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Probabilistic View of Occurrence of Large Earthquakes in Iran

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Abstract

In this research seismicity parameters, repeat times and occurrence probability of large earthquakes are estimated for 35 seismic lineaments in Persian plateau and the surrounding area. 628 earthquakes of historical time and present century with $M_W>5.5$ were used for further data analysis. A probabilistic model is used for forecasting future large earthquake occurrences in each chosen lineament. Based on the processing, it reveals that high risk (P>66%) regions in Iran for $M_W\geq7.0$ earthquake occurrence in the next 20 years are Apsheron, Main Recent Fault, Dasht-e Bayaz, Golbaf, Minab, Makran and Bandar-e Abbas areas. North Tabriz fault and Ipac, Toroud and Neyshabour fault systems, which are form the southern border between the north and central Iran, have the largest repeat times (>40 years) for $5.5\leq M_W<7.0$ within the seismic regions in Iran. They are mainly associated with very low probabilities. Furthermore, the results show that central Iran is the calmest area for earthquake occurrence, especially in the next 20 years. The important areas for earthquake occurrence with $5.5\leq M_W<7.0$ in the next 10 years are Talesh, Apsheron, north of Kopeh Dagh, Dorouneh and Golbaf areas. Probability of occurrence of an earthquake in the next 10 years in Alborz including capital and important industrial cities with combined population of 15,000,000 is up to 66%.

Keywords: Earthquake; Probabilistic; Prediction; Lineament; Iran.

Introduction

According to the complex tectonic settings of Iran, which is a result of convergence between Arabia and southeast of Eurasia, Touran plate (Fig. 1), the demand for earthquake prediction is prominent in the Persian plateau, which is often struck by large destructive earthquakes. Many researchers have followed the probabilistic approach in the world [e.g. 1, 2, 3, 4, 5, 6]. Papazachos et al. (1987) used information about repeat times to identify regions of special interest to earthquake prediction and also to seismic hazard assessment in the most clearly defined tectonic features of the Hellenic arc-trench system in Greece, a subduction zone of about 1000 km length and the Aegean Sea, which is a back-arc marginal sea. Holliday et al. (2016) also estimated earthquake probabilities on global scales. Their method counts the number of small events since the last large

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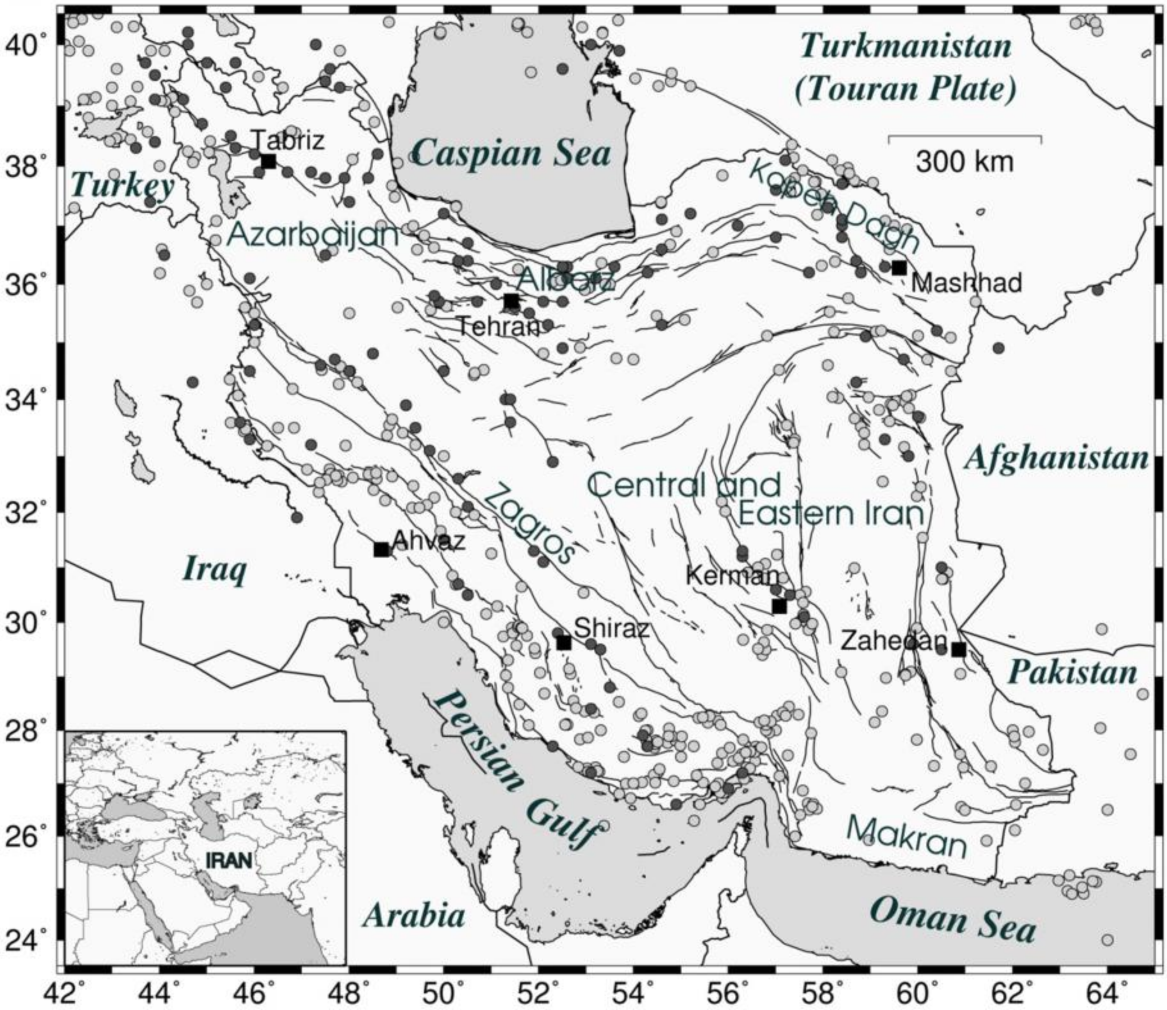


Figure 1. The map shows the epicenters of all large, great, shallow and intermediate depth (h <100 km) earthquakes occurred in Iran in the periods 400 B.C.-1963 C.E. [13] (dark-gray circles) and 1964-2015 C.E. (International Institute of Earthquake Engineering and Seismology of Iran IIEES; light-gray circles) without a magnitude scale. Faults are adopted from the active fault map of Iran [32].

event and then converts this count into a probability by using a power probability law.

Many of the large (M≥5.5) and shallow (<100 km) earthquakes of Iranian territory occur by thrust or strike-slip fault movements along the Alborz, Azarbaijan, Kopeh Dagh, Eastern Iran and Zagros seismotectonic provinces, while, the other great (M~8.0) intermediate focal depth earthquakes occur by normal or thrust faulting in the Makran subduction zone.

Estimation of repeat times of the earthquakes is useful to identify regions of special interest to earthquake prediction and especially to seismic hazard assessment (e.g. 7, 8). Even for a particular point along a given plate boundary, repeat times may vary by at least a factor of 1.5 to 2.0 [1, 9]. For the first time in Iran, repeat times of earthquake have been calculated directly from observations for various regions of the Iranian territory. About estimation of the rate of seismicity in Persia, which is in direct dependence to probability of occurrence of the earthquakes, we could point to Nemati (2015a and b [10, 11]) researches. The mentioned works investigated accelerating and decelerating rates of earthquake occurrence in Iran in the next decades.

Here, the probability of occurrence of large shocks in the next 10 and 20 years were calculated assuming the time elapsed since the last earthquake, the mean repeat time and estimates of the variation (standard deviation) of the repeat time for the different seismic fracture zones were examined.

Materials and Methods

We use 628 large-great ($5.5 \leq M_S \leq 8.2$) earthquakes occurred in the Persian plateau during the period 400 B.C.-2015 C.E. in 24-41°N and 42-64°E. The mentioned data was taken from International Institute of Earthquake Engineering and Seismology of Iran (IIEES) [12] seismological network catalog. Source of this data is mainly is composed of two catalogues published by Ambraseys and Melville (1982) [13] and seismological network of IIEES. The first catalogue covers the historical seismicity of Iran for the period 400 B.C.-1963 C.E. Majority of these events are in shallow and intermediate focal depth ranges (h<100 km) [10, 11]. Unavoidable part of uncertainties in our work is arisen from merging the historical and instrumental earthquake catalogs, which are from different categories.

In this paper, 35 fracture zones were distinguished in Iran regardless the fault systems, preliminary. We had to merge these two databases, because of less number of earthquakes in each lineament (Table 1; Fig. 2). Apart from these lineaments, the earthquake activity in Iran seems to be rather random. Dividing the seismicity into

Table 1. 35 fracture zones defined in Iran.

Lineament			N	D	QF	Ms	Correlation with
No	Region	Symbol		(Year)		(Maximum)	A fault system
1	Alborz	Al-1	15	1404	2.106	7.7	-
2		Al-2	14	1149	1.6086	7.9	Shahroud
3		Al-3	6	825	0.495	7.2	Ipac
4		Al-4	4	202	0.0808	6.9	Toroud
5		Al-5	7	663	0.4641	6.4	Kushk-e Nosrat
6		Al-6	10	128	0.128	7.7	Talesh-Manjil
7	Azarbaijan	Az-1	8	352	0.2816	7.2	Salmas
8		Az-2	16	669	1.0704	7.4	Chalderan
9		Az-3	15	1125	1.6875	7.7	North Tabriz
10		Az-4	8	147	0.1176	6.8	Talesh-Dasht-e Moghan
11		Az-5	11	1277	1.4047	7.4	Ararat
12	Kopeh Dagh	Kp-1	11	156	0.1716	7.5	Apsheron
13		Kp-2	8	114	0.0912	7.3	Kashafroud
14		Kp-3	9	775	0.6975	7.6	Quchan
15		Kp-4	9	305	0.2745	7.0	-
16		Kp-5	6	919	0.5514	7.1	Neyshabour-Binaloud
17	Eastern Iran	EI-1	14	1170	1.638	7.6	Dorouneh
18		EI-2	10	431	0.431	7.4	Abiz-Dasht-e Bayaz
19		EI-3	10	1235	1.235	7.6	Ferdows-Nozad
20		EI-4	21	151	0.3171	7.1	Kuhbanan-Golbaf-Bam
21		EI-5	3	87	0.0261	5.7	Lalehzar
22		EI-6	10	1276	1.276	7.0	Nehbandan
23	Zagros	Zg-1	16	998	1.5968	7.4	Main Recent Fault
24		Zg-2	10	1126	1.126	7.1	-
25		Zg-3	19	348	0.6612	6.5	Mountain Frontal Fault
26		Zg-4	16	958	1.5328	6.8	Mishan
27		Zg-5	13	1006	1.3078	7.0	Mountain Frontal Fault
28		Zg-6	10	1268	1.268	6.5	Lar
29		Zg-7	26	514	1.3364	7.3	-
30		Zg-8	3	66	0.0198	6.2	Zendan-Minab
31		Zg-9	14	514	0.7196	7.2	Karehbas-Qir
32		Zg-10	14	1248	1.7472	7.2	Piranshahr
33	Makran	Mk-1	4	79	0.0316	7.7	Saravan
34		Mk-2	12	86	0.1032	6.4	Kashin-Zabol
35		Mk-3	6	59	0.0354	8.2	Makran

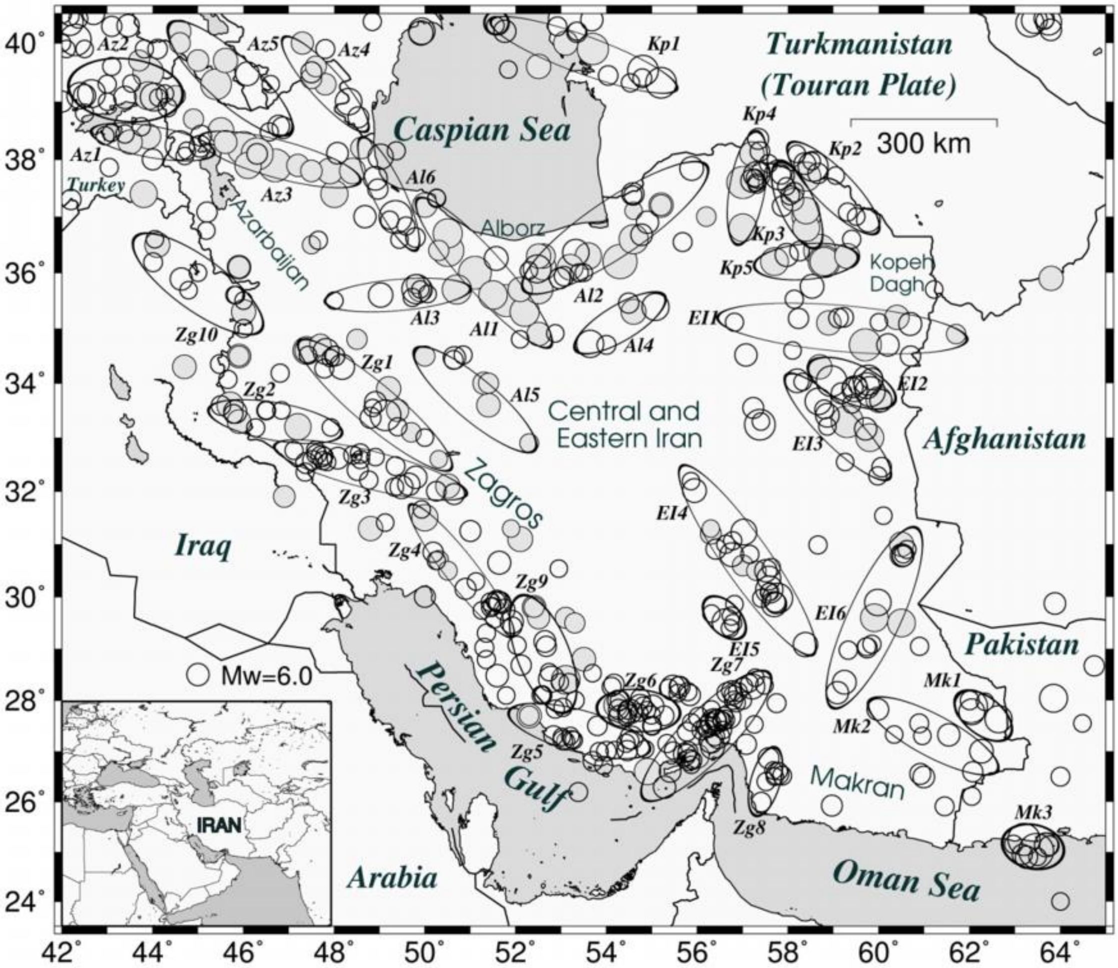


Figure 2. 35 lineaments of earthquakes separated preliminary regardless to the fault systems in Iran.

separate lineaments is based on their dimensions, size of lineaments, different tectonic complexity and different strike; although, the exact number of segments, included earthquakes and their boundaries are, inevitably, somewhat arbitrary. In particular, it is not possible giving any ideas about how did we consider an event to be included in a particular lineament group. Indeed, there is not specific criterion in this case. Especially, there is also possible that one historical event could be associated with more than one lineament.

A data quality factor (QF; equation 1) is defined representing quality and quantity of the data for each lineament. It is a relative parameter and it is composed from earthquake number (N) and also duration of the data sample (D) between them. QF is ranging from 2.10 for Al-1 and 0.019 for Zg-8. Average QF for all the data is 0.78. The fractures associated with the Main Recent Fault (MRF), Shahroud Fault System (SFS), North Tabriz Fault (NTF), Dorouneh and Piranshahr faults have high QF within 35 fracture zones in Iran. For simplicity, QF was divided to 10,000 for its comparable to 1.0.

1) $QF = N \times D / 10{,}000$

Before data processing, transforming the magnitude scales of the earthquakes to a unified scale is necessary. The scale chosen for this purpose is M_W. A significant reason for these conversions is that various seismological agencies report different magnitude scales for the earthquakes in different catalogues. We converted various magnitude scales to the main and authentic magnitude scale of M_W for most of the seismological catalogues. Because, m_b, M_S, M_L and also M_N scales are independently calculated using maximum amplitude of body wave, surface wave, and shear wave of an earthquake in appropriate specific frequencies, respectively. Therefore, they cannot represent all the source process energy of an earthquake; because the frequencies at which the mentioned scales are calculated do not cover the whole rupture process [14]. For unification of the magnitude scale of the earthquakes, which is necessary for drawing the diagrams and also achievement a reasonable result, according to Nemati and Tatar (2015) [15] relations, we preferred to used following relationships (equations 2-5):

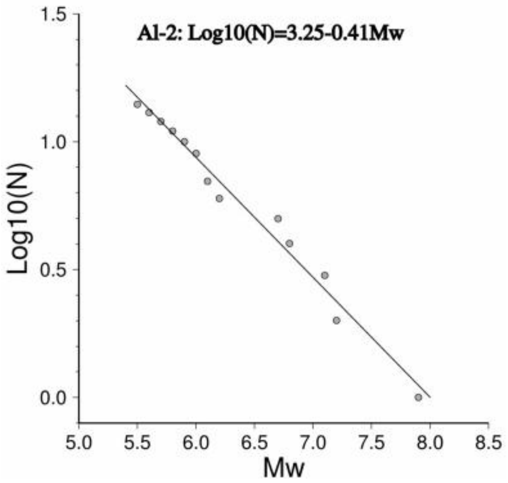
2) $M_W=m_b+0.19$ $(3.5\leq M_S\leq 6.7)$
3) $M_W=0.59M_S+2.46$ $(3.0\leq M_S\leq 6.1)$
4) $M_W=0.92M_S+0.51$ $(6.1\leq M_S\leq 7.4)$
5) $M_W=0.54M_L+2\ 34$ $(3.4\leq M_S\leq 6.3)$ [16]

Earthquakes have been assumed to occur randomly in time, space and magnitude in Poisson process, the method we used for processing. Therefore, we disregarded all foreshocks and aftershock in our selected catalogue. They were therefore excluded from our database based on their origin times, relative location according to the mainshock and also over than 1 magnitude unit difference to the mainshock magnitude. Considering longer durations of foreshocks and aftershocks for larger earthquakes, no constant durations were considered for the foreshocks and aftershocks. Nemati (2014) [17] has introduced equations for both the ISC and IGUT databases for spatially separating the aftershocks from the background seismicity in Iran. We also took advantage from Nemati (2014) [17] relation ($Log_{10}(A)=0.45M_S+0.23$) as a general guide for separating the aftershocks situated in an equivalent circular area of $A(km^2)$ centered by the mainshock location.

In this part, famous Iranian earthquakes [17] are explained according to their lineaments.

2003 Bam earthquake

2003/12/26 Bam destructive earthquake (M_W 6.6) has occurred on continuation of the Golbaf-Shahdad strike-slip and thrust fault zone along the western edge of the Lut block at the Eastern Iran (E-I4 fracture zone, Table 1, Fig. 2). This is an area with predictable seismotectonical patterns for potential of seismic activity [18]. Bam earthquake aftershocks had N-S trending with ~25 km elongation in surface, also 20 km vertical extension and showed right-lateral strike-slip dominant mechanism [19].



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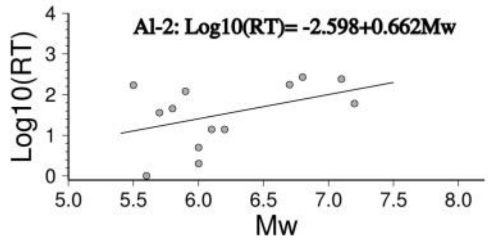

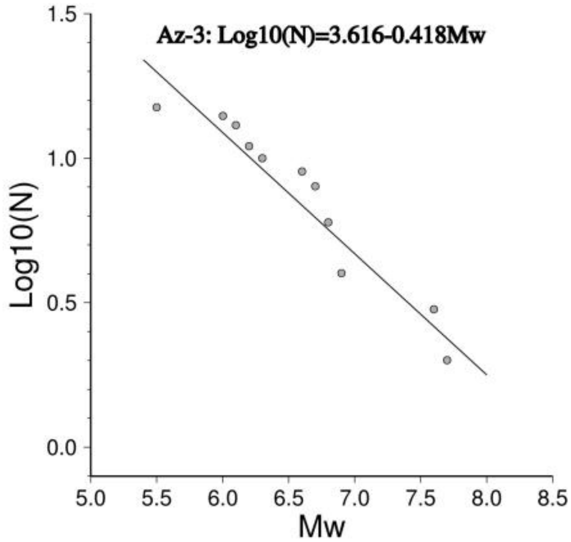

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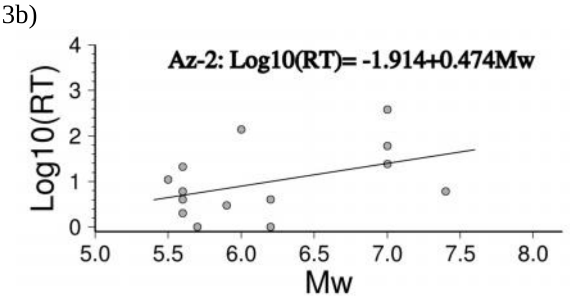
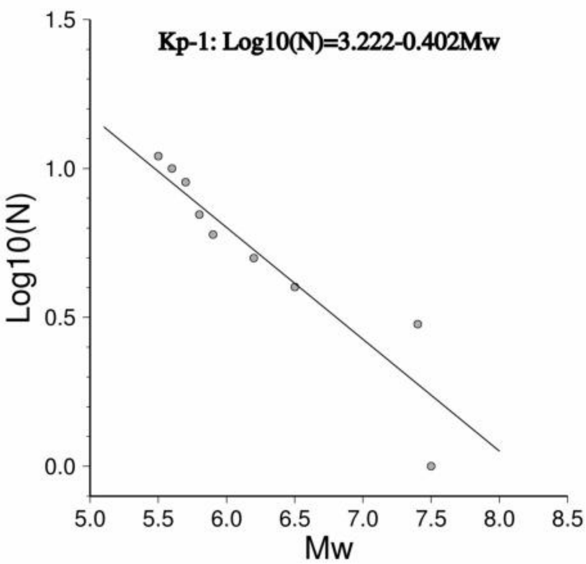


Figure 3. Gutenberg-Richter diagrams and plots of the logarithm of the repeat time RT, in years, derived directly from the observations, versus the moment magnitude, M_W, for the shallow earthquakes, which occurred in fracture zones in a) Alborz (Al-2), b) Azarbaijan (Az-3, 2), c) Kopeh Dagh (Kp-1, 4), d) eastern Iran (EI-4, 6), e) and Zagros (Zg-7, 1) seismotectonic provinces and f) M_C for IIEES catalog.



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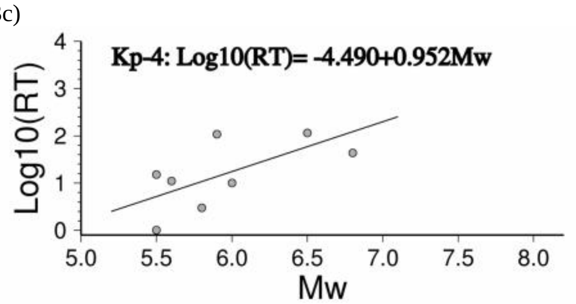

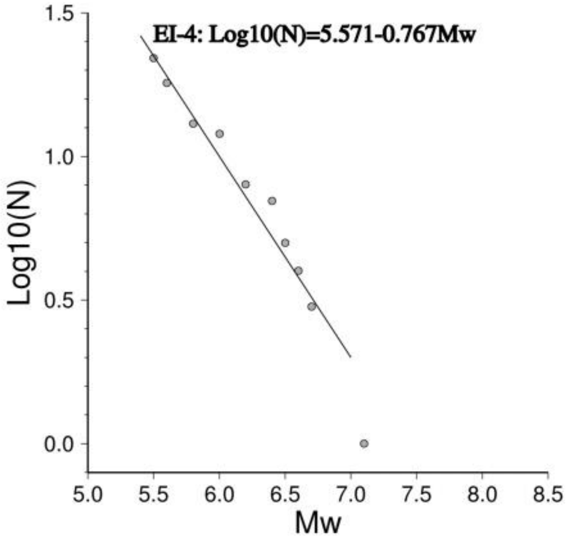

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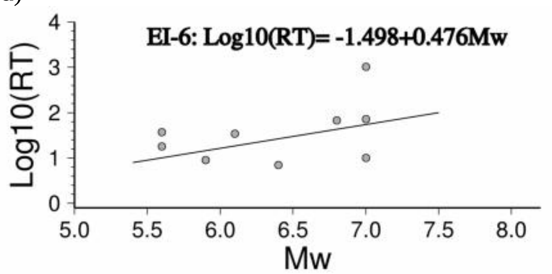


1981, 1989 and 1998 Sirch-Golbaf earthquakes

11 moderate and large earthquakes have occurred on Golbaf fault system (EI-4 fracture zone, Table 1, Fig. 2) from 1877 to 2012. Golbaf fault is a rare and also typical example for a multi rupture fault in Persia and maybe in the world. The Golbaf super active fault has been ruptured and healed over and over at the historical and instrumental period. 1877 (5.6), 1909 (5.5), 1911 (5.6), 1948 (6.0), 1969 (5.2), 1981/6/11 (6.7), 1981/7/28 (7.1), 1989 (5.7), 1998/3/14 (6.6), 1998/11/8 (5.4) [18] and 2011 (5.2; IGUT) historical and instrumental earthquakes are found in the historical records and recent literatures for this faults.

1990 Roudbar-Tarom earthquake

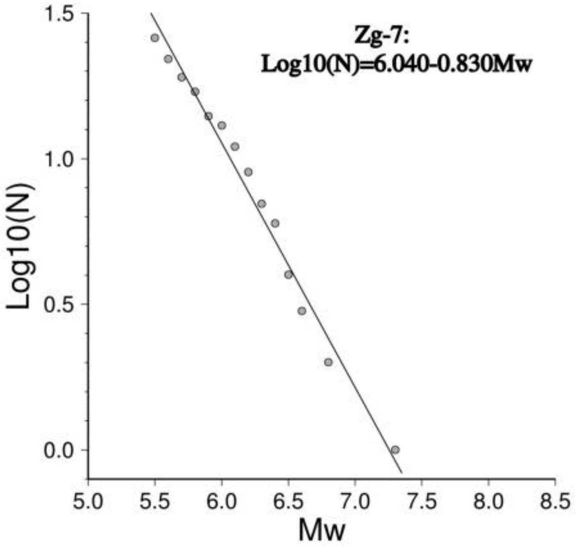
A remarkable example for a devastating earthquake in Iran is 1990/6/20 Roudbar-Tarom (M_S 7.7, with 14 km focal depth) event (Al-6 fracture zone, Table 1, Fig. 2). The coseismic rupture was a right-stepping, left-lateral and steep south plunging fault with three separate segments (Baklor, Kabateh and Zardgoli) and with a combined length of 80 km [20]. The earthquake surprisingly disrupted the high elevation of the Alborz Mountain.

1990 Darab (Fars Province) earthquake

The 1990 Nov. 6 Darab earthquake (Zg-6 fracture zone, Table 1, Fig. 2) is a scarce example of an earthquake with ~15 km clear co-seismic surface rupture (dipping 33°N), which has been exposed in the Zagros with measurable slips [21] (Figure 4a, b). The earthquake occurrence was presumably due to reactivation of segment from the High Zagros fault [21]. There is not a perfect correlation between the co-seismic surface slip and the asperities on the fault plane distinguished by the aftershocks distribution [14].

2005 Dahouieh Zarand earthquake

The 2005/2/22 Dahouieh Zarand moderate event (M_W 6.4) is a typical example for a reverse fault (EI-4 fracture zone, Table 1, Fig. 2) in eastern Iran. Right-lateral movement of the Kuhbanan mega fault with NW-SE strike in the eastern Iran has concluded a 13 km E-W intra-mountain reverse and uncontinuous rupture (with hidden parts) at east of the Kuhbanan fault. Its mechanism has changed from steeply dipping reverse movement in the western part to a partially right-lateral strike-slip displacement in the east [22,



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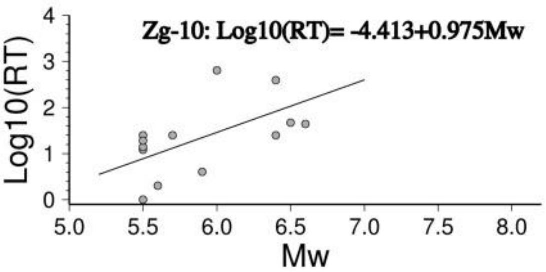

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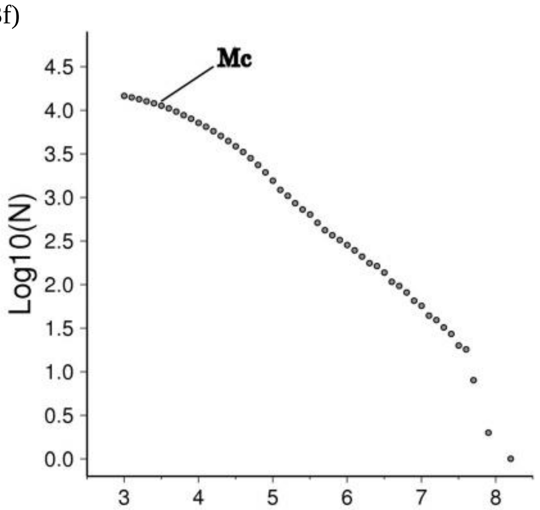

23].

1997 Zirkuh-e Qaen earthquake

The 1997 May 10 Zirkuh-e Qaen (M_W 7.2) calamitous earthquake (EI-2 fracture zone, Table 1, Fig. 2) is characterized with a 125 km surface rupture along the Abiz fault [24]. This is the longest co-seismic rupture ever produced and mapped in Persia among the instrumental earthquakes. Aftershocks spatial distribution illustrated that the causative co-seismic fault has plunged steeply, extended 20 km vertically and initiated at the NW and extended to the SE in a unilateral manner [25].

Estimation of Repeat Times

An expanded ellipse was used to depict all the earthquakes, which occurred in a fracture zone in such a way that it includes information on all the observed shocks. Thus, for each fracture zone, a catalogue of the earthquakes, which ruptured the whole zone or part of it over a certain period of time, was compiled. Each fracture zone was separately examined and in each one, the data set has a certain magnitude threshold (3.5, Fig. 3f).

For each fracture zone, the seismicity parameters (a and b-values; the Gutenberg-Richter (1956) (GR) [26] formula (6)) and observed repeat time, RT, in years, for all earthquakes of each magnitude class (at least differing by 0.1 magnitude values; formula 7) were calculated. Table 2 summarizes the values of the constants a′ and b′ for each fracture line, for the shallow and intermediate depth earthquakes. Close relationship of the Gutenberg-Richter formula, 6 and equation 7 is interesting. If it is assumed that the GR relation holds for independent events, b′-value in equation 7 proportions to b-value in GR relation (Fig. 3a-f).

6) $\mathrm{Log}_{10}\,(N) = a + bM_W$
7) $\mathrm{Log}_{10}\,(RT) = a' + b'M_W$

Straight lines drawn through the observations in Fig 3a-e were determined in the least squares sense since a linear relation is assumed to hold between the repeat time, RT and the magnitude, M_W. In other words, ordinary linear regression technique was used to compute the relationships between the variables. All the regressions for the plots were derived using the Origin software (www.microcal.com) [27]. Furthermore, all the maps and diagrams were generated by the GMT [28].

The basic need for any earthquake catalogue is homogeneity in the magnitude and also data completeness. Meaning of the completeness is that the data must include all earthquakes occurring in a seismotectonical region during a specific time interval with magnitude larger than a certain value (magnitude of completeness, M_C). Although, there are theoretical methods to determine M_C of a database [e.g. 29]; usually, M_C is estimated from bending of the Gutenberg-Richter diagram [26]. Woessner and Wiemer (2005) also estimated a same value for M_C for their catalogue using

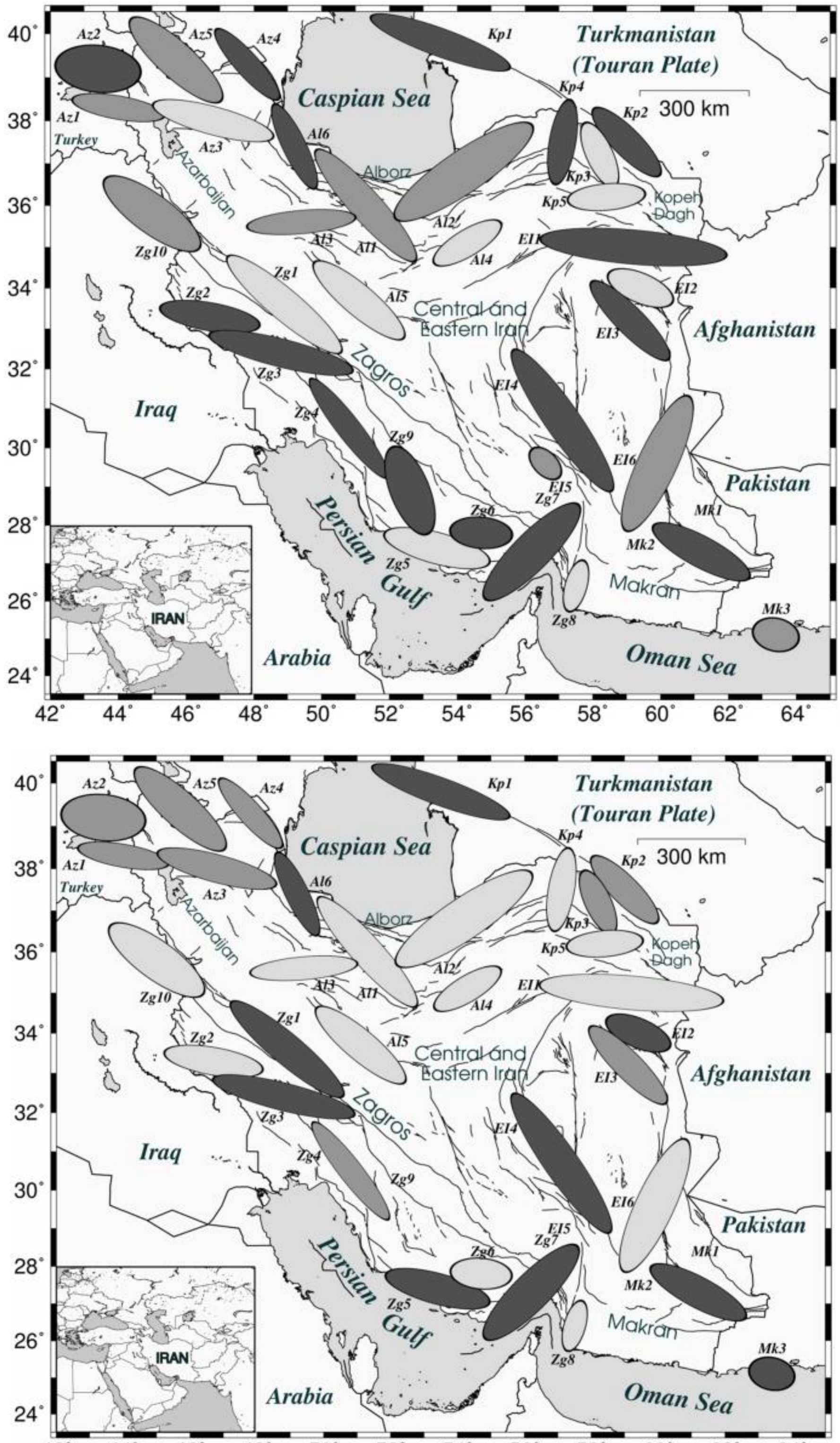

Figure 4. The probabilistic maps show the seismic areas in three categories of low (P≤33.33%; light-gray), intermediate (33.33% <P≤66.66%; gray) and high (P>66.66%; strong-gray) risks of occurrence of an earthquake with a) $5.5 \leq M_W < 7.0$ and b) $M_W \geq 7.0$ in the next 10 and 20 years, respectively.

the two theoretical and practical methods. M_C is the smallest magnitude above which the catalogue is

Table 2. Numerical seismicity parameters and repeat times with standard deviations (SD) for 35 defined fracture zones in Iran.

Lineament		Gutenberg-Richter Parameters				Repeat Time Parameters		
No	Symbol	a-value	b-value	SD	Average b	a′-value	b′-value	SD
1	Al-1	3.520±0.446	(-0.41±0.067)	0.161	0.5	(-1.637±1.287)	0.526±0.196	0.529
2	Al-2	3.759±0.126	(-0.47±0.019)	0.050		(-2.598±2.347)	0.662±0.377	0.741
3	Al-3	3.520±0.448	(-0.437±0.021)	0.031		0.910±8.915	0.085±1.513	1.255
4	Al-4	3.266±0.609	(-0.279±0.094)	0.068		1.818±3.766	0.010±0.572	0.068
5	Al-5	3.282±1.168	(-0.960±0.195)	0.131		1.642±4.485	0.040±0.742	0.477
6	Al-6	3.561±0.255	(-0.473±0.040)	0.074		(-0.168±2.210)	0.144±0.358	0.722
7	Az-1	3.816±0.206	(-0.526±0.033)	0.048	0.6	0.719±2.444	0.112±0.399	0.610
8	Az-2	4.102±0.413	(-0.533±0.066	0.121		(-1.914±1.760)	0.474±0.286	0.704
9	Az-3	3.616±0.275	(-0.418±0.041)	0.087		1.299±1.533	0.050±0.229	0.557
10	Az-4	5.380±0.743	(-0.796±0.122)	0.116		(-1.067±4.004)	0.355±0.663	0.627
11	Az-5	4.178±0.386	(-0.553±0.060)	0.099		0.197±2.752	0.211±0.437	0.817
12	Kp-1	3.222±0.361	(-0.402±0.057)	0.123	0.4	(-1.829±1.480)	0.419±0.234	0.579
13	Kp-2	2.978±0.406	(-0.390±0.063)	0.109		(-1.299±1.808)	0.384±0.300	0.500
14	Kp-3	3.304±0.276	(-0.419±0.042)	0.085		2.277±2.821	(-0.140±0.451)	0.743
15	Kp-4	3.936±0.305	(-0.546±0.049)	0.073		(-4.490±2.878)	0.952±0.482	0.606
16	Kp-5	3.131±1.215	(-0.400±0.185)	0.221		(-1.406±1.286)	0.547±0.196	0.234
17	EI-1	4.243±0.226	(-0.565±0.036)	0.064	0.8	(-3.740±2.000)	0.838±0.329	0.638
18	EI-2	3.568±0.317	(-0.456±0.049)	0.098		0.590±3.156	0.055±0.495	0.976
19	EI-3	3.516±0.226	(-0.454±0.035)	0.068		(-1.938±4.021)	0.518±0.653	1.041
20	EI-4	5.618±0.382	(-0.767±0.061)	0.094		1.094±1.418	(-0.076±0.235)	0.505
21	EI-5	13.618±2.019	(-2.385±0.360)	0.051		(-12.354)	2.486	0.000
22	EI-6	3.029±0.154	(-0.358±0.024)	0.029		(-1.498±2.435)	0.476±0.380	0.642
23	Zg-1	4.987±0.229	(-0.666±0.036)	0.064	0.8	3.396±2.399	(-0.333±0.387)	0.731
24	Zg-2	3.747±0.448	(-0.501±0.072)	0.113		(-4.931±1.252)	1.067±0.205	0.345
25	Zg-3	8.379±0.602	(-1.269±0.100)	0.097		(-0.360±3.850)	0.183±0.658	0.679
26	Zg-4	5.982±0.559	(-0.857±0.091)	0.119		(-2.728±3.171)	0.625±0.532	0.753
27	Zg-5	5.147±0.364	(-0.742±0.060)	0.082		6.751±3.071	(-0.949±0.523)	0.727
28	Zg-6	5.785±0.513	(-0.868±0.085)	0.081		(-7.179±5.425)	1.451±0.930	0.870
29	Zg-7	6.040±0.196	(-0.830±0.031)	0.057		(-2.610±1.592)	0.545±0.264	0.591
30	Zg-8	7.416±1.082	(-1.192±0.180)	0.051		3.931	(-0.029)	0.000
31	Zg-9	4.974±0.463	(-0.661±0.073)	0.116		1.295±2.754	(-0.395)	0.696
32	Zg-10	4.518±0.339	(-0.628±0.054)	0.086		(-4.413±2.705)	0.975±0.458	0.692
33	Mk-1	2.134±0.503	(-0.267±0.074)	0.117	0.5	2.137±1.938	(-1.121±0.289)	0.451
34	Mk-2	7.184±0.778	(-1.104±0.131)	0.107		2.192±3.843	(-0.254±0.650)	0.107
35	Mk-3	3.131±0.232	(-0.256±0.035)	0.086		2.566±1.575	(-0.279±0.234)	0.571

considered to be fully reported. In 1964-2014 period in IIEES catalog, which partly reports seismic data with a regional seismological network, this magnitude could optimistically be assumed to be 3.5 with a reliable and confidence (Fig. 3g).

Although, in data of some diagrams of the Fig. 3 and some equations of the Table 2, the scatter was considerable, the linear trend was evident and mathematically meaningful. Considering the uncertainties, the repeat times of the earthquakes along some fracture zones including of the Makran subduction zone is strongly under influenced of less earthquake data in fractures.

Probabilistic estimations

Probabilities of occurrence of large shocks (5.5≤M<7.0) and that of great earthquakes (M≥7.0) for time intervals of 10 and 20 years in each fracture zone were respectively estimated. Time interval (TI) of 10-20 years, which was chosen on the basis that probability calculations are often more stable and real than they are for shorter and longer time intervals, respectively. Technologically, this period is long enough for various constructing purposes such as engineering design and possible strengthening of buildings and structures (Table 3).

There are various processing methods calculating the probability of occurrence of an earthquake, P(T), during the time T. A significant example (eq. 8 and 9), which is based on Gaussian distribution of repeat time n(t) is:

8) $P(t \leq T \leq t+\Delta t)=\int_t^{t+\Delta t} n(t)dt / \int_t^{\infty} n(t)dt$, (T>t)

9) $n(t)=1/\sigma(2\pi)^{-0.5}\mathrm{Exp}[-0.5(t-T_m/\sigma)^2]$, (σ is standard deviation)

In this relations T is the repeat time of an earthquake

Table 3. Repeat times and probabilities of occurrence of large shocks (5.5≤M<7.0) and great earthquakes (M≥7.0) for time intervals of 10 and 20 years in each fracture zone. Bold values are for the lineaments, which were displayed in the Fig. 3.

Lineament		Last Earthquake		Minimum Repeat time (RT)			Poisson Probability of Occurrence (%)	
No	**Symbol**	**5.5≤M<7.0**	**M≥7.0**	**5.5≤M<7.0 (Month)**	**5.5≤M<7.0 (Year)**	**M≥7.0 (Year)**	**5.5≤M<7.0 (TI 10 years)**	**M≥7.0 (TI 20 years)**
1	Al-1	2004	1608	215	17.9	110.9	42.77	16.49
2	Al-2	2005	1890	132	11.0	108.6	59.71	16.76
3	Al-3	2002	1177	286	23.8	32.0	34.27	6.04
4	**Al-4**	**2010**	**-**	**896**	74.7	**77.3**	**12.53**	22.87
5	Al-5	2007	-	873	72.8	83.6	12.84	21.19
6	Al-6	1991*	1990	50	4.2	6.9	90.93	94.26
7	Az-1	2000	1930	260	21.7	31.8	36.97	46.47
8	Az-2	1988*	1976	59	4.9	25.4	86.92	55.07
9	Az-3	1997	1780	450	37.5	44.6	23.41	35.88
10	Az-4	1998*	-	92	7.7	26.2	72.87	53.66
11	Az-5	2012	819	273	22.8	47.2	35.57	34.66
12	Kp-1	2009*	2000	36	3.0	12.7	96.43	78.53
13	Kp-2	1985*	1948	78	6.5	24.5	78.53	56.54
14	Kp-3	1984	1893	386	32.2	19.8	26.72	63.21
15	Kp-4	2000*	1695	67	5.6	149.3	83.32	12.56
16	Kp-5	1971*	1493	480	40.0	264.9	22.12	7.27
17	EI-1	2010	1336	89	7.4	133.7	74.03	13.86
18	EI-2	1980*	1979	94	7.8	9.4	11.93	89.16
19	EI-3	1998*	1493	98	8.2	48.8	70.16	33.51
20	EI-4	2005*	1981	57	4.8	3.6	87.82	99.87
21	**EI-5**	**2010**	**-**	**250**	20.8	**-**	**38.12**	-
22	EI-6	2010	1838	158	13.2	68.2	53.21	25.48
23	Zg-1	2006	1909	440	36.7	11.6	23.87	81.11
24	Zg-2	1998*	1830	104	8.7	345.1	68.46	5.63
25	Zg-3	2014	-	53	4.4	8.3	89.61	91.79
26	Zg-4	2010	-	61	5.1	44.4	86.02	36.53
27	Zg-5	2014	1957	408	34.0	1.3	25.48	100.00
28	Zg-6	2003*	-	76	6.3	950.6	79.38	2.08
29	Zg-7	2011*	1997	29	2.4	16.0	98.40	71.35
30	**Zg-8**	**2013**	-	-	-	-	**0.17**	0.37
31	Zg-9	1999*	1957	2	0.2	-	100.00	-
32	Zg-10	1991*	743	107	8.9	258.2	42.92	7.46
33	**Mk-1**	**2013**	**2013**	-	-	-	**-**	-
34	Mk-2	2005*	-	75	6.3	2.6	79.81	99.87
35	Mk-3	1991*	1974	129	10.8	4.1	60.55	99.33

of certain magnitude in a fracture zone during the next Δt years [30, 31].

Our analysis is based on simple Poisson's model (eq. 10) for estimate the probability of occurrence of events. An important primacy of the Poisson's model is that occurrence of earthquake is supposed independent of the time t elapsed since the previous earthquake and is the same before and after its occurrence. The Poisson probability of occurrence of large shocks along each of the earthquake lineament was estimated using the repeat time and time interval for large and great earthquakes, separately (Table 3).

10) $P(Poisson\%) = [1-Exp(-TI/RT)]\times 100$

Considering the uncertainties in the input data and in Poisson's model for earthquake occurrence, Papazachos et al. (1987) believe that a probabilistic analysis is more useful than estimates of actual dates of future earthquakes.

According to the data presented in the table 3, which has summarized for each zone, the minimum repeat time, the date of the last large shock, the probability of occurrence of shocks and the magnitude of the maximum earthquake ever occurred, we could compare the data and test the reliability of model and data processing for Iran. Assuming the table 3 and the seismic behavior of each area, the probabilistic map of figure 4a and b shows the seismic areas in three categories of high, intermediate and low risks. It represents the probability that a certain zone will be the location of an earthquake with $5.5 \le M_W < 7.0$ (a) and $M_W \ge 7.0$ (b) during the next 10 and 20 years, respectively.

Regarding to average b-values for the Zagros (0.8; table 3) fracture zones and earthquake ($5.5 \le M_W < 7.0$) occurrence probabilities (Fig. 4a), it is acceptable that the Zagros will only be location of intermediate-large earthquakes in the next 10 years (Fig. 4a). Table 2 and 3 and figure 4a and b show that there is not strong correlation between average b-values of the Alborz (0.5), Azarbaijan (0.57), eastern Iran (0.83), Kopeh Dagh (0.43) and Makran (0.54) areas and earthquake probabilities in these regions. Because of lack of earthquake data in some fracture zones in some seismotectonic provinces, any interpretations should be presented based on average b-values of the lineaments in the province not based on b-values of each fracture lonely.

According to the time lapse since the last shocks with $5.5 \le M_W < 7.0$ that is more than the mean repeat time estimated for some lineaments, north of Azarbaijan, Kopeh Dagh, Dasht-e Bayaz, Ferdows, Piranshahr, Lar and Zabol area, an earthquake of magnitude around $5.5 \le M_W < 7.0$ may be likely to occur in these regions. We could not present a similar interpretation for $M_W \ge 7.0$ earthquakes, because of fewer numbers of great earthquakes occurred within the fracture zones in Iran. Regarding to the Fig. 4, Chalderan, Talesh, Kashafroud and Qir areas (Table 1) have been recognized as seismic gaps.

Results and Discussion

According to the probabilistic maps of earthquake occurrence in Iran, it reveals that high risk (P>66%) regions for earthquake occurrence with $M_W \ge 7.0$ in the next 20 years are the fault systems related to the Talesh, Apsheron, MRF, Dasht-e Bayaz, Golbaf, Minab and Bandar-e Abbas areas. Apsheron, Talesh, MRF, Golbaf, Bandar-e Abbas and Iranian Makran areas situate in high-risk areas for occurrence of earthquakes with both $M_W \ge 5.5$ and $M_W \ge 7.0$ magnitudes in the next 10 and 20 years, respectively. Fortunately, probability of occurrence of a great event in the next 20 years in south of Azarbaijan, entire Alborz and central Iran and also south of Kopeh Dagh areas is low (P<33%).

The areas of interest for earthquake occurrence with $5.5 \le M_W < 7.0$ in the next 10 years are the Talesh, Apsheron, north of Kopeh Dagh, Dorouneh, Zagros and Golbaf. It is important that probability of occurrence of a large event in the next 10 years in Alborz, which is the location of Iranian capital, and important industrial cities with combined population of 15,000,000 is up to 66%. Also, according to the past seismicity of Central Iran, it is not surprising that this region is the calmest area for earthquake occurrence in the next 20 years. There are not clear relationships between the areas of low probabilities of occurrence for $5.5 \le M_W < 7.0$ earthquakes and low risk areas for $M_W \ge 7.0$ in the central Kopeh Dagh, NTF, MRF and Dasht-e Bayaz areas.

The fractures NTF, Ipac, Toroud and Neyshabour, which are part of the southern border between the north of Iran and central Iran, have the largest repeat times (>40 years) for $5.5 \le M_W < 7.0$ earthquakes in Iran. They are associated with very low Probability (7 and 6% for the Neyshabour and Ipac faults, respectively).

Regarding to the belief of some researchers that a probabilistic analysis is more useful than estimates of actual dates of future earthquakes, we estimated the probabilities based on the large earthquakes repeat times, involve a number of basic physical assumptions and we would think that they provide a useful approach to the problem of earthquake prediction in Iran. Our estimated probabilities for great shocks will be better constrained when a longer record of great earthquakes is available. In other words, the probabilities are well constrained, where the number of the historical and instrumental records is adequate and its duration is long enough. Also, repeat times of Iranian earthquakes in seismic zones are rather different. A possible explanation for this issue is that variation of repeat times among regions with comparable relative plate velocities is resulted by the other factors besides the rate of convergence.

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