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Evaluation of the Deterministic Seismic Hazard by using Fuzzy Inference System, Case Study: Tabriz city, Iran

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Abstract

The Iranian plateau is located in the high seismicity belt. Earthquake can inflict severe loss of life and property, especially when they occur in densely populated areas. Therefore, seismic hazard evaluation is very essential to prevent the harmful effects. The region of the study is located in the northwest of Iran, between 43°-50° E longitude and 35.5°-40.5° N latitude. This city which is located in the center of East Azerbaijan province, has been ruined by terrible earthquakes, which is due to the presence of active faults in the region. Seismic hazard assessment similar to other seismology researches is very complicated due to the effect of different parameters in an earthquake occurring with uncertainty. The amount of uncertainty should be considered in a rational way. The fuzzy method is a suitable method that is used as a decision-making method for solving problems and modeling uncertainties and ambiguities. We used a fuzzy inference system, as the practice is based on uncertainty estimation of seismic hazard for Tabriz region. Peak ground Acceleration value is estimated for fuzzy Logic System in deterministic method 0.55g which is obtained from a seismic source with a Mmax=8.0 at a distance of 36.98 km of Tabriz city._The contour map of the peak ground acceleration throughout Tabriz city can help in urban planning.

Keywords: Fuzzy inference system, Seismic hazard, Deterministic approach, Peak ground acceleration, Tabriz, Iran

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1 Introduction

Fuzzy logic is a technique that can be used to take into account the uncertainties existed in the phenomenon enter probabilistic or mathematical models. Fuzzy set theory was first introduced by (Zadeh1965) who developed the concepts of classical sets. Information is obtained from data, measurement or past knowledge, and approximation must often be made which in turn introduce the uncertainties. Fuzzy expert systems are modeled capable of solving the problem as well as expert human. The fuzzy logic can integrate numerical data and linguistic variables into the fuzzy model and insert the uncertainties via an approximate argument algorithm. The Fuzzy logic has been applied to many fields, from control theory to artificial intelligence.

Earthquake phenomenon is one of the most destructive natural disasters that occur every several years and it caused vast human and financial losses. In such awfully status, it is necessary to investigate the different sight of the earthquake. Earthquake is a complex issue, which result from various variables that affect its occurrence, like seismic hazard assessment. Uncertainty, which is a result of vagueness and incompleteness of the data, should be considered in a rational way. Fuzzy logic can be modeled for two kinds of uncertainties (as low knowledge and human instrumentation and as lack of perspicuity in complex phenomenon), whereas seismic hazard assessment (SHA) face with many uncertainties. Using fuzzy logic system can help us to take into account the existed uncertainty for solving the problems. Fuzzy set logic has been used in some earthquake studies (Lamarreand Dong 1986; Chen et al. 1988; Furuta 1993; Chongfu 1996; Wadia-Fascetti and Gunes 2000).Recently, it was used to develop controlling seismic vibrations of the buildings (Kim et al. 2010), classifying the seismic damages in the buildings (Anaxagoras et al. 2003), discriminating the seismic signal between earthquakes and quarry blasts (Lassari et al. 2012), assessing the bridge risk under multiple hazard (Andric and Lu 2016), evaluating the fuzzy seismic hazard analysis (Andric and Lu 2017) and evaluating attenuation relationships of the strong ground motion earthquake record (Ahumuda et al. 2015).

Iran is located in Himalaya-Alpine seismic belt where destructive earthquake occurs every several years. Northwest Iran is situated between three seismic thrust belts; the Caucasus thrust belt from the North and the Zagros seismic belt from the South and the Alborz Mountain belt to the East, and has experienced many destructive earthquakes. The presence of the active faults by different focal mechanism have produced high seismicity in this region, especially Tabriz which is considered as one of the most important and densely populated cities in the country with a population of more than 1.6 million people in this seismic zone.

The northwestern region of Iran has experienced devastating earthquakes in recent years, causing irrecoverable mortalities and financial losses, which worth mentioning. The 858-year earthquake in Tabriz, which completely destroyed the city, earthquake of November 4, 1042 that killed 40,000 people of the city and completely destroyed the city, and the earthquake of January 8, 1780, which destroyed the city of Tabriz, and killed about 50,000 people (Ambraseys and Melville. 1982).As a result, the risk assessment in this area is necessary for reducing the uncertainties.

Our main goal is Fuzzy-logic system approach for deterministic seismic hazard (DSH) assessment of Tabriz region. This is the first time that a fuzzy logic system is used in DSH assessment for this region. The fuzzy logic method in this study is characterized by some inputs: maximum earthquake magnitude, shortest site-to-source distance, and fault-type while the output is the peak ground accelerations (PGA).

2 Methodology and Data

Seismic hazard assessment (SHA) is a basic study for all studies in various fields of geotechnics, structure, management and economy. The main goal of SHA is to evaluate the ground motion parameters like peak ground acceleration or peak ground velocity in a certain site (Green and Hell 1994).

In general, an SHA can be classified as either to three methods to evaluate seismic hazard. Statistical-Empirical seismic hazard evaluation or deterministic seismic hazard evaluation and last method are probabilistic seismic hazard evaluation. We used DSH method to evaluate the seismic hazard in Tabriz area via Fuzzy Logic System.

An appropriate method for solving difficult simulated problems with many input and output variables is fuzzy logic, which is a complicated mathematical method. Fuzzy logic allows to lower the complexity by allowing the use of incomplete information in a reasonable way.

Fuzzy logic is a method of computing based on the degrees of correct and completely false rather than the usual "correct or false" Boolean logic on which the modern computer science is based. Fuzzy logic is applied in situation where a significant amount of uncertainties is involved and in conditions where an approximate but quick solution is expected. Firstly, the input and output linguistic variables and linguistic scales of fuzzy logic controller should be defined. Linguistic scale represents a set of possible linguistic values of input and output variables, and it is used to measure the potential values of input variables. For instance, in the case of source-to-site distance, fuzzy sets can be defined as "near", "medium'' or "far". When a linguistic variable is used, these degrees maybe managed by specific membership functions. Various types of functions with different shapes are being used for membership functions, such as triangular, Gaussian, trapezoidal, bell-shape and others. The following step in fuzzy logic controller is fuzzification. A Fuzzy inference system (fuzzification) is a system that uses fuzzy set theory to map inputs to outputs. There are two fuzzy inference systems, Mamdani's and Sugenu's fuzzy inference system. Mamdani's fuzzy inference system is suitable for defined input by the expert and it's intuitive, so we used Mamdani's fuzzy inference system. To compute the output of this method, one must go follow these steps:

- Identification of seismic sources,

- Fixing the maximum magnitude earthquake (Mmax) and site-to-source distance (R) for each source

- Determining a set of fuzzy rules by an expert,

- Fuzzifying the inputs membership functions, (according to our data ranges for parameters and expert human idea, the bell membership function is considered),

- Aggregation of the ruled outputs,

- Defuzzifying the output distribution (we used centroid defuzzification of the area).

A schematic of fuzzy expert system components is shown as a flowchart in figure 1.

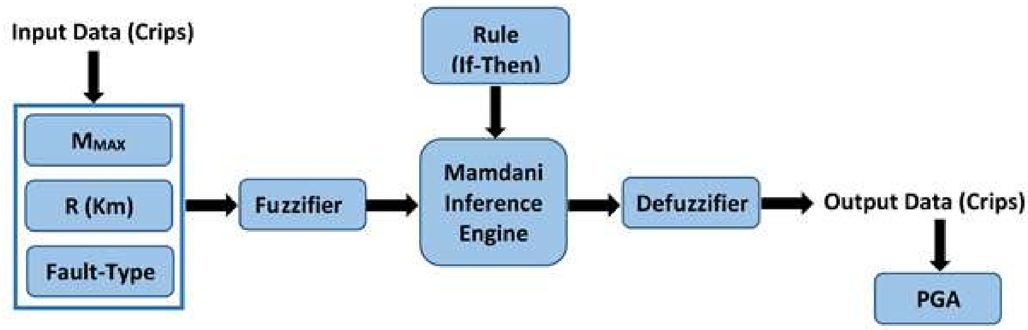

Figure 1.A schematic of fuzzy expert system components.

3 Identification of the Potential Seismic Source

The explanation of the shape of the potential seismic tectonic source needs much guidance such as tectonic geological, geophysical and earthquake data.

The number of 232 potential seismic sources in Iran were defined by Mirzaei et al. (1999) has been improved up to 238 by Mousavi-Bafrouei et al. (2015).In this study, 34 of these potential seismic sources located between 35.5°-40.5° N latitude and 43°-50° E longitude have been used (Figure 2).

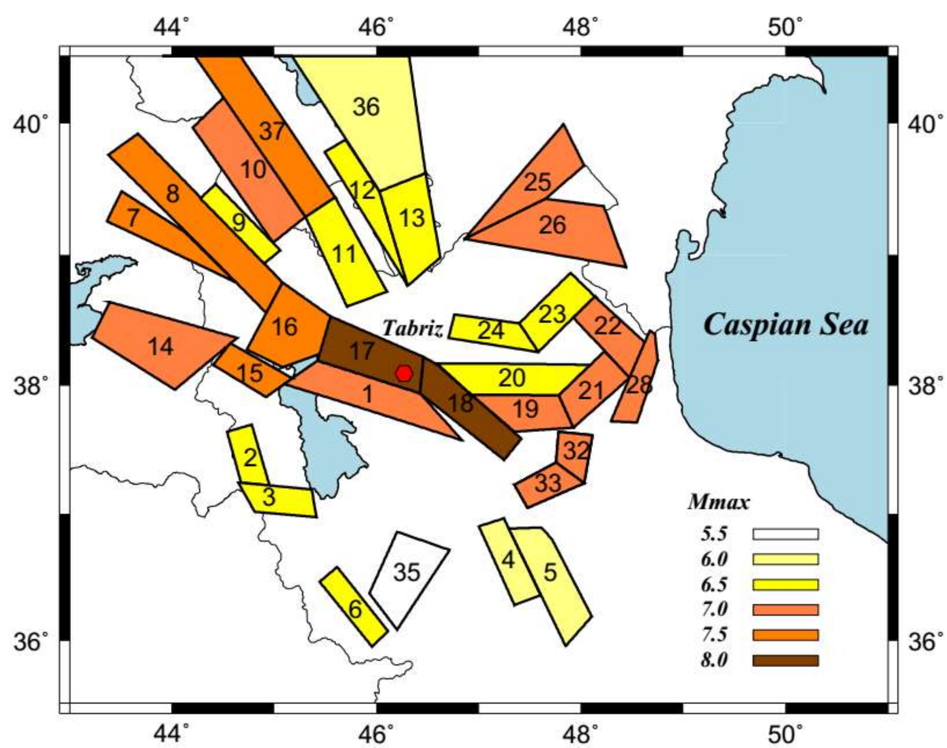

Figure 2. Potential seismic source in the study with maximum magnitude (M_{max}). The Red hexagonal represents the site of Tabriz city.

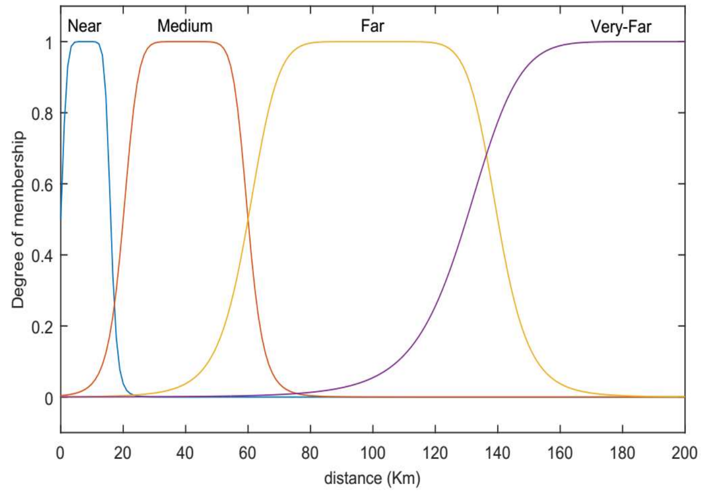

Figure3. Membership functions for R (distance site-to-source).

4 Mmax and Distance (R) for each source

In this step, maximum magnitude, Mmax must be evaluated for each source in which the amount of Mmax has been determined as expert human. The distance between each site-to-source is being determined.

-Linguistic Variables

According to most of the attenuation relationships, this study is established with three input parameters of the earthquake maximum Magnitude (Mmax), source-to-site distance (R) and fault type (S) whereas the output is the peak ground acceleration (PGA) which is defined as the fuzzy set by discrete membership functions μ(Mmax), μ(R), μ(S) and μ(PGA), respectively, for providing a fuzzy inference engine.

- Input parameters

We choose the amount of distance site-to-source between zero to 250km. We used four bill membership functions with a range of, near, medium, far and very far as in figure 3.

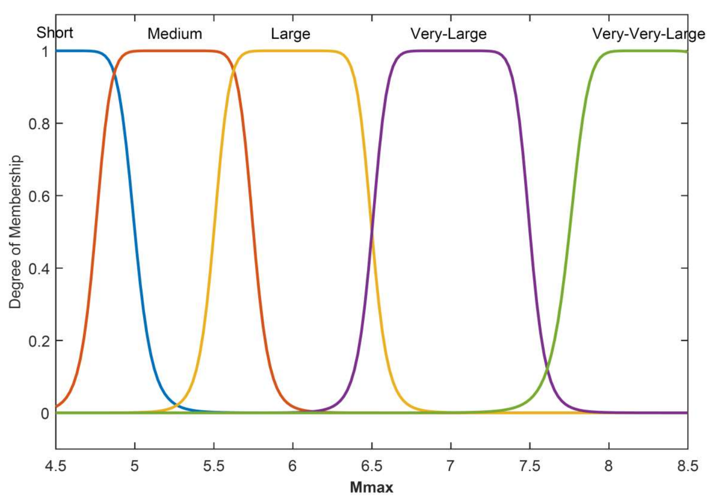

Figure 4. Membership functions for M_{max}.

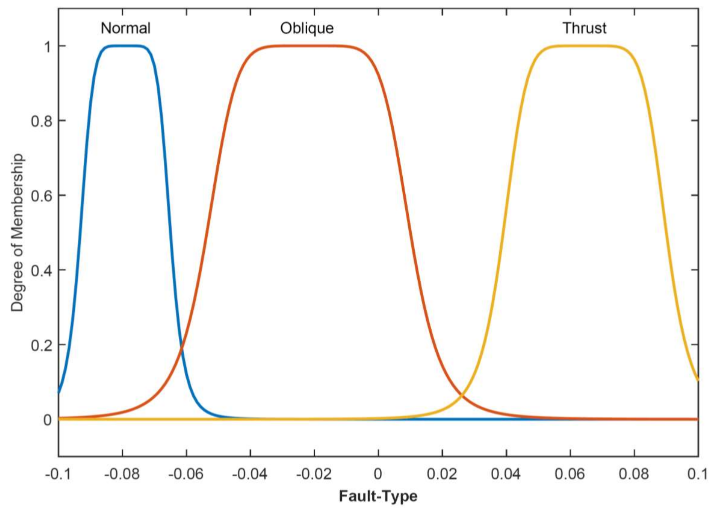

Figure 5. Membership functions for S (fault-type).

For the amount of the maximum magnitude (Mmax), the values have been considered between 4.5 to 8.5, and five bill membership functions with ranges of short, medium, large, very large and very very large as shown in figure 4.

Three main fault types exist (Normal, Reverse, Oblique), so three bill membership functions have been considered with the ranges of Normal, Reverse and Oblique (figure 5).

-Output Parameter

For the amount of the output parameter, PGA is considered between zero to 0.9g (g is ground acceleration, ~9.8 m/s2). Six bill membership functions with ranges of very low, low and medium, much, very much and very very much are being used (figure 6).

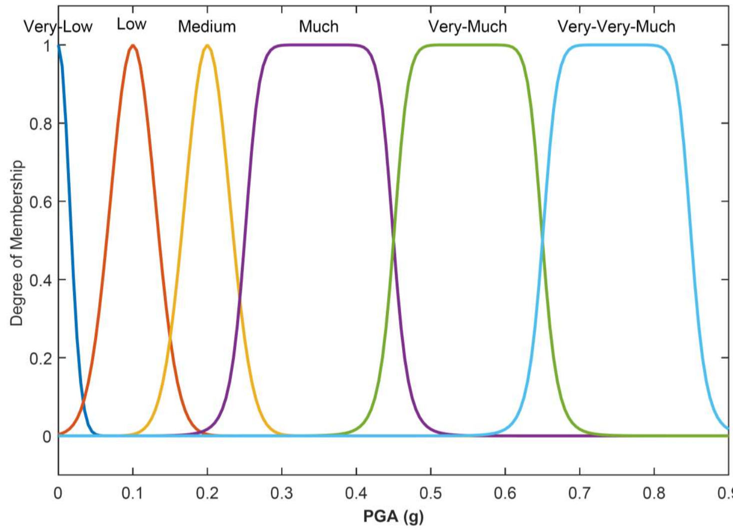

Figure 6. Membership functions of PGA.

5 Design of Set Fuzzy Rules

According to our data set, 60 set fuzzy rules are defined by an expert human. The inference rules in the fuzzy logic system are defined through "IF - THEN"-clause. Some of these 60 fuzzy rules which are used for fuzzy inference engine are defined as follow:

- If (distance is near) and (Mmax is short) and (fault-type is thrust) then (PGA is low),
- If (distance is medium) and (Mmax is short) and (fault-type is thrust) then (PGA is low),
- If (distance is near) and (Mmax is medium) and (fault-type is normal) then (PGA is very low),
- If (distance is near) and (Mmax is very large) and (fault-type is oblique) then (PGA is very much),

6 Computation of the PGA

The earthquake generated with the largest acceleration in the site is selected to define the site design ground motion. We used Mamdani method (Mamdani and Assilian 1975) and centroid defuzzification of the area to defuse the output distribution.

7 Discussion

Math-lab software is used for making a fuzzy inference system. According to our data set (input and output parameters), Mamdani method is used.

PGAs are determined for all sources. The behavior of input-output is shown at inference surfaces in 3D level for the fuzzy logic systems in figure 7a-c. According to figure 7, the horizontal area shows M_{max}, site-to-source distance, fault-type, and vertical area shows PGA. When M_{max}(site-to-source distance) is increased (decreased) and the type of fault is located in the thrust fault, so the amount of PGA will increase.

According to the results of a deterministic seismic hazard estimation using fuzzy logic, we plotted contour map of the PGA based on the values of PGA for each source in the Tabriz region (Figure 8). Figure 8 indicates that the horizontal acceleration of Tabriz province varies between 0.02g to 0.55g for Tabriz site. According to the results, the PGA in the adjacent areas of Tabriz exceeds 0.3g.

According to PGA zonation map of Iran (BHRC 2008), the city of Tabriz is located in a relatively high seismic zone. Our result is in good agreement with the seismic zonation map of Iran. Some seismic hazard studies have been done for Iran that is being considered in our study area, and yield different results based on the data set and methods, like Moeinfar et al. (2012) via probabilistic and deterministic seismic hazard, Hamzehloo et al. (2012) based on the probabilistic earthquake hazard analysis, Tavakoli and Ghafori-Ashtiani (1999) via probabilistic seismic hazard Karimiparidari et al. (2013).

Also, probabilistic seismic hazard assessment in Tabriz city (Ghodrati-Amiri et al. 2011) is evaluated from PGA=0.35-0.87g in the northeast to PGA=0.19-0.36g in the southwest. Recently, Moosavi-Bafrouei et al. (2015) have studied on seismic hazard zoning based on improved probabilistic seismic hazard in Iran and estimated the PGA in the provincial capitals, so they evaluated PGA=0.45-0.55g in Tabriz city. The previous study areas are in good agreement with our results.

In addition, the fuzzy system is flexible based on the expert knowledge in order to solve the problems and it would simplify the process of the deterministic seismic hazard and considering the uncertainties, so it improves the accuracy and can help the seismologist to reach the deterministic risk, and our findings are good in validity.

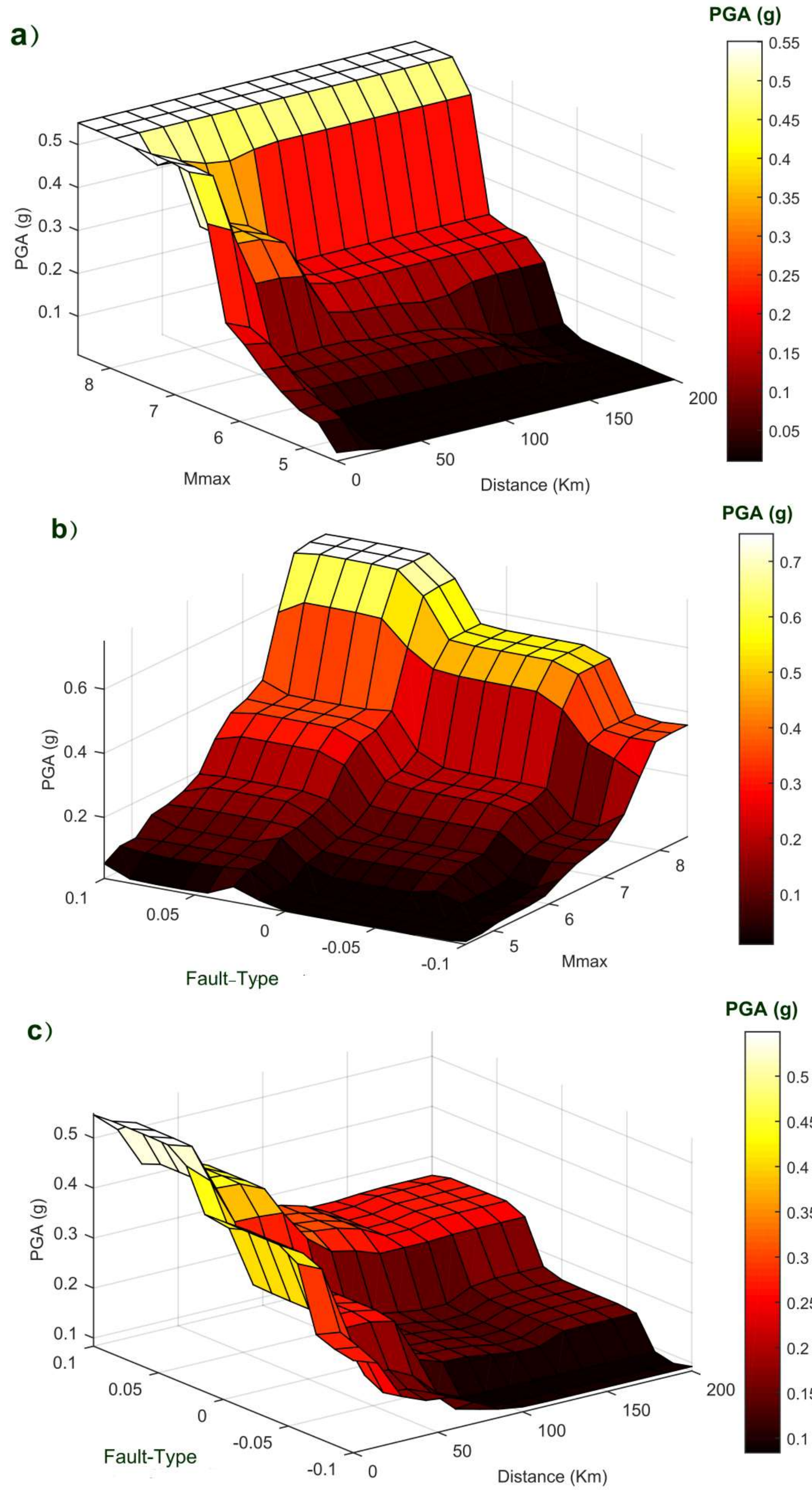

Figure 7. Surfaces of fuzzy logic input-output systems. a) The horizontal area shows M_{max} and site-to-source distance. b) The horizontal area shows M_{max} and the type of fault. c) The horizontal area shows site-to-source distance and type of fault. The vertical axe is PGA in all parts.

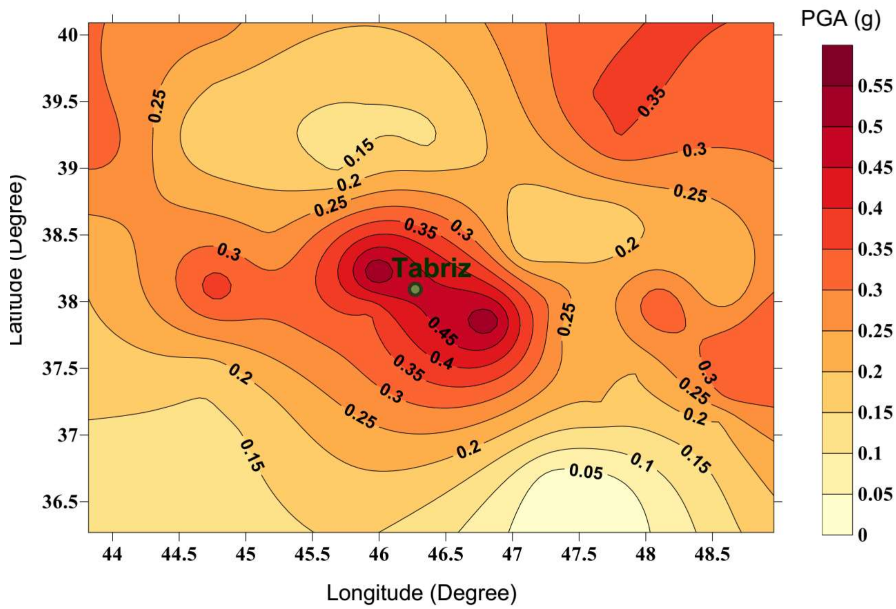

Figure 8. Contour map shows the spatial variation of PGA over Tabriz.

8 Conclusion

Evaluation of seismic hazard is an approach for obtaining estimates of future earthquakes. We evaluated deterministic seismic hazard in Tabriz City which is the center of the Northwest of Iran by using Fuzzy Inference System. Our data were 34 potential seismic sources with M≥5.5. This research allows us to reach the following main conclusions:

1- The result is shown the largest of the PGA=0.55g belongs to the source 17 with Mmax value of 8.0 and the distance of 36.98 Km of Tabriz city,

2- The range of PGA amount in this study area varies between 0,02g to 0,55g.

3-According to the results, the PGA in the adjacent areas of Tabriz exceeds 0.3g.

4-The highest acceleration (0.55g) includes Tabriz Fault Zone.

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