Development of Seismic Hazard Zoning Map for Iran, Based on New Seismic Source Determination

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SUMMARY:
The determination of new seismic source zones for Iran is developed based on active tectonic, topography, magnetic intensity data and seismicity catalogue. The seismic source zones have with different seismotectonic characteristics. The active fault traces and magnetic intensity data have significant role in defining the intersections and final boundaries of some zones. The empirical relationships models was based on the selected strong motions records in Iran, specially related to the major earthquake recorded by the Iranian accelerometric network since the mid-1970's meanwhile a strong motion catalog was established by the author that provided a basis for the first attenuation laws for the country based on the re-evaluated and processed input data in 1999 and then 2008. The seismicity data used in this study is from a new updated earthquake catalogue for Iran. The recently developed maps show improvement of acceleration levels using the parametric method (PSHA approach) in most parts of Central and southern Iran. Spectral Attenuation models may provide new tools for further hazard zone mapping in Iran.

Keywords: Hazard, Iran, Seismicity, Source Zone

1. INTRODUCTION

The active tectonic of Iran and the hazard of earthquakes lead us to do more detailed seismic hazard studies for Iran. In the first steps of seismic hazard investigations we need to investigate in seismotectonic situation of Iran.

The seismotectonic of Iran was studied by several researchers, the primary seismotectonic maps are developed by Stoklin (1968) with 9 zones, Takin (1972) which has 4 zones and Berberian (1976) with 4 zones, in 1976 Nowroozi proposed a new map which had indicate 23 different zones, after then Nogol Sadat in 1994, Tavakoli in 1996, Mirzaei in 1998 and Zaré in 2010 published seismotectonic maps with 23, 20, 5 and 18 zones respectively. Recently, Karimiparidari et al (2011) proposed 29 seismotectonic provinces with different specification (Figure-1). The seismicity catalogue, Active fault maps, magnetic intensity map and topography data was applied to define the borders of each zone. The scale of this map was 1:1,000,000, thereby for small scale studies it is needed to define the zones with more details. The boundaries of zones mainly follow the active fault traces that are in good agreement with changes in the magnetic intensity map. Input data is not distributed homogeneously in all parts of Iran so the uncertainty of boundaries in all zones is not same.

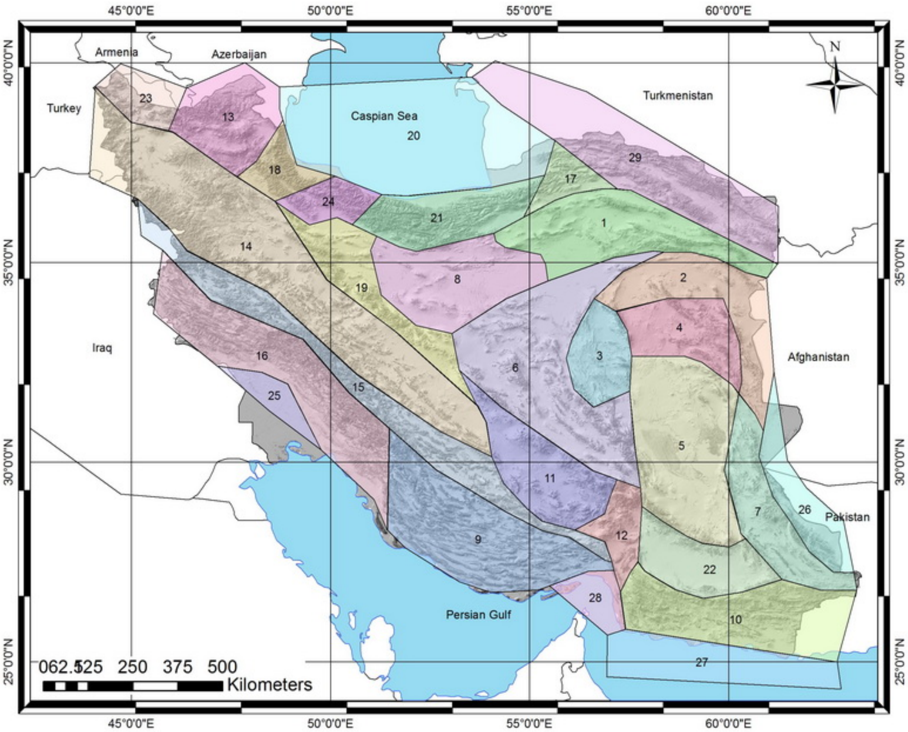


Figure 1. New seismotectonic zoning map of Iran which includes 29 zones with different seismotectonic characteristics (Karimiparidari et al 2011).

2. SEISMICITY AND SEISMOTECTONIC

Iranian plateau is a part of Alpine – Himalayan orogenic belt which has a high level of seismic activity and a unique pattern of deformation. Iranian plateau is located between Arabian Plate in the south-east, and the Turan Shield in the north-west, and the pressure caused by the convergent movement between these plates has built Iran mountain ranges. Based on the global positioning system (GPS), Vernant et al. (2004) indicated the rate of deformation from less than 2 mm/yr in Central Iran to 19.5 ± 2 mm/yr in the Makran subduction zone.

As for the seismicity catalogue of Iran, it is developed an Instrumental catalog including all accessible events with Mw≥4 and a Historical catalog. The Historical data same as the instrumental records with 4 ≤ Mw<5 needed to be simplified in the case of removing duplicates. Any new events can easily be added to the both catalogs in the future for the further development of the work, in order to make them more comprehensive. This new data can undoubtedly be recent events (occurring now and in the future) that will make it up to date, and they can also be earlier events with new information and conclusions on their parameters value.

Magnitudes are expressed on the M_w scale, when available; otherwise, priority is given to M_s for events of $M > 6$ and to m_b for $M < 6$. Figure 2 illustrates the magnitudes of the earthquakes as a function of time. The historical database extends from 734 until the early 20th century and largely relies on the work of Ambraseys and Melville (1982). The first half of the 1900s can be defined as an early instrumental period. The locations for Iranian earthquakes were mainly provided by international agencies at that time. The deployment of national seismograph stations improved the location accuracy especially since the mid-1960s. Magnitude and epicentral errors may be significant especially for the oldest observations. The magnitude uncertainties were assumed to be in the interval of ± 0.25 magnitude units and epicentral errors ± 30 km. Although the errors associated with historical data may easily be much larger, these values were chosen, because only about 5.5% of the data stem from the time prior to the mid-1960s. The hypocentral depths given in the database are considered very uncertain. Engdahl *et al.* (2006) determined the depth distribution of earthquakes throughout the Iran region. Focal depths of 45 km and deeper were found in the Makran region in the south and in the central Caspian Sea, while most earthquakes occur in the upper crust. Offshore seismicity was not considered in the present study, and an average focal depth of 15 km was used. After removing dependent events for all of the earthquakes reported in the applied catalog based on method described by Gardner and Knopoff (1974), the completeness of all zones determined. The magnitude completeness for most zones is around Mw 4.0 except in Makran coast which is Mw 4.5.

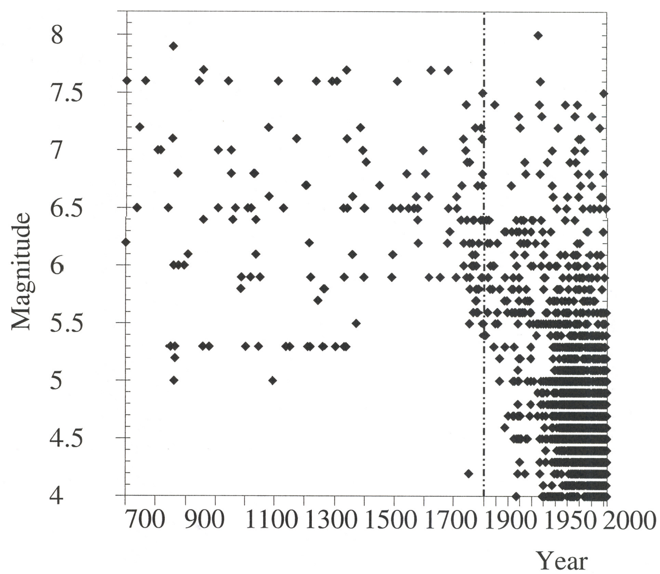


Figure 2. An illustration of the earthquake database. Almost 3,500 main shocks of magnitude M4 and greater since the year 734 were used in the present study. Note that the time scale changes in the year 1900.

The method to evaluate the Mmax for seismic source zones is explained herein for the region of Tehran in northern Iran, as an example. The region of Tehran is located in the southern parts of the Central Alborz belt that is formed during compression and strike slip tectonic activities. Twenty percent of the Iranian population lives in the capital, Tehran, and its suburbs. The main structural trends in this region are Northwest-Southeast (Mosha and Eyvanekey faults), ENE-WSW (North Tehran fault system) and East-West (the Ipak, South and North Rey faults). In this paper, the regional seismicity and related tectonic features are studied first in order to define the main seismic source zones around Tehran. The M_{max} values for each source zone are estimated based on maximum observed magnitude, empirical relationship between the rupture length and magnitude, and maximum probable magnitude for a return period of 2000 years. Ambraseys and Melville (1982) estimate the magnitudes for the pre-20th century period based on the macroseismic intensities. The greatest earthquake assigned to each main fault systems in the region are the earthquake of 4^{th} century BC in SE Rey (historical city in the adjacent vicinity of southern Tehran), M7.6, which seems to be initiated by the reactivation of the Eyvanekey fault; the event of 958 AD (M7.7) in Rey probably related to the reactivation of Mosha fault; and the Boin-Zahra earthquakes of 1177 (M7.2) and 1962 (Ms=7.2) apparently caused by the reactivation of a trend parallel to the North Tehran fault or Ipak fault. The M_{max} for an earthquake with a return period of 2000 years are hence concluded to be 7.5, 7.0 and 7.4 for Mosha, North Tehran and Eyvanekey fault zones, respectively, in Tehran region.

3. ATTENUATION RELATIONSHIPS

Zaré *et al.* (1999) derived attenuation relationships for ground motion in Iran in terms of PGA, PGV and PGD. Their database consisted of 468 three-component accelerograms recorded between 1975 and February 1996. The magnitudes of the earthquakes recorded ranged between M_w 2.7 and 7.4, and the hypocentral distances between 4 and 224 km. The focal depths were in the range of 9 to 133 km but the majority were shallow (Bard *et al*., 1998). Both horizontal and vertical components were included in the analysis. Soil type was classified into four categories on the basis of the receiver function.The basic form of the attenuation relationship given by Zaré *et al.* (1999) is as follows:

$$\log(a) = a{\cdot}M + b{\cdot}X - d{\cdot}\log(X) + c_i{\cdot}S_i + \sigma{\cdot}P, \quad i = 1,2,3,4, \tag{1}$$

where a is the strong motion parameter, M earthquake magnitude (on the M_w scale), X is hypocentral distance (in km), S represents site classification for four soil categories, σ is the standard deviation of log(a), P = 1 or 0, and a', b', c'^{i} and d' are known coefficients. The logarithm is to the base 10. The coefficient b' describes anelastic attenuation with distance X, whereas the coefficient for the log(X) term, d', has been introduced to allow for geometrical expansion, which may be different from the body wave $1/x$ dependence. Zaré (1999) studied such dependence for the coefficient value d = 0.5, and Zaré *et al.* (1999) compared the results with the value d = 1. Zaré *et al*. (1999) derived values of regression coefficients for the ground motion in terms of PGA (in units of m/sec^2), PGV (m/sec) and PGD (m) for the whole territory as well as for the Alborz - central Iran and Zagros areas separately.

3.1. Spectral Attenuation Laws

The regressions were performed for various ground motion parameters for the spectral accelerations (Sa(T)). The regression on Sa(T) was fulfilled for 7 different periods between 0.1 and 2 seconds. These values are found for 5 percent of damping. The general form of the attenuation relationship for the spectral acceleration (Sa) is;

$$\text{Log Sa(T)}=a(T).M+b(T).R-\text{Log } R+ci(T).Si+\sigma(T).P \tag{2}$$

In the regression performed for establishing the spectral attenuation law Zaré et al (2008) used another form of this relationship, according to a better coordination with the input data is used.

$$\ln \text{Sa}(T) = b_1(T).S_i + b_2(T)(M-6) + b_3(T)(M-6)^2 + b_5(T).\ln R + \sigma\text{Sa}(T).P \tag{3}$$

b_2 and b_3 are assumed as constant coefficients and only b_1 and b_5 are calculated for different site types in the study.

The data-base used as the input for this study consists of 89 three components accelerograms (Zaré et al 2008), recorded between 1975 and December 2003 by the national Iranian strong motion network. The moment magnitude and hypocentral distance for these records have thus been estimated directly from the strong motion records. The hypocentral distance was obtained from the S-P time difference, while the seismic moment was directly calculated from the level of acceleration spectra plateau and the corner frequency (Zaré, 1999).

The spectral values of the selected records were used in Zaré et al (2008) to derive the empirical attenuation laws for different response spectral ordinates, on different site conditions. The strong motions are selected based on their peak acceleration value (having a PGA of 0.05g on at least one component) and the good signal quality in the low frequency band of 0.3Hz or lesser. The empirical relationships are established for the spectral acceleration as a function of the moment magnitude, the hypocentral distances, and a constant parameter representing the site conditions. The data is split in two subsets corresponding to two geographical areas: during the period of observation (1975-2003), stronger earthquakes occurred in central Iran and Alborz region and were recorded at distances as far as 60km. The soil effects are considered in the regressions, mainly based on an assessment of site class based on the fundamental frequency obtained on H/V amplification functions. The results presented in this paper are the coefficients obtained for all of those selected data (89 records) (with no data separation for Alborz-Central Iran and Zagros, Zaré et al 2008).

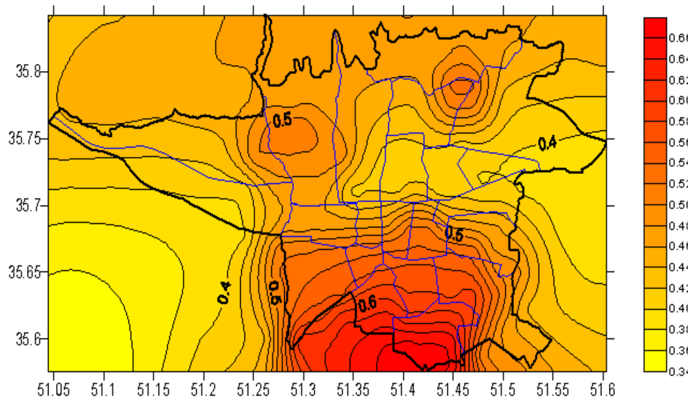
Site conditions are considered through the categorization in four site classes on the basis of the receiver function (Zaré et al 1999). Site class 1 is defined as sites that do not exhibit any significant amplification below 15 Hz. It corresponds to rock and stiff sediment sites with an average S-wave velocity over the top 30 meters in excess of 700m/sec. Site class 2 determined as sites for which the receiver function (RF) exhibits a fundamental peak exceeding 3 at a frequency located between 5 and 15 Hz. It was shown to correspond to stiff sediments and/or soft rocks with Vs30 between 500 and 700 m/sec. Site class 3 is representative for the sites for which RF shows the peaks between 2 and 5Hz and corresponds to the alluvial sites with Vs30 between 300 and 500 m/sec. Finally site class 4 is defined as sites for which RF indicates the peaks in frequencies below 2Hz, and it maybe viewed as corresponding to thick soft alluvium. This ranking was the result of the geotechnical measurements on 50 sites (compressional and shear wave velocity and microtremors) and the calculation of the receiver function for the strong motions using the three component accelerograms. This categorization show some similarity to that of Boore et al (1994) (based on the average Vs for the 1st 30m) for the northwestern American data. The average Vs limits to distinguish the site classes in Boore et al (1994) reports are 180 m/sec, 360 m/sec, 750 m/sec and greater than 750 m/sec (to be compared with our values of 300, 500 and 700 m/sec).

The results of the regressions obtained for the horizontal components are presented in Table-1. The coefficients are presented for 7 different periods from 0.1 sec (PGA) to 2 seconds.

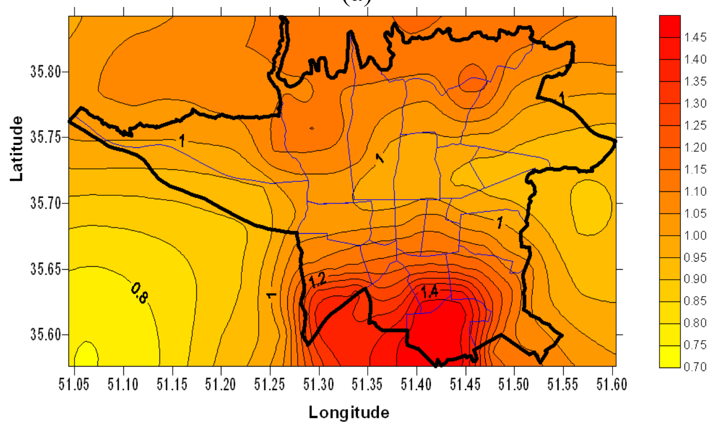
Table 1. The attenuation coefficients for horizontal component (Zaré et al 2008).

$\ln Sa(T) = b_1(T).S_i + b_2(T)(M-6) + b_3(T)(M-6)^2 + b_5(T).\ln R + \sigma_{Sa}(T).P$								
Iran	Constant		Calculated					
period (sec)	b2	b3	b1.1	b1.2	b1.3	b1.4	b5	sigma
0.10	0.753	-0.226	0.037	0.304	-0.480	-0.186	-0.037	0.48
0.14	0.707	-0.230	0.279	0.337	0.015	0.210	-0.054	0.47
0.20	0.711	-0.207	0.459	0.349	0.257	0.373	-0.102	0.50
0.44	0.852	-0.108	-0.431	-1.023	-0.986	-0.736	-0.093	0.67
0.70	0.962	-0.053	-0.459	-0.833	-0.778	-0.231	-0.251	0.74
1.30	1.073	-0.035	-1.710	-2.537	-2.961	-1.884	-0.178	0.84
2.00	1.085	-0.085	-1.204	-2.268	-1.154	-1.265	-0.546	0.91

The study employs the attenuation relationship given by Zaré *et al*. (1999), which was the first based solely on accelerograms recorded inside the territory of Iran. The resulting PGA values are somewhat lower than those of previous work. However the spectral values obtained from the new law (this study) show greater values comparing to that of the previous law (1999). The difference might be inferred according to the selection of greater motions recorded in the nearer distances to the seismic sources than those of the catalog used for the previous law developed in 1999. The near-fault strong motion record obtained in the Bam earthquake of 26 December 2003 is included in the input data of the present study. Figure 3 represent the result of hazard zoning including soil conditions in Tehran region using the described attenuation law (Zaré et al 2008) in the region of Tehran for the return period of 475 years, for PGA and spectral acceleration for T=0.2 sec.



(a)



(b)

Figure 3. a) Sa for T=0 Sec (PGA), Horizontal Comp. 475 years return Period, Site effect included (calculated for the Soil surface), b) Sa for T=0 Sec (PGA), Horizontal Comp. 475 years return Period, Site effect included (calculated for the Soil surface).

4. RECENT ZONING MAPS

The hazard zoning in Iran using different algorithms and seismicity parameters. Mäntyniemi et al (2007) used the parametric-historic procedure developed by Kijko and Graham (1999) to map ground motion in Iran. The procedure does not require any definition of seismic sources and/or seismic zones, which has a significant effect on the appearance of the maps. The new maps do not show such strong elongation of contours as previous maps that are based on assumptions of seismotectonic units. The parametric-historic procedure takes the earthquake locations as manifestations of seismic activity. However, the uncertainties of earthquake locations are considered, which is a new feature added to the basic formulation of the technique (Kijko *et al.* 2003). This study employs the attenuation relationship given by Zaré *et al*. (1999), which was the first based solely on accelerograms recorded inside the territory of Iran. The resulting PGA values are somewhat lower than those of previous work (Figure-4).

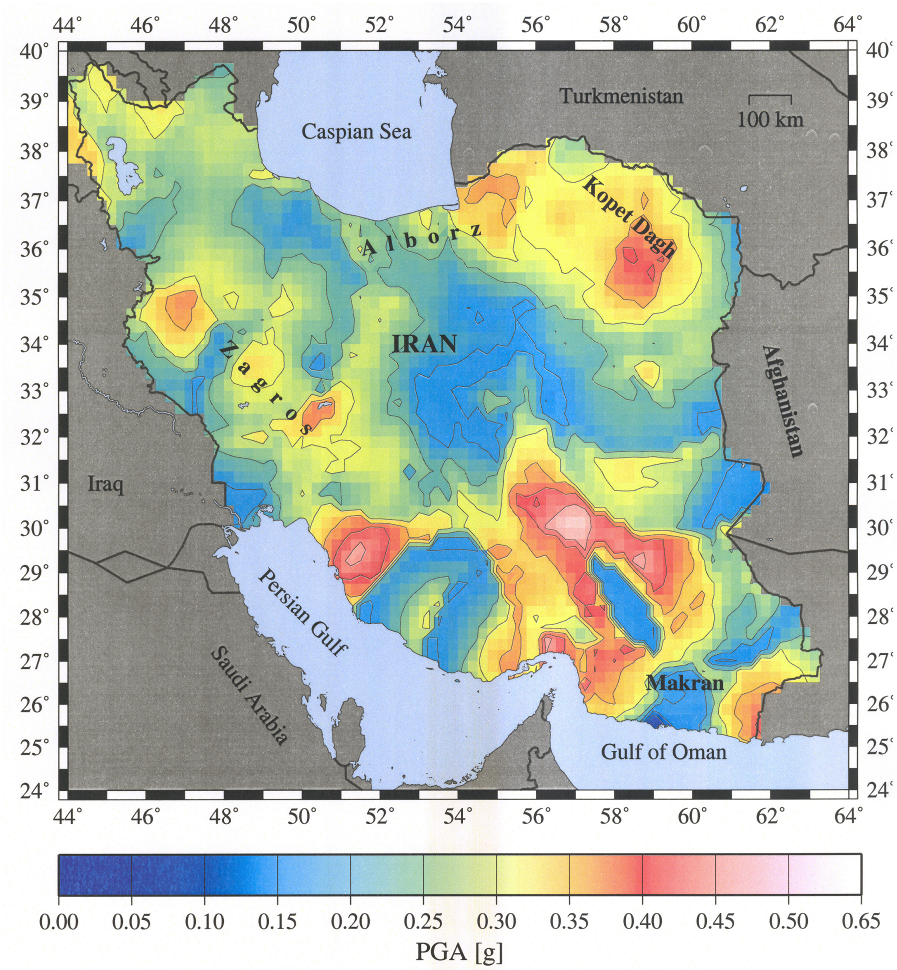


Figure 4. Hazard zoning map using parametric-historic method, resulting peak ground acceleration for a return period of 475 years (Mäntyniemi et al 2007).

The seismic hazard zoning using a parametric method may result to higher acceleration values for a return period of 475 years in Iran (Figure-5). The hazard levels in Alborz and Azarbayjan based on existing seismicity data might seems still to be a challenge to be discussed in the future; there are lack of recent seismicity, meanwhile there are a reported historical earthquakes. Comparing the results for regional assessments (Figure 4 and 5) with local hazard zoning (i.e. for the region of Tehran; Figure-3) indicate that there is major challenge for such locations, having great risk, referring the concentration of the population to be 8,500,000 people by the end of 2011 in Tehran.

5. CONCLUSION

The seismic hazard zoning maps are developing in Iran using seismicity and active tectonic data since the mid-1970's. Recent studies are focused more new methods such as parametric-historic methods and revision on the seismotectonic zoning. The determination of seismic source zones are performed using the up-to-date geophysical and geodetical measurements. The new data show that the revision in seismic hazard zoning maps in local and regional (nation-wide) scale is necessary. It is expected that the further studies to be focused on developing of spectral zoning maps as well as a new focus on Mmax assignments and incorporation of seismic historical data in hazardous region having rare instrumental seismicity data.

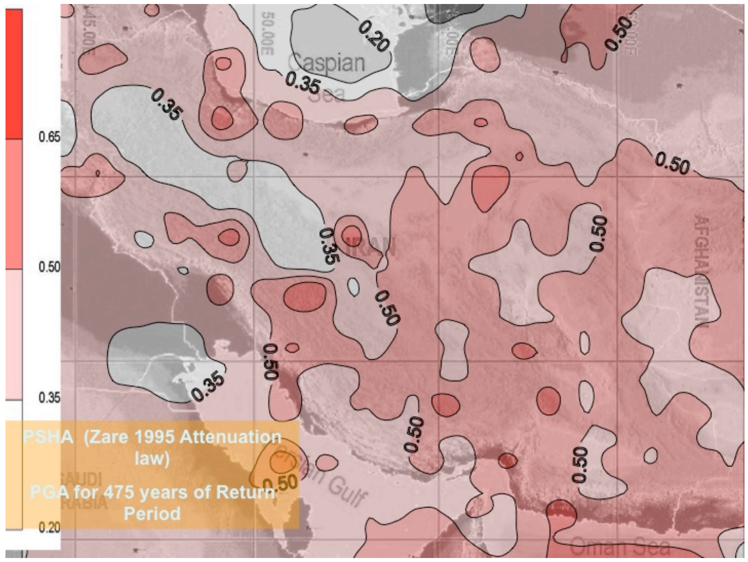


Figure 5. Seismic Hazard Zoning for Iran, using parametric method and assessing PGA for 475 years of return period.

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