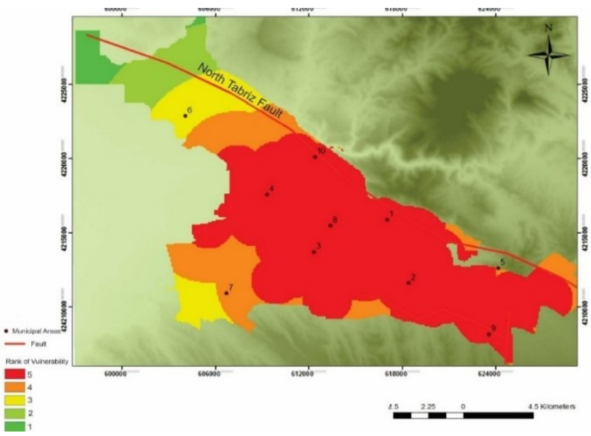

Fig. 9. Vulnerability map of Tabriz City based on distance from hazardous areas layer

Table 10. Vulnerability and its ranking based on distance from open spaces and streets

Rank	Vulnerability	Range (m)
1	Very low	0-50
2	Low	51-100
3	Medium	101-150
4	Much	151-200
5	Very much	201 ≤

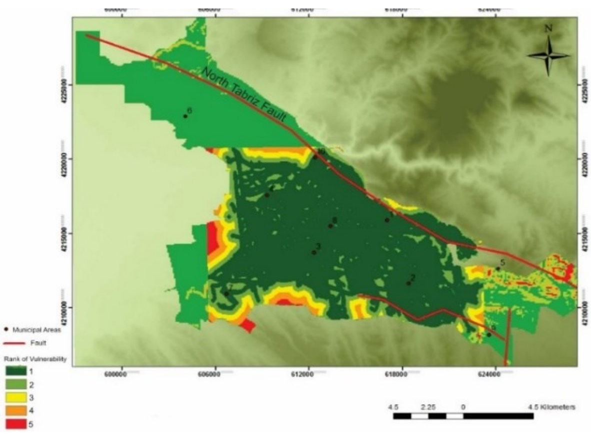

Fig. 10. Vulnerability map of Tabriz city based on distance from streets

As can be seen in Fig. 10, Tabriz city has a favorable status in terms of access to open spaces and streets in the northern and central parts, and this advantage results in rapid services after an earthquake. However, the marginal areas are not in good conditions in this regard, which increases their vulnerability.

Access to green spaces and parks

Green spaces and parks include gardens, parks, and the barren lands that have the capacity for gathering and sheltering. Increased access to such places[24] lowers earthquake vulnerability. Fig. 11 shows a map of the green spaces and parks in Tabriz. Table 11 shows the rank of vulnerability based on the distance from green spaces and parks. Fig. 11 shows the valuation map of Tabriz city based on the layer of distance from green spaces and the parks.

Table 11. Vulnerability and its ranking based on range of distance from green spaces and parks

Rank	Vulnerability	Range (m)
1	Very low	0-100
2	Low	101-200
3	Medium	201-300
4	Much	301-400
5	Very much	401 ≤

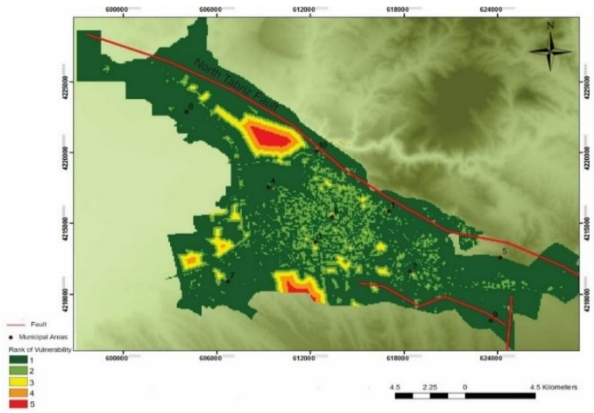

Fig. 11. Vulnerability map of Tabriz city based on distance from parks and green spaces

As is depicted in map in Fig. 11, the access to the open spaces and parks in Tabriz city was favorable, and most of these points are within 100 meters, which is beneficial in the event of an earthquake.

Weighting of the factors

At this stage, the criteria defined by experts were weighted using the AHP model and executed in the Super Decisions software. The weighted criteria are shown in Table 12. Accordingly, the distance from the fault layer had the highest weight and significance, as well as a higher significance compared to the other criteria.

Table 12. Weight of layers affected by seismic vulnerability

Layer	Oral weight	Weight obtained from AHP method
Distance from the fault (F)	5	0.286
Material of bedrock (R)	4	0.195
Land slope (S)	3	0.50
Groundwater level of the area (W)	1	0.017
population density (Po)	3	0.024
Hazardous areas (H)	4	0.174
Access to street passages (P)	3	0.066
Access to relief and treatment centers (C)	3	0.108
Access to green space (G)	2	0.052
Building density (B)	3	0.028

Overlap of information

After weighing and preparing the raster maps, Eq. 1 (sum of the product of the weight of each layer in the ranks of the same layer) was used to combine the layers to obtain the final vulnerability map of Tabriz city to earthquakes, for which the raster calculator command was employed, as follows:

$$SVI: (F_r.\ F_W) + (R_r.\ R_W) + (S_r.\ S_W) + (W_r.\ W_W) + (Po_r.Po_W) + (H_r.\ H_W) + (P_r.\ P_W) + (C_r.\ C_W) + (G_r.\ G_W) + (B_r.\ B_W) \tag{1}$$

where r and w show the rank and weight of each layer, respectively, and F, R, S, W, Po, H, P, C, G, and B are the 10 effective layers in vulnerability (Table 12). In this formula, considering the oral weight and the weight obtained from the AHP method, the map of vulnerabilty was obtained as shown in Fig. 12 and Fig. 13, respectively.

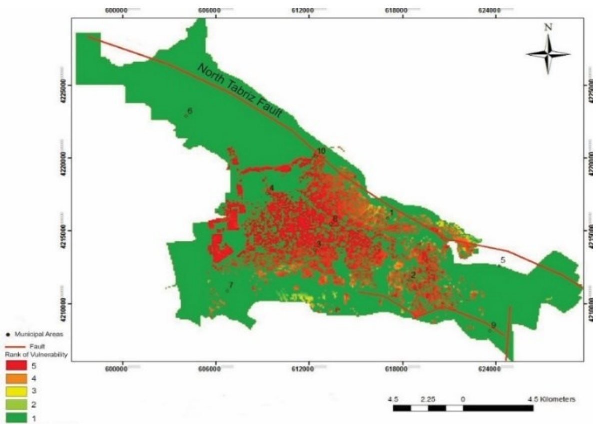

Fig. 12. Final vulnerability map of Tabriz based on oral weights

Following that, all the layers were Fuzzy, and an output map based on the Fuzzy method was obtained (Fig. 14). As a result, the maps were obtained to divide Tabriz city into five regions in terms of vulnerability as very high, high, medium, low, and very low.

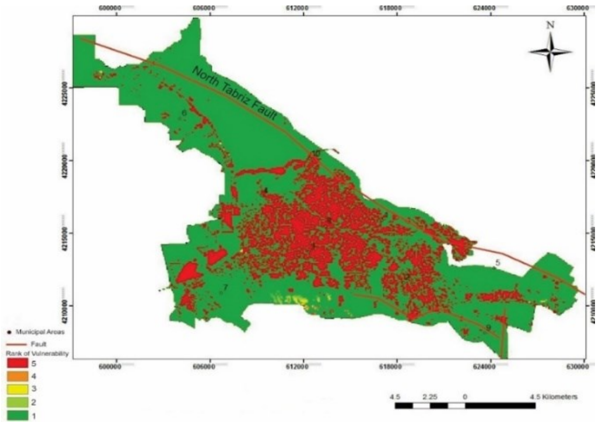

Fig. 13. Vulnerability map of area based on AHP weights

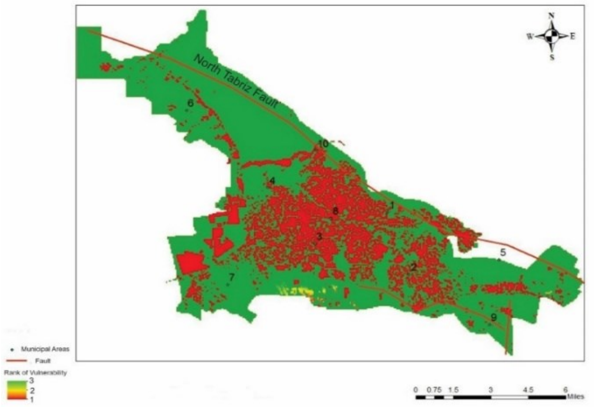

Fig. 14. Final map based on Fuzzy method

In the present study, the city was divided into five zones in terms of seismic vulnerability, including very high vulnerability, high vulnerability, moderate vulnerability, low vulnerability, and very low vulnerability. The comparison of Figs. 12-14 shows that most of the northern areas of the city (except for the limited regions in the east and west with very low population density) had very high vulnerability. This was also observed in most of the northern parts and suburbs of the city (Shahid Beheshti, Yousef Abad, Silab, Malazinal, Ahmad Abad, Ghanbarabad, Ghorbani, and Idehloo), old neighborhoods, and dilapidated areas of the city, which had extremely poor conditions in terms of spatial location, location on steep faults and slopes, and construction and urban planning (informal settlements without the necessary building and urban planning standards). High building and population densities, narrow and impenetrable alleys, lack of open and green spaces, and distance from medical centers are the main characteristics of these neighborhoods. In addition, new towns such as Eram, Baghmisheh, Elahieh, Fereshteh, Valiasr 2, Rushdieh, Nasr, Besat, and Marzdaran are located in this area. These settlements have a very high density of buildings and buildings with more than 15 floors, rapid development of construction and population settlement, growth of mass and tower construction, and lack of open spaces. According to the statistical blocks of 2016 based on the general population and housing census, the presence of more than 500,000 people in vulnerability zones is estimated to be extremely high. By moving away from the northern fault line, the vulnerability gradually reduces in Tabriz. Moreover, the middle parts and parts of the southwest and northeast are in the high vulnerability zone, and the most important parts of this area are Tabriz Airport, Tabriz Bazaar, Valiasr, and Zafaraniye neighborhoods. At the southwestern, eastern and western end of the city, the level of vulnerability is moderate, which are among the important regions of this part of Il Goli promenade and its surrounding areas, such as Ferdows alley, Baghcheban neighborhood, Yaghchian Town, Khavaran Town, and Azaran Town. Therefore, moving to the southeast of the city reduces vulnerability, leading these areas to have low and relatively low vulnerability.

Conclusion

It is not possible to predict the exact time of an earthquake or prevent its occurrence, while the possible damages could be minimized. In this study, the Fuzzy method was used to assess the earthquakes vulnerability of Tabriz city, Iran. For this purpose, 10 influential factors of distance from the fault, material of bedrock, land slope, groundwater level of the area, population density, hazardous areas, access to street passages, access to relief and treatment centers, access to green space, and building density were investigated. In addition, the maps obtained from municipal and road and urban development organizations were applied, and field surveys in some cases, in order to prepare the information layers of the selected criteria. After data collection, zoning maps were drawn, and by combining all the information layers in the GIS software and applying the scores of each layer and their weighting, the final maps of the earthquake vulnerability zoning of Tabriz were developed. According to the results, most of the northern areas of the city (except for the limited regions in the east and west) have very low population density and are very-high-risk zones. In conclusion, it could be stated that Tabriz City does not have a favorable status in terms of vulnerability to the risk of earthquake.

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