Evaluation of Earthquake Hazard Parameters by Bayesian Method for Different Source Regions in Zagros Seismotectonic Province

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ABSTRACT

In this study, we used the program for seismic hazard Bayesian estimate elaborated by Alexey Lyubushin. However, earthquake hazard parameters of maximum magnitude (M_{max}), β value, and seismic activity rate or intensity (λ) and their uncertainties for the 30 different source regions in Zagros seismotectonic province have been evaluated with the help of a complete and homogeneous earthquake catalog during the period 1900-2019 with $M_w \geq 4.0$. The estimated M_{max} values vary between 5.05 and 7.41. The lowest value is observed in the MZ3 source whereas the highest value is observed in the MZ2 source. Also, it is observed that there is a strong relationship between the estimated maximum earthquake magnitudes estimated by the Bayesian method and maximum observed magnitudes. Moreover, quantiles of functions of distributions of true and apparent magnitude for future time intervals of 10, 20, 50, 100, 475 years are calculated with confidence limits for probability levels of 50, 60, 70, 80, 90, 95, and 98% in 30 different source regions. MZ2 source shows earthquake magnitude greater than 7.0 in next 100-years with 90% probability level as compared to other regions, which declares that these regions are more susceptible to the occurrence of a large earthquake. The outcomes obtained in the study may have useful implications in probabilistic seismic hazard studies of Zagros seismotectonic province.

Keywords:
Earthquake hazard parameter; Bayesian method; Maximum magnitude (M_{max}); Zagros seismotectonic province

1. Introduction

The Iranian Plateau is impressed by different convergences among the Indian, Eurasian and African plates, which has ensued in high mountain ranges accompaniment its southwestern (Zagros) boundaries, northern (Alborz) and northeastern (Kopet Dagh), and lower, rugged mountains along its eastern margins (East Iran). The seismicity map of Zagros seismotectonic province is demonstrated in Figure (1). Zagros and its surrounding region have experienced repeated moderate to large magnitude earthquakes during the previous centuries.

The issue of earthquake hazard evaluations requires a profound and stable statistical and/or probabilistic technique that can offer outcomes with minimum uncertainties. The assessment of earthquake hazard parameters such as mean activity

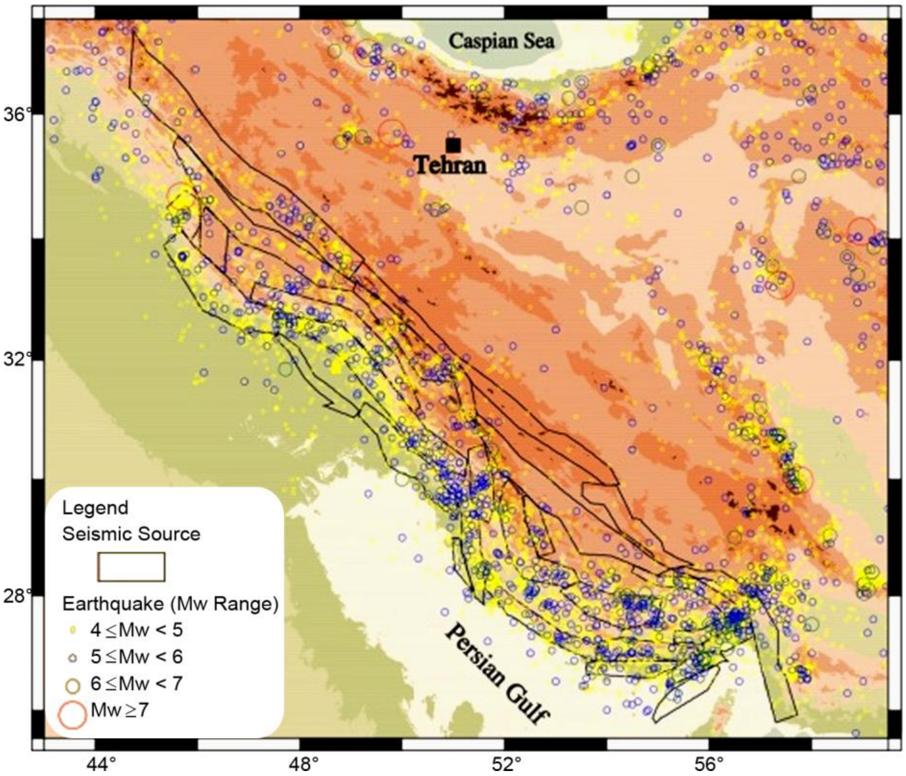

Figure 1. Seismicity map of Zagros seismotectonic province and locations of earthquakes M_w ≥4.

rate (λ), b value of the G-R relationship, and maximum magnitude M_{max} is the primary goal in the preparation of a probabilistic seismic hazard map in any seismically active region. Generally, it has been accepted that maximum magnitude M_{max} (and its uncertainty) is the most important parameter among earthquake hazard parameters. The "apparent" magnitude [1], which displays the observed magnitude (M_{max} obs) is equal to the "true" magnitude M, plus an uncertainty, e. The probability distribution of this uncertainty can be modeled by various distribution functions. The maximum possible earthquake magnitude (M_{max}) assessment is required in many seismic/engineering usages. The maximum magnitude is determined as the upper limit of earthquake magnitude for a given area and is identical with the size of the largest reliable earthquake. It presumes a sharp cutoff magnitude at a maximum magnitude so that by description, no earthquakes are anticipated with magnitude overstepping M_{max} [2].

The statistical approach plays a major role in estimating the earthquake hazard parameter, via, the average inter-event time, the size, and the location of seismic activity since no successful physical method has yet tried to be effective. A large number of probabilistic models and statistical methods have been offered by several researchers of the world to estimate mean activity rate (λ), b value of the G-R relationship, and maximum regional magnitude M_{max} [2-8]. Modern statistical theories offer methods that may be profitable to earthquake data. Among statistical methods, the Bayesian approach has an especial interest that comes from its power or ability to grow into the regard uncertainty of parameters in fitted probabilistic laws and a priory given information [9-11]. Moreover, this theory has an extraordinary noteworthiness for the estimation of earthquake parameters that comes from its two components. The first is a thorough method for consolidating earlier data seismicity, whether it is judgmental, geological, or statistical with the historical observation of earthquake incidences. Its second component gives a method for joining the statistical uncertainty related to the computation of the parameters used to evaluate seismicity notwithstanding the probabilistic uncertainty connected with the characteristic haphazardness of earthquake events [12].

Nowroozi and Ahmadi [13] forecast that the regions located southwest of the Zagros Thrust and northeast of the Arabian landmass (NWZ7, NWZ8, NWZ6, NWZ2, NWZ3, Ah1, NWZ4, SZ6 sources) are the most probable to create earthquakes with magnitudes of six in less than a decade. Yazdani and Kowsari [14] (using Bayesian estimation) showed results for the cutoff magnitude of 6.5 indicates that the largest probability of seismic hazard exists in the Kopet Dagh, Kerman (Central Iran), Bandar-eAbbas (SE-Zagros), Alborz and Zagros regions. Karimiparidari et al. [15] estimated M_{max} by Kijko and Sellevoll [1, 3] in Zagros Mountain Range ($M_{max} = 7.5$).

Different numbers of earthquakes in different parts of the magnitude-frequency relationship are considered for the estimation of slope β value in the Bayesian method. Therefore, a significant number of earthquakes are used to estimate it for lower magnitude and fewer at larger magnitudes. However, Zafarani et al. [16] estimate b value for the same regions using event $M_w \geq 4.5$ for the period 1900-2010. Moreover, Karimiparidary et al. [15] reported b value for Zagros Mountain Range as 1.20 ± 0.03.

In the present research, we have been using a procedure which developed by Pisarenko et al. [4] to evaluate earthquake hazard for the 30 different regions of Zagros seismotectonic province. For this purpose, earthquake hazard parameters [M_{max}, β value of the G-R relationship, and activity rate (λ) and their uncertainties are computed. In addition, the quantiles of M_{max} probabilistic distribution in future time intervals of 10, 20, 50, 100, and 475 years are evaluated'.

2. Data Used and Zonation

The catalog of earthquakes is the most important prerequisite in this method. In this regard, for this study, the seismic catalog of Shahvar et al. [17] is used, referring to USGS and ISC. An earthquake data set used in seismicity or seismic hazard assessments must surely be uniform, in other words, it is essential to use the same magnitude scale. All data in this study are unified to the Mw scale. The epicentral distributions of earthquakes with $M_{max} \geq 4$ that occurred in the instrumental period covering between 1900 and 2019 are shown in Figure (1). To convert the scale of events from the magnitudes of m_b or M_s reported by ISC or USGS, the relationships provided by Shahvar et al. [17] have been used. One of the most important assumptions used in the Pisarenko et al. [4] method is the Poissonian character of events. Thus we only need the major events, and the associated events (i.e., foreshocks and aftershocks) are eliminated from the total data. For this purpose, we have used Gardner and Knopoff [18] method.

Karimiparidari et al. [15] developed a new seismotectonic zoning map for Iran. In this research, we utilized the regions defined by Karimiparidari et al. [15]. They updated Zagros seismotectonic province into 30 seismic regions (Figure 2).

From north to south, both the style and kinematics of active deformation differ along the Zagros fold-and-thrust belt (Table 1). The Silakhor 1909/1/23 earthquake (M_s = 7.4) is the largest recorded earthquake in the Zagros (Zone 3), solve the focal mechanism and the effect left on the fault plane of this earthquake, shows the dominant right-lateral strike-slip movement. The historical earthquakes of each zone are listed in Table (1). In northern Zagros, ongoing deformation is postulated to be partitioned along with a parallel major reverse and strike-slip faults (e.g. [19]), while there is no convincing evidence attesting to such partitioning in central and south Zagros.

3. Method

The employed method is delineated in particular in some references [4, 20-25]. However, we will give the main assumptions and key equations only.

Let R be the value of magnitude (M), which is a measure of the size of earthquakes that happened in a sequence on a past-time interval $(-\tau, 0)$:

$$\vec{R}^{(n)} = (R_1, \ldots, R_n),\ R_i \geq R_0$$
$$R_\tau = \max_{1 \leq i \leq n} (\mathrm{R}_1, \ldots, R_n) \tag{1}$$

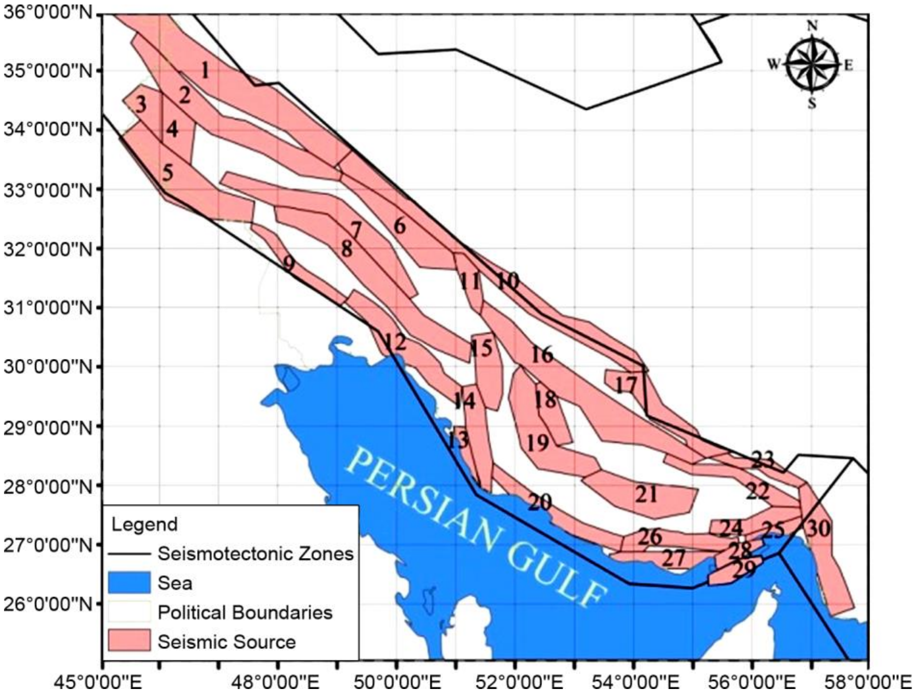

Figure 2. Zoning of the province and locations of the 30 different source regions, 1-MZ1, 2-NWZ1, 3-NWZ7, 4-NWZ8, 5-NWZ6, 6-MZ6, 7-NWZ2, 8-NWZ3, 9-Ah1, 10-MZ2, 11-MZ5, 12-NWZ5, 13-KH1, 14-NWZ4, 15-SZ6, 16-SZ1, 17-MZ3, 18-SZ8, 19-SZ7, 20-SZ5, 21-SZ9, 22-SZ2, 23-MZ4, 24-SZ3, 25-SH1, 26-SZ4, 27-PG1, 28-PG2, 29-PG3, 30-SH2 [15].

Table 1. The historical earthquakes and dominant mechanism of each zone.

Source	Region	Historical Earthquakes	Dominant Mechanism
1	MZ1	1310 (M 5.3) – 1430 (M 5.9) – 1661 (M 6) – 1872/6/1 (M 6.1) – 1135/8/13 (M 6.4) – 1107/9/1 (M 6.5) – 1008/4/27 (M 7)	Right Lateral Strike-Slip & Transpression
2	NWZ1	1226/11/18 (M 6.5)	Transpression
3	NWZ7	958/4/1 (M 6.4) – 1150/4/1 (M 5.9)	Thrust
4	NWZ8	-	Thrust
5	NWZ6	1130/2/27 (M 6.8) – 1864/12/7 (M 6.4)	Thrust
6	MZ6	1666 (M 6.5) – 1880 (M 5.3)	Right Lateral Strike-Slip
7	NWZ2	872/6/22 (M 6.8) – 1052 (M 6.8)	Transpression
8	NWZ3	1085/5/1 (M 5.8) – 1875/3/21 (M 5.7)	Transpression with Left Lateral Component
9	Ah1	840 (M 6.5)	Thrust
10	MZ2	1459 (M 6.6) – 1876/9/28 (M 5.8) – 1853/6/5 (M 5.5) – 1853/6/11 (M 5.5)	Right Lateral Strike-Slip
11	MZ5	-	Compressive with Right-Lateral Component
12	NWZ5	-	Thrust
13	KH1	-	Right Lateral Strike-Slip
14	NWZ4	-	Right Lateral Strike-Slip & Thrust
15	SZ6	1891/12/14 (M 5.3)	Right Lateral Strike-Slip
16	SZ1	1824/6/25 (M 6.4) – 1890/3/25 (M 6.4) – 1865/6/1 (M 6) – 1591 (M 5.9) – 1894/2/26 (M 5.9) – 1623 (M 5.5)	Thrust
17	MZ3	-	Compressive
18	SZ8	1853/5/5 (M 6.2) – 1862/12/21 (M 6.2) – 1892/8/15 (M 5.3)	Thrust
19	SZ7	1440 (M 7.1)	Thrust
20	SZ5	1008 (M 6.5) – 1883/10/16 (M 5.8) – 1865 (M 5.6) – 978 (M 5.3)	Thrust
21	SZ9	1593/9/1 (M 6.5) – 1677 (M 6.4)	Thrust
22	SZ2	-	Thrust
23	MZ4	-	Thrust
24	SZ3	-	Thrust
25	SH1	1497 (M 6.5) – 1622/10/4 (M 5.5)	Thrust

Table 1. Continue

Source	Region	Historical Earthquakes	Dominant Mechanism
26	SZ4	1880/8/1 (M 5.3)	Thrust
27	PG1	1703 (M 6.8)	Thrust
28	PG2	1897/1/10 (M 6.4) – 1361 (M 5.3) – 1884/5/19 (M 5.3)	Thrust
29	PG3	-	Thrust
30	SH2	-	Left Lateral Strike-Slip

where i =1, 2,…, n; and R_0 is the minimum cutoff value of magnitudes (M), i.e., determined by possibilities of the registration system, or it may be a minimum value from which the value is written in Equation (1) the statistically representative.

Two main assumptions for Equation (1) were proposed. The first assumption is that Equation (1) follows the G-R law of distribution:

$$Pr\{R < x\} = F(x \mid R_0, \rho, \beta) = \frac{e^{-\beta R_o} - e^{-\beta x}}{e^{-\beta R_o} - e^{-\beta \rho}}, \quad R_o \le x \le \rho \qquad (2)$$

where ρ is the unknown parameter that represents the maximum possible value of R, for instance, 'maximum regional magnitudes (M)' in a given seismogenic region. The unknown parameter β is the 'slope' of the Gutenberg-Richter law of magnitude-frequency relationship at small values of x when the dependence (Equation 2) is plotted on double logarithmic axes.

The second assumption is that λ is an unknown parameter and a Poisson process with some activety rate or intensity λ in the sequence (Equation 1). If three unknown parameters (ρ, β and λ) can be written, the full vector is

$$\theta = (\rho, \beta, \lambda) \qquad (3)$$

Apparent magnitude is a magnitude that is observed, i.e., those values that are presented in seismic catalogs. True magnitude is a hidden value and is unknown that is defined by the formula:

$$\bar{R} = R + \varepsilon \qquad (4)$$

Let $n(x \mid \delta)$ be a density of probabilistic distribution of error ε where δ is a given scale parameter of the density and epsilon (ε) value is the error between the true magnitude R and the apparent magnitude ($\bar{R}$). We can estimate values of true magnitude taking into account different hypotheses about the probability distribution of epsilon (for example, uniform) and about parameters of this distribution. Below, we shall use the following uniform distribution density:

$$n(x \mid \delta) = \begin{cases} 1/2\delta, & |x| \le \delta \\ 0 & |x| > \delta \end{cases} \qquad (5)$$

Let Π be a priori uncertainty domain of values of parameters θ:

$$\Pi = \{\lambda_{min} \le \lambda \le \lambda_{max}, \beta_{min} \le \beta \le \beta_{max}, \rho_{min} \le \rho \le \rho_{max}\} \qquad (6)$$

We should consider the a priori density of the vector θ to be uniform in the domain Π.

According to the definition of conditional probability, a posteriori density of distribution of vector of parameters θ is equal to:

$$f(\theta \mid \vec{R}^{(n)}, \delta) = \frac{f(\theta, \vec{R}^{(n)} \mid \delta)}{f(\vec{R}^{(n)} \mid \delta)} \qquad (7)$$

but $f(\theta \mid \vec{R}^n, \delta) = f(\vec{R}^n \mid \theta, \delta) f^a(\theta)$, where $f^a(\theta)$ is the *a priori* density of the distribution of vector θ in domain Π. As $f^a(\theta) = const$ according to our assumption and taking into consideration that:

$$f(\vec{R}^{(n)} \mid \delta) = \int_{\Pi} f(\vec{R}^{(n)} \mid \theta, \delta)\, d\theta \qquad (8)$$

Then, we will obtain using a Bayesian formula [26]. The Bayesian formula is as follows:

$$f(\theta \mid \vec{R}^n, \delta) = \frac{f(\vec{R}^n \mid \theta, \delta)}{\int_{\Pi} f(\vec{R}^n \mid \vartheta, \delta)\, d\vartheta} \qquad (9)$$

An expression for the function $f(\theta \mid \vec{R}^n, \delta)$ should be used in Equation (9).

To use Equation (9), we must have an expression for the function $f\,(\theta \mid \vec{R}^{\,n}, \delta)$. With the assumption of Poissonian character sequence in Equation (1), and independent of its members, should give us:

$$f\,(\vec{R}^{(n)} \mid \theta, \delta) = \hat{f}\,(R_1 \mid \theta, \delta) \times \hat{f}\,(R_n \mid \theta, \delta) \frac{\exp\left(-\bar{\lambda}(\theta, \delta)\tau\right)\left(-\bar{\lambda}(\theta, \delta)\tau\right)^n}{n} \tag{10}$$

Now, we can calculate a Bayesian estimate of vector θ:

$$\hat{\theta}(\vec{R}^{\,n} \mid \delta) = \int_{\Pi} \vartheta f\,(\vartheta \mid \vec{R}^{\,n}, \delta)\, d\vartheta \tag{11}$$

An estimate of maximum value, ρ, is one of the computations of Equation (11). We must obtain Bayesian estimates of any of the functions to use a formula analogous to Equation (11).

One of the computations in Equation (11) contains an estimate of the maximum value of ρ. Using a formula analogous to Equation (11), we must obtain Bayesian estimates for any of the functions. The most important are estimates of quantiles of distribution functions of true and apparent values on a given future time interval [0,T], for instance for α quantiles of apparent values:

$$\hat{\bar{Y}}_T\,(\alpha \mid \vec{R}^{(n)}, \delta) = \int_{\Pi} \bar{Y}_T\,(\alpha \mid \vartheta, \delta) f\,(\vartheta \mid \vec{R}^{(n)}, \delta) d\vartheta \tag{12}$$

$\hat{Y}_T\,(\alpha \mid \vec{R}^{(n)}, \delta)$ for α quantiles for true values is written analogously to Equation (12). We must estimate variances of Bayesian estimates (Equations (11) and (12)) using averaging over the density (Equations (9) and (10)). For example:

$$\mathrm{var}\left\{\hat{\bar{Y}}_T\,(\alpha \mid \vec{R}^{(n)}, \delta)\right\} = \int_{\Pi} \bar{Y}_T\,(\alpha \mid \vartheta, \delta) - \hat{\bar{Y}}_T\,(\alpha \mid \vec{R}^{(n)}, \delta)^2 f\,(\vartheta \mid \vec{R}^{(n)}, \delta) d\vartheta \tag{13}$$

First of all, we will set $\rho_{\min} = R_\tau - \delta$. As for the values of $\rho_{\max}$, they depend on the specific data in the series (Equation 1) and are produced by the user of the method. Boundary values for the slope β are estimated by the formula:

$$\beta_{\min} = \beta_0(1-\gamma),\ \beta_{\max} = \beta_0(1+\gamma),\ \ 0 < \gamma \le 1 \tag{14}$$

where β_0 is the "central" value and is obtained as the maximum likelihood estimate of the slope for the Gutenberg-Richter law:

$$\sum_{i=1}^{n} \ln\left\{\frac{\beta . e^{-\beta R_i}}{e^{-\beta R_0} - e^{-\beta R_\tau}}\right\} \to \max_{\beta,\ \beta \in (0,\ \beta_s)} \tag{15}$$

Here, β_s is a rather large value.

For setting boundary values for intensity λ in Equation (6), we used the following rationale. As a consequence of normal approximation for a Poisson process for a rather large n (Cox and Lewis 1966), the standard deviation of the value $\lambda\tau$ has the approximation value $\sqrt{n} \approx \sqrt{\lambda_\tau}$. Thus, taking boundaries at ±3σ, we will obtain:

$$\lambda_{\min} = \lambda_0 (1 - \frac{3}{\sqrt{\lambda_0 \tau}}),\ \lambda_{\max} = \lambda_0 (1 + \frac{3}{\sqrt{\lambda_0 \tau}}),$$
$$\lambda_0 = \frac{\bar{\lambda}_0}{c_f\,(\beta_0, \delta)},\ \bar{\lambda}_0 = \frac{n}{\tau} \tag{16}$$

4. Comparison of Bayesian Estimates of Seismicity Parameters with Karimiparidari et al. [15] Results

Zagros seismotectonic province is divided into smaller zones using different data. The nationality of the active fault trend is the most significant parameter used in determining these zones [15]. The sub-seismotectonic provinces of Zagros and their associated seismicity parameters are introduced (Table 2). The Mmax values vary between 6.35 and 7.47. The lowest $M_{\max}$ value (6.35) is estimated for Ahvaz. However, in the Zagros seismotectonic province, the $M_{\max}$ values larger than 7.0 are calculated in Main Zagros fault ($M_{\max}$ bayes = 7.47) and Nw Zagros ($M_{\max}$ bayes = 7.27).

The computed β values vary between 1.25 and 2.06. The highest value is observed in Nw Zagros and the lowest value is observed in the Strait of Hormoz. The seismic activity rate or intensity λ estimated in the present study is on the scale of events per day.

The effective probabilistic implements for earthquake hazard assessment are evaluated for seven sub-provinces in this province. The posterior probability densities (Figure 3) and the posterior probability distribution functions of

M_{max} (T) (Figure 4), that will occur in future time intervals of 10, 20, 50, 100, and 475 years is illustrated for one sample sub-province. We have also calculated 'tail' probabilities $P(M_{max}(T) \geq M)$ of the magnitude for all sub-provinces, but this is shown in Figure (5) only for one sample sub-province for the future time intervals of 10, 20, 50, 100, and 475 years.

Table 2. The estimates of the Bayesian analysis for the seven different sub-provinces of Zagros.

Regions	N	M_{max}	M_{max} obs	β±σ	λ±σ
Ahvaz	57	6.35 ± 0.58	6.0	2.04 ± 0.20	0.11 ± 0.14
Khuzestan	63	6.48 ± 0.37	6.1	1.52 ± 0.16	0.13 ± 0.16
Main Zagros Fault	206	7.47 ± 0.25	7.4	2.05 ± 0.14	0.39 ± 0.28
Nw Zagros	588	7.27 ± 0.27	7.3	2.06 ± 0.19	0. 45 ± 0.31
Persian Gulf Coast	60	6.84 ± 0.44	6.5	1.44 ± 0.16	0.12 ± 0.16
South Zagros	603	6.93 ± 0.22	6.7	1.78 ± 0.16	0.52 ± 0.51
Strait of Homoz	39	6.50 ± 0.41	6.2	1.25 ± 0.13	0.10 ± 0.13

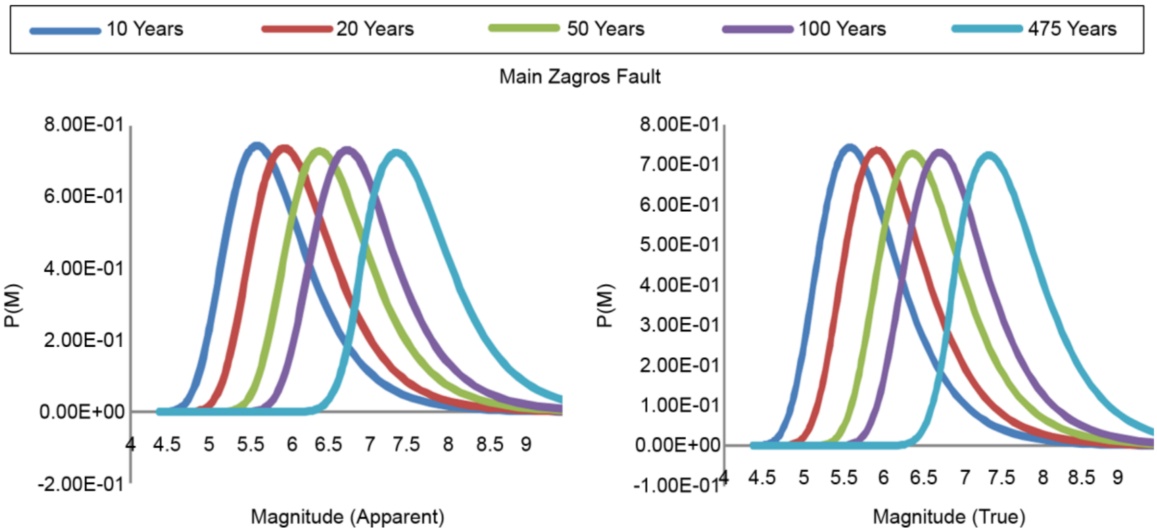

Figure 3. A posteriori probability densities of M_{max} (T) showing statistical characteristics of seismic hazard parameters for one sample sub-province in next T = 10, 20, 50, 100, and 475 years.

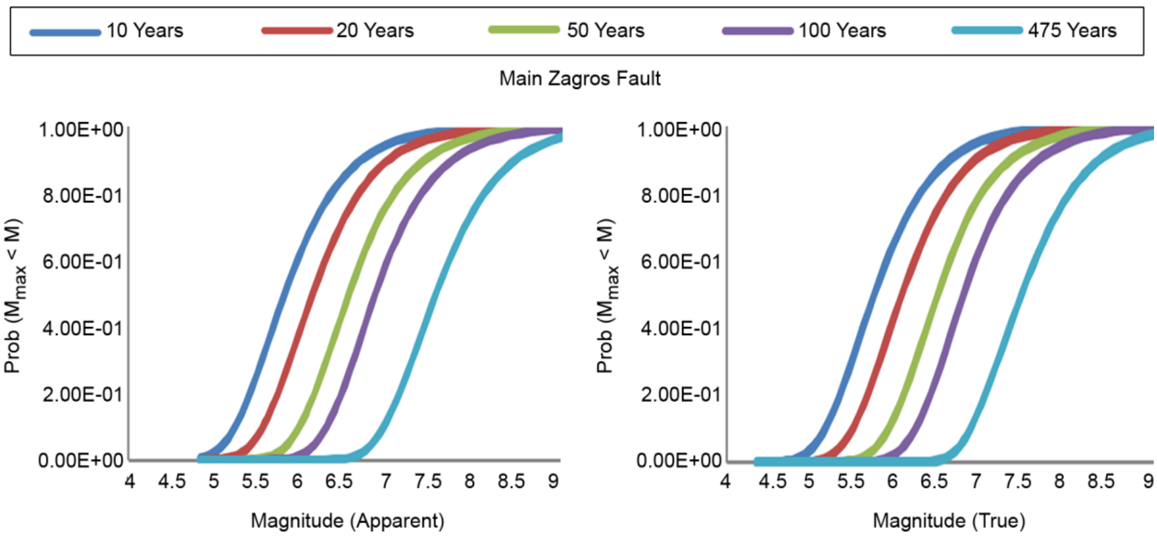

Figure 4. A posteriori probability functions of M_{max} (T) showing statistical characteristics of seismic hazard parameters for one sample sub-province in next T = 10, 20, 50, 100, and 475 years.

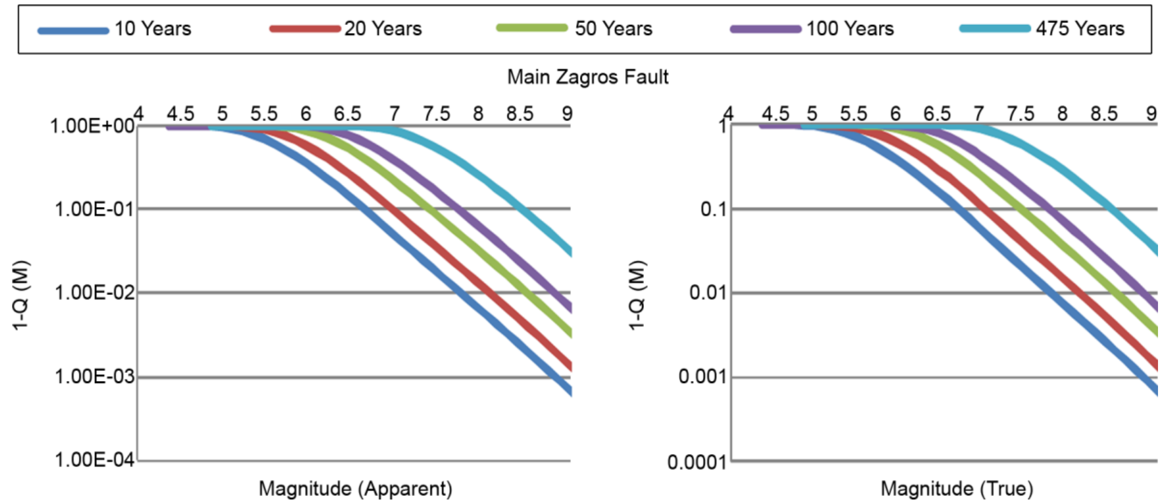

Figure 5. 'Tail' probabilities 1 - ϕ(M) = Prob(M_{max} (T) ≥ M) showing statistical characteristics of seismic hazard parameters for one sample sub-province in next T=10, 20, 50, 100, and 475 years.

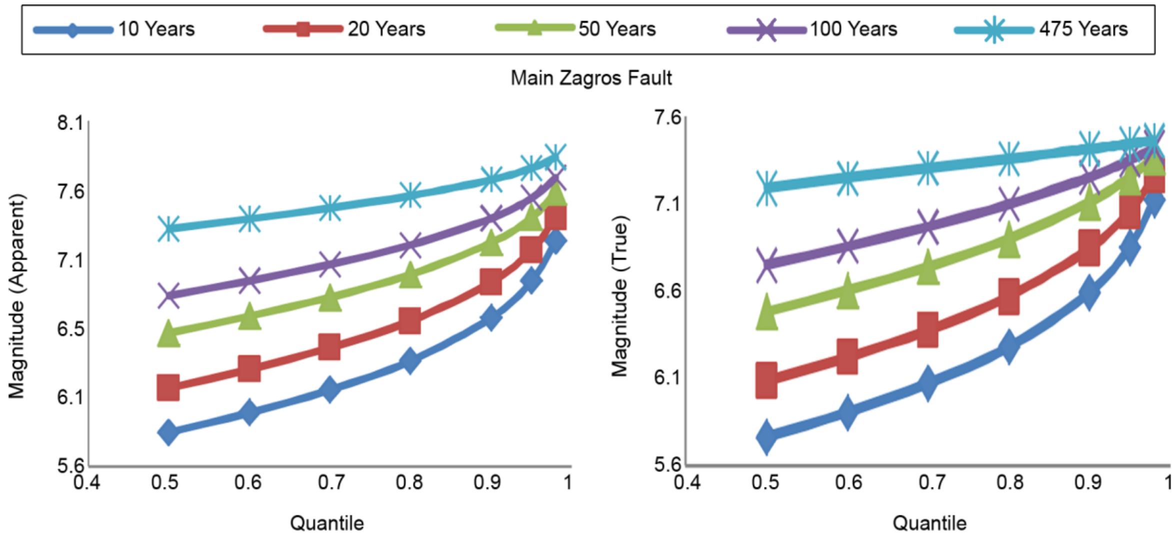

Figure 6. Quantiles for 'apparent and true magnitudes' (of 50, 60, 70, 80, 90, 95 and 98%) of function of distribution of maximum values of M_{max} for a given length T of future time interval for the one sample sub-province of Zagros seismotectonic province.

Lastly, we have estimated the a posteriori M-quantiles for the seven sub-province in the examined province and for probabilities 0.50, 0.60, 0.70, 0.80, 0.90, 0.95, and 0.98 in the future time intervals of 10, 20, 50, 100, and 475 years (Figure 6).

The apparent and true magnitudes for 50, 70, and 90% probability levels within the next 10, 20, 50, 100, and 475 years are calculated for all sub-provinces. The estimated values are listed in Tables (3) and (4). The highest apparent and true magnitude values are equal to 7.67 and 7.41, respectively, observed in Main Zagros fault for the next 475 years. The values recorded in Table (4) are less than those in Table (3). The differences between these two values are very low.

Seismicity parameters of a number of seismic sources cannot be calculated due to the lack of data, but Karimiparidari et al. [15] solved this problem by using weight ratio; however, in this study, despite the small data, the parameters were calculated with low uncertainty. The results of the two approaches are almost identical, and in general, when we have relatively sufficient data in each zone, Karimiparidari et al. [15] estimate larger values than this study, which uses only data enclosed in zones.

Table 3. The quantiles of the 'apparent magnitudes' M_{max} (T) estimated for the levels of probability 0.50, 0.70 and 0.90 for the seven sub-provinces of Zagros seismotectonic province future T = 10, 20, 50, 100 and 475 years.

Regions	Future Years				
	10	**20**	**50**	**100**	**475**
	Quantiles of Probability Level %50				
Ahvaz	5.17 ± 0.08	5.43 ± 0.11	5.73 ± 0.17	5.93 ± 0.22	6.25 ± 0.34
Khuzestan	5.42 ± 0.10	5.70 ± 0.13	5.99 ± 0.18	6.17 ± 0.21	6.43 ± 0.28
Main Zagros fault	5.84 ± 0.10	6.16 ± 0.12	6.56 ± 0.13	6.83 ± 0.13	7.31 ± 0.15
Nw Zagros	6.17 ± 0.07	6.25 ± 0.08	6.37 ± 0.10	6.77 ± 0.12	7.20 ± 0.17
Strait of Hormoz	5.41 ± 0.12	5.76 ± 0.15	6.14 ± 0.21	6.36 ± 0.25	6.68 ± 0.32
South Zagros	6.27 ± 0.07	6.45 ± 0.09	6.63 ± 0.12	6.74 ± 0.14	6.89 ± 0.18
Persian Gulf coast	5.38 ± 0.10	5.64 ± 0.14	5.92 ± 0.20	6.07 ± 0.25	6.31 ± 0.33
	Quantiles of Probability Level %70				
Ahvaz	5.42 ± 0.11	5.65 ± 0.15	5.92 ± 0.22	6.08 ± 0.27	6.35 ± 0.39
Khuzestan	5.69 ± 0.13	5.92 ± 0.17	6.16 ± 0.21	6.30 ± 0.25	6.49 ± 0.30
Main Zagros fault	6.15 ± 0.11	6.46 ± 0.13	6.82 ± 0.17	7.06 ± 0.14	7.47 ± 0.16
Nw Zagros	6.14 ± 0.08	6.39 ± 0.10	6.76 ± 0.12	6.98 ± 0.14	7.29 ± 0.19
Strait of Hormoz	5.77 ± 0.15	6.05 ± 0.19	6.32 ± 0.25	6.52 ± 0.28	6.77 ± 0.34
South Zagros	6.44 ± 0.09	6.59 ± 0.12	6.73 ± 0.14	6.81 ± 0.16	6.92 ± 0.19
Persian Gulf coast	5.63 ± 0.14	5.85 ± 0.18	6.07 ± 0.24	6.19 ± 0.28	6.37 ± 0.36
	Quantiles of Probability Level % 90				
Ahvaz	5.82 ± 0.19	5.99 ± 0.24	6.19 ± 0.31	6.30 ± 0.36	6.47 ± 0.46
Khuzestan	6.07 ± 0.19	6.22 ± 0.23	6.38 ± 0.28	6.47 ± 0.29	6.58 ± 0.33
Main Zagros fault	6.67 ± 0.13	6.93 ± 0.14	7.22 ± 0.15	7.39 ± 0.16	7.67 ± 0.19
Nw Zagros	6.55 ± 0.11	6.84 ± 0.13	7.13 ± 0.16	7.35 ± 0.18	7.61 ± 0.22
Strait of Hormoz	6.25 ± 0.23	6.43 ± 0.26	6.62 ± 0.31	6.73 ± 0.33	6.87 ± 0.37
South Zagros	6.68 ± 0.13	6.77 ± 0.15	6.86 ± 0.17	6.91 ± 0.19	6.97 ± 0.20
Persian Gulf coast	5.99 ± 0.22	6.15 ± 0.26	6.27 ± 0.31	6.34 ± 0.34	6.44 ± 0.39

Table 4. The quantiles of the 'true magnitudes' M_{max}(T) estimated for the levels of probability 0.50, 0.70 and 0.90 for the seven sub-province of Zagros seismotectonic province future T = 10, 20, 50, 100 and 475 years.

Regions	Future Years				
	10	**20**	**50**	**100**	**475**
	Quantiles of Probability Level %50				
Ahvaz	5.09 ± 0.09	5.34 ± 0.12	5.62 ± 0.19	5.79 ± 0.27	6.03 ± 0.43
Khuzestan	5.36 ± 0.10	5.63 ± 0.14	5.89 ± 0.21	6.03 ± 0.26	6.14 ± 0.34
Main Zagros fault	5.76 ± 0.11	6.08 ± 0.12	6.48 ± 0.13	6.75 ± 0.14	7.19 ± 0.17
Nw Zagros	5.61 ± 0.11	5.97 ± 0.17	6.38 ± 0.17	6.68 ± 0.18	7.18 ± 0.22
Strait of Hormoz	5.37 ± 0.12	5.71 ± 0.16	6.07 ± 0.22	6.25 ± 0.27	6.44 ± 0.37
South Zagros	6.17 ± 0.09	6.32 ± 0.11	6.43 ± 0.16	6.47 ± 0.18	6.51 ± 0.21
Persian Gulf coast	5.32 ± 0.10	5.57 ± 0.15	5.79 ± 0.23	5.89 ± 0.28	6.00 ± 0.39
	Quantiles of Probability Level %70				
Ahvaz	5.34 ± 0.12	5.55 ± 0.17	5.78 ± 0.26	5.90 ± 0.34	6.07 ± 0.48
Khuzestan	5.62 ± 0.13	5.83 ± 0.18	6.01 ± 0.26	6.09 ± 0.30	6.16 ± 0.33
Main Zagros fault	6.07 ± 0.12	6.37 ± 0.13	6.74 ± 0.14	6.97 ± 0.15	7.30 ± 0.19
Nw Zagros	5.95 ± 0.11	6.12 ± 0.14	6.57 ± 0.16	6.86 ± 0.18	7.22 ± 0.24
Strait of Hormoz	5.72 ± 0.15	5.99 ± 0.20	6.25 ± 0.27	6.39 ± 0.33	6.47 ± 0.39
South Zagros	6.31 ± 0.11	6.41 ± 0.15	6.47 ± 0.18	6.50 ± 0.20	6.52 ± 0.22
Persian Gulf coast	5.56 ± 0.15	5.78 ± 0.21	5.89 ± 0.28	5.96 ± 0.34	6.02 ± 0.41
	Quantiles of Probability Level %90				
Ahvaz	5.70 ± 0.22	5.85 ± 0.30	5.94 ± 0.39	6.04 ± 0.45	6.12 ± 0.51
Khuzestan	5.98 ± 0.23	6.06 ± 0.28	6.12 ± 0.31	6.15 ± 0.35	6.18 ± 0.37
Main Zagros fault	6.59 ± 0.14	6.84 ± 0.14	7.11 ± 0.16	7.25 ± 0.18	7.41 ± 0.23
Nw Zagros	6.38 ± 0.12	6.73 ± 0.16	6.97 ± 0.20	7.20 ± 0.23	7.26 ± 0.27
Strait of Hormoz	6.17 ± 0.25	6.30 ± 0.30	6.41 ± 0.36	6.46 ± 0.38	6.49 ± 0.40
South Zagros	6.45 ± 0.17	6.49 ± 0.19	6.51 ± 0.21	6.52 ± 0.21	6.53 ± 0.22
Persian Gulf coast	5.84 ± 0.26	5.93 ± 0.32	5.99 ± 0.37	6.01 ± 0.41	6.03 ± 0.42

5. Results and Discussion

In this study, earthquake hazard parameters (β value of G-R relationship, mean activity rate (λ), and maximum regional magnitude M_{max}) have been calculated using the method of Bayesian to see the susceptibility in Zagros seismotectonic province with the assistance of a homogeneous and complete seismic catalog. It seems calculated earthquake hazard parameters by the Bayesian method are more static and reliable with low standard deviations than other approaches. The standard deviation value of the measured calculation showed the precision and accuracy of this method. When other methods are used a higher standard, deviation has been observed. Therefore results were not confident anymore. Also, standard deviation growth decreases the reliability and accuracy of results. In any case, the Bayesian approach gives low standard deviation according to other methods, so our results are better and more confident. Low standard deviation computed with this method, and it is a property of the Bayesian method. The estimated low standard deviation values of earthquake hazard parameters are shown in Table (5).

The M_{max} is a great issue that should be concerned in any seismic active regions. Therefore Significance is given to the estimation of this parameter as well as the quantiles of the M_{max} dispersion in a future time interval. The M_{max} values vary between 5.05 and 7.41. The lowest M_{max} value (5.05) is estimated for source 17 (MZ3). However, in the Zagros seismotectonic province, the M_{max} values larger than 7.0 are calculated in source 3 (NWZ7) (M_{max} bayes = 7.01) and 10 (MZ2) (M_{max} bayes = 7.41). These are the source regions that have encountered observed magnitude larger than 7.0 in the past century. By taking into account the tectonics and seismicity of these regions, we can conclude that these regions are able of producing such large events in the close future.

Table 5. The estimates of the Bayesian analysis for the 30 different source regions of this province.

Num.	Regions	N	M_{max}^{obs}	M_{max}^{est}	β	λ
1	MZ1	65	6.6	6.68 ± 0.25	2.62 ± 0.25	0.11 ± 0.15
2	NWZ1	45	5.6	6.57 ± 0.26	2.80 ± 0.30	0.77 ± 0.12
3	NWZ7	9	7.2	7.01 ± 0.24	1.90 ± 0.21	0.19 ± 0.59
4	NWZ8	10	5.6	5.64 ± 0.25	2.11 ± 0.24	0.20 ± 0.60
5	NWZ6	52	5.8	5.69 ± 0.17	1.95 ± 0.10	0.11 ± 0.15
6	MZ6	54	6.0	6.00 ± 0.26	2.51 ± 0.26	0.97 ± 0.13
7	NWZ2	75	6.1	6.17 ± 0.23	1.90 ± 0.19	0.14 ± 0.17
8	NWZ3	145	6.1	6.04 ± 0.25	2.26 ± 0.20	0.27 ± 0.24
9	Ah1	4	5.5	6.57 ± 0.25	1.79 ± 0.20	0.96 ± 0.39
10	MZ2	13	7.3	7.41 ± 0.24	1.96 ± 0.21	0.27 ± 0.70
11	MZ5	14	5.2	5.07 ± 0.19	1.71 ± 0.36	0.33 ± 0.83
12	NWZ5	45	5.5	5.50 ± 0.24	2.49 ± 0.26	0.81 ± 0.12
13	KH1	5	5.8	5.86 ± 0.25	2.17 ± 0.13	0.12 ± 0.47
14	NWZ4	49	6.3	6.36 ± 0.25	2.23 ± 0.23	0.93 ± 0.13
15	SZ6	36	6.3	6.26 ± 0.23	2.05 ± 0.11	0.80 ± 0.12
16	SZ1	26	6.2	6.24 ± 0.26	1.84 ± 0.20	0.53 ± 0.10
17	MZ3	3	4.8	5.0 5 ± 0.23	1.99 ± 0.11	0.86 ± 0.38
18	SZ8	15	6.0	6.05 ± 0.26	1.92 ± 0.21	0.31 ± 0.76
19	SZ7	55	6.7	6.77 ± 0.25	1.91 ± 0.19	0.10 ± 0.14
20	SZ5	40	5.6	6.41 ± 0.21	1.67 ± 0.19	0.83 ± 0.12
21	SZ9	64	6.5	6.46 ± 0.26	1.52 ± 0.16	0.13 ± 0.16
22	SZ2	45	6.5	6.47 ± 0.25	1.34 ± 0.14	0.97 ± 0.14
23	MZ4	12	5.8	5.78 ± 0.24	1.67 ± 0.77	0.28 ± 0.76
24	SZ3	36	6.7	6.78 ± 0.25	1.95 ± 0.20	0.72 ± 0.11
25	SH1	6	6.3	6.38 ± 0.23	1.40 ± 0.46	0.15 ± 0.54
26	SZ4	33	6.0	5.99 ± 0.24	1.44 ± 0.16	0.70 ± 0.11
27	PG1	20	5.8	6.78 ± 0.25	1.51 ± 0.16	0.43 ± 0.92
28	PG2	12	6.1	6.10 ± 0.23	1.45 ± 0.52	0.29 ± 0.76
29	PG3	7	5.6	5.67 ± 0.25	1.57 ± 0.18	0.16 ± 0.54
30	SH2	18	5.6	6.60 ± 0.24	2.07 ± 0.23	0.36 ± 0.81

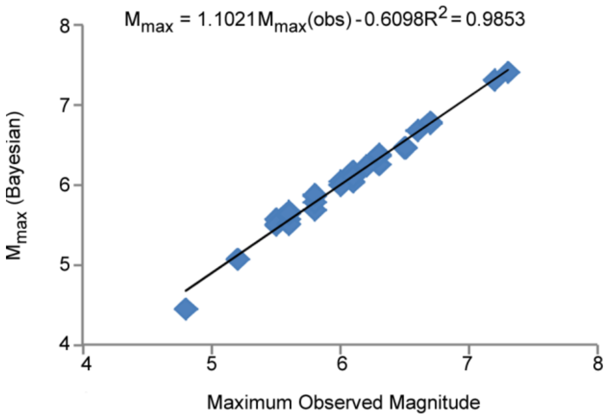

Figure 7. The relationship between maximum magnitudes estimated by Bayesian approach and maximum observed magnitude for the 30 different source region of Zagros seismotectonic province.

However, the close agreement among calculated M_{max} by Bayesian approach and maximum observed magnitudes (M_{max} obs) accredits the good quality of data employed and appropriateness of the adopted cutoff magnitude. In other words, it is seen that the calculated M_{max} values for the examined area are in good agreement with M_{max} (obs) for the 30 source region (Figure 7) and the regression relation takes the form of:

$$M_{max}(\text{Bayes}) = 1.1021 M_{max}(\text{obs}) - 0.6098 R^2 = 0.9853 \tag{17}$$

The correlation coefficient, r, is approximately 0.98 for Equation (17). This means that there is a tight relationship between the two values. Also, it is seen that their differences vary from 0.09 to 0.9 with a mean of 0.44 proposing a good linear relationship among these two values for the examined province. Thus, if we have the observed magnitude in any zone of the Zagros seismotectonic province, we can evaluate the M_{max} which can be generated by that zone.

The validity of the evolution of hazard parameters (slope β value of G-R relationship and activity rate or intensity λ) relies on the time period covered by the used instrumental catalog. According to Pisarenko et al. [4], the data set must coat events for a period of 50 years or more. The catalog employed in this research covers a time period of 119 years and thus we think that the calculated above parameters are reliable. The computed β values vary between 1.34 and 2.80. The highest value is observed in source 2 (NWZ1) and the lowest value is observed in source 22 (SZ2). The distinction in other studies' computed values with our study may be due to the different earthquake data utilized for examination, the size of seismic zones, and the method applied. The seismic activity rate or intensity λ estimated in the present study is on the scale of events per day. The highest λ value of the order of 0.01 events per day for Mw ≥ 4.0 is observed in source 6 (MZ6) and lowest the λ value related with source 19 (SZ5).

The effective probabilistic implements for earthquake hazard assessment are evaluated for 30 source regions in this province. The posterior probability distribution functions for M_{max} (T) (Figure 8), which will occur in future time intervals of 10, 20, 50, 100, and 475 years are illustrated for one sample source. We have also calculated ' tail' probabilities $P(M_{max}(T) \geq M)$ of the magnitude for all source regions, but this is shown in Figure (9) only for one sample source for the future time intervals of 10, 20, 50, 100, and 475 years.

Lastly, we have estimated the a posteriori M-quantiles for the 30 source regions in the examined province and for probabilities 0.50, 0.60, 0.70, 0.80, 0.90, 0.95, and 0.98 in future time intervals of 10, 20, 50, 100, and 475 years (Figure 10). It can be observed that the differences among apparent and true magnitude quantiles are very low, and this is due to the high quality of the data used.

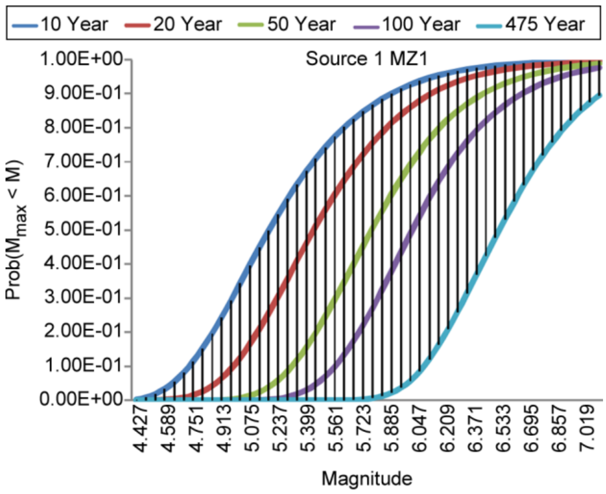

Figure 8. A posteriori probability functions of $M_{max}(T)$ showing statistical characteristics of seismic hazard parameters for one sample source in next T = 10, 20, 50, 100 and 475 years.

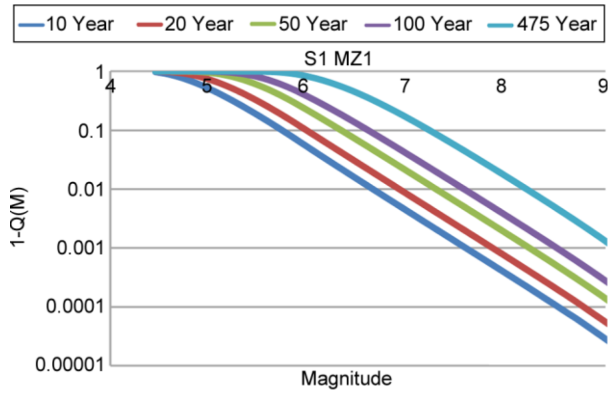

Figure 9. 'Tail' probabilities 1-ϕ(M)=Prob(M_{max}(T)≥M) showing statistical characteristics of seismic hazard parameters for one sample source in next T=10, 20, 50, 100, and 475 years.

The apparent and true magnitudes for 50, 70, and 90% probability levels within the next 10, 20, 50, 100, and 475 years are calculated for all seismogenic source regions. The estimated values are listed in Tables (6) and (7). The highest apparent and true magnitude values are equal to 7.11 and 7.06, respectively, observed in source 10 (MZ2) for the next 475 years. The values recorded in Table (7) are less than those in Table (6). This is obvious since Table (6) includes the magnitudes (apparent) of Table (7) (true) plus the error e. The differences between these two values are very low.

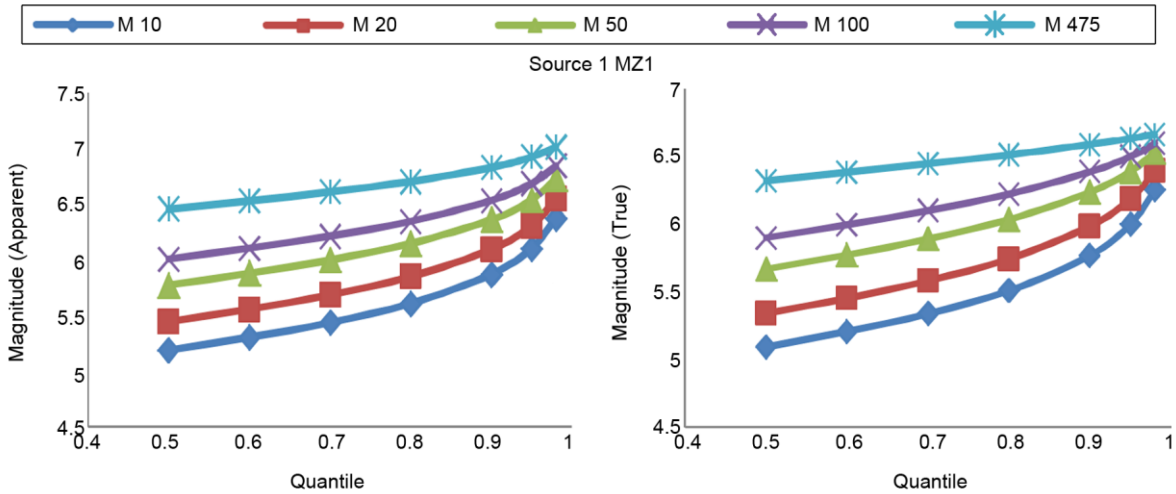

Figure 10. Quantiles for 'apparent and true magnitudes' (of 50, 60, 70, 80, 90, 95, and 98%) of function of distribution of maximum values of M_{max} for a given length T of future time interval for the one sample sources of Zagros seismotectonic province.

Table 6. The quantiles of the 'apparent magnitudes' M_{max}(T) estimated for the levels of probability 0.70 and 0.90 for the 30 different source regions of Zagros seismotectonic province future T = 10, 20, 50, 100 and 475 years.

Num.	Regions	Future Years 10	20	50	100	475
		Quantiles of Probability Level %70				
1	MZ1	5.43+/- 0.10	5.68+/-0.11	5.99 +/-0.13	6.20+/-0.14	6.60+/-0.15
2	NWZ1	5.07+/-0.65	5.25+/-0.90	5.47+/-0.11	5.60+/-0.13	5.82+/-0.18
3	NWZ7	5.18+/-0.96	5.33+/-0.12	5.66+/-0.19	5.99+/-0.21	6.66+/-0.21
4	NWZ8	5.01+/-0.71	5.12+/-0.94	5.34+/-0.12	5.51+/-0.14	5.81+/-0.18
5	NWZ6	5.59+/-0.11	5.75+/-0.12	5.91+/-0.13	5.99+/-0.14	6.10+/-0.15
6	MZ6	5.26+/-0.90	5.48+/-0.10	5.74+/-0.11	5.90+/-0.13	6.18+/-0.17
7	NWZ2	5.61+/-0.10	5.85+/-0.11	6.09+/-0.13	6.24+/-0.14	6.46+/-0.18
8	NWZ3	5.66+/-0.89	5.85+/-0.10	6.05+/-0.13	6.18+/-0.15	6.36+/-0.19
9	Ah1	4.91+/-0.72	4.97+/-0.87	5.11+/-0.12	5.27+/-0.16	5.63+/-0.19
10	MZ2	5.12+/-0.10	5.31+/-0.14	5.69+/-0.19	6.03+/-0.21	6.70+/-0.22
11	MZ5	5.00+/-0.12	5.10+/-0.13	5.25+/-0.15	5.34+/-0.16	5.46+/-0.17
12	NWZ5	5.12+/-0.80	5.29+/-0.97	5.50+/-0.12	5.62+/-0.14	5.81+/-0.18
13	KH1	5.14+/-0.96	5.23+/-0.11	5.42+/-0.16	5.61+/-0.18	5.98+/-0.21
14	NWZ4	5.36+/-0.10	5.62+/-0.11	5.93+/-0.13	6.13+/-0.14	6.46+/-0.17
15	SZ6	5.73+/-0.12	5.97+/-0.14	6.23+/-0.16	6.38+/-0.18	6.58+/-0.20
16	SZ1	5.28+/-0.10	5.52+/-0.12	5.85+/-0.14	6.06+/-0.15	6.58+/-0.20
17	MZ3	4.71+/-0.68	4.73+/-0.76	4.76+/-0.97	4.79+/-0.12	4.87+/-0.17
18	SZ8	5.10+/-0.76	5.27+/-0.11	5.58+/-0.14	5.79+/-0.15	6.15+/-0.18

Table 6. Continue

Num.	Regions	Future Years				
		10	20	50	100	475
		Quantiles of Probability Level %70				
19	SZ7	5.59+/-0.12	5.90+/-0.13	6.25+/-0.14	6.48+/-0.15	6.84+/-0.17
20	SZ5	5.24+/-0.96	5.42+/-0.11	6.25+/-0.14	5.71+/-0.15	5.87+/-0.18
21	SZ9	5.80+/-0.11	6.07+/-0.13	6.34+/-0.15	6.50+/-0.17	6.73+/-0.21
22	SZ2	5.76+/-0.12	6.04+/-0.14	6.33+/-0.16	6.50+/-0.17	6.73+/-0.21
23	MZ4	5.39+/-0.13	5.52+/-0.16	5.74+/-0.18	5.89+/-0.19	6.10+/-0.21
24	SZ3	5.40+/-0.12	5.70+/-0.14	6.08+/-0.15	6.33+/-0.15	6.76+/-0.17
25	SH1	5.69+/-0.14	5.80+/-0.16	6.04+/-0.20	6.24+/-0.21	6.58+/0.22
26	SZ4	5.44+/-0.11	5.66+/-0.13	5.92+/-0.15	6.07+/-0.17	6.29+/-0.20
27	PG1	5.25+/-0.99	5.44+/-0.12	5.72+/-0.14	5.89+/-0.16	6.14+/-0.19
28	PG2	5.63+/-0.15	5.78+/-0.17	6.02+/-0.19	6.18+/-0.20	6.40+/-0.22
29	PG3	5.02+/-0.84	5.11+/-0.10	5.31+/-0.14	5.50+/-0.16	5.82+/-0.19
30	SH2	5.02+/-0.81	5.18+/-0.10	5.43+/-0.13	5.60+/-0.14	5.86+/-0.19
		Quantiles of Probability Level %90				
1	MZ1	5.86+/-0.12	6.09+/-0.13	6.35+/-0.14	6.52+/-0.15	6.82+/-0.17
2	NWZ1	5.39+/-0.10	5.53+/-0.12	5.69+/-0.14	5.78+/-0.17	5.93+/-0.21
3	NWZ7	5.77+/-0.14	5.93+/-0.17	6.25+/-0.21	6.53+/-0.22	7.06+/-0.20
4	NWZ8	5.38+/-0.11	5.47+/-0.12	5.63+/-0.15	5.76+/-0.17	5.95+/-0.21
5	NWZ6	5.85+/-0.13	5.94+/-0.14	6.03+/-0.15	6.08+/-0.15	6.14+/-0.16
6	MZ6	5.64+/-0.11	5.81+/-0.12	6.01+/-0.14	6.13+/-0.16	6.31+/-0.20
7	NWZ2	6.00+/-0.12	6.16+/-0.13	6.33+/-0.16	6.42+/-0.17	6.55+/-0.20
8	NWZ3	5.97+/-0.11	6.11+/-0.14	6.25+/-0.16	6.33+/-0.18	6.44+/-0.21
9	Ah1	5.30+/-0.11	5.35+/-0.12	5.40+/-0.15	5.58+/-0.17	5.81+/-0.20
10	MZ2	5.71+/-0.15	5.90+/-0.18	6.27+/-0.21	6.57+/-0.22	7.11+/-0.20
11	MZ5	5.25+/-0.15	5.31+/-0.15	5.39+/-0.17	5.45+/-0.17	5.51+/-0.18
12	NWZ5	5.42+/-0.11	5.55+/-0.13	5.69+/-0.15	5.77+/-0.17	5.89+/-0.20
13	KH1	5.60+/-0.14	5.66+/-0.16	5.80+/-0.18	5.92+/-0.20	6.15+/-0.22
14	NWZ4	5.81+/-0.12	6.02+/-0.13	6.26+/-0.15	6.40+/-0.16	6.62+/-0.19
15	SZ6	6.15+/-0.16	6.30+/-0.17	6.46+/-0.19	6.54+/-0.20	6.66+/-0.21
16	SZ1	5.77+/-0.12	5.95+/-0.14	6.19+/-0.16	6.33+/-0.18	6.54+/-0.21
17	MZ3	4.82+/-0.12	4.91+/-0.13	5.04+/-0.17	5.11+/-0.19	5.20+/-0.20
18	SZ8	5.56+/-0.11	5.70+/-0.13	5.93+/-0.16	6.08+/-0.17	6.32+/-0.21
19	SZ7	6.12+/-0.14	6.36+/-0.14	6.62+/-0.16	6.78+/-0.17	7.02+/-0.20
20	SZ5	6.11+/-0.15	6.22+/-0.14	6.30+/-0.17	6.41+/-0.19	6.53+/-0.21
21	SZ9	6.24+/-0.14	6.41+/-0.16	6.59+/-0.18	6.69+/-0.20	6.83+/-0.23
22	SZ2	6.23+/-0.15	6.41+/-0.16	6.60+/-0.19	6.70+/-0.20	6.84+/-0.23
23	MZ4	5.76+/-0.17	5.85+/-0.18	5.98+/-0.20	6.06+/-0.21	6.18+/-0.22
24	SZ3	5.95+/-0.14	6.20+/-0.15	6.50+/-0.16	6.68+/-0.16	6.97+/-0.19
25	SH1	6.20+/-0.18	6.27+/-0.19	6.41+/-0.21	6.53+/-0.21	6.72+/-0.22
26	SZ4	5.84+/-0.14	5.99+/-0.16	6.16+/-0.18	6.25+/-0.20	6.38+/-0.22
27	PG1	6.69+/-0.13	6.81+/-0.15	6.63+/-0.17	6.79+/-0.17	6.80+/-0.20
28	PG2	6.04+/-0.18	6.13+/-0.19	6.28+/-0.21	6.37+/-0.21	6.44+/-0.22
29	PG3	5.43+/-0.13	5.50+/-0.14	5.65+/-0.17	5.77+/-0.18	5.97+/-0.21
30	SH2	6.40+/-0.12	6.52+/-0.15	6.71+/-0.16	6.80+/-0.18	6.97+/-0.20

Table 7. The quantiles of the 'true magnitudes' $M_{max}(T)$ estimated for the levels of probability 0.70 and 0.90 for the 30 different source regions of Zagros seismotectonic province future T = 10, 20, 50, 100 and 475 years.

Num.	Regions	Future Years				
		10	20	50	100	475
		Quantiles of Probability Level %70				
1	MZ1	5.33+/-0.10	5.58+/-0.12	5.89+/-0.14	6.10+/-0.14	6.44+/-0.17
2	NWZ1	4.97+/-0.80	5.13+/-0.10	5.31+/-0.13	5.41+/-0.17	5.53+/-0.23
3	NWZ7	5.16+/-0.95	5.29+/-0.12	5.60+/-0.18	5.91+/-0.22	6.58+/-0.22
4	NWZ8	4.98+/-0.74	5.06+/-0.96	5.24+/-0.13	5.38+/-0.16	5.57+/-0.22
5	NWZ6	5.49+/-0.12	5.58+/-0.14	5.65+/-0.16	5.67+/-0.16	5.69+/-0.17
6	MZ6	5.17+/-0.94	5.37+/-0.11	5.62+/-0.13	5.75+/-0.16	5.93+/-0.22
7	NWZ2	5.54+/-0.10	5.75+/-0.12	5.98+/-0.15	6.05+/-0.18	6.14+/-0.21
8	NWZ3	5.56+/-0.96	5.73+/-0.12	5.88+/-0.16	5.95+/-0.19	6.02+/-0.23
9	Ah1	4.89+/-0.75	4.93+/-0.89	5.05+/-0.12	5.19+/-0.16	5.44+/-0.21
10	MZ2	5.09+/-0.10	5.26+/-0.14	5.62+/-0.19	5.95+/-0.21	6.68+/-0.22
11	MZ5	4.90+/-0.14	4.95+/-0.16	5.02+/-0.17	5.04+/-0.18	5.06+/-0.19
12	NWZ5	5.02+/-0.87	5.17+/-0.11	5.32+/-0.15	5.40+/-0.18	5.48+/-0.22
13	KH1	5.12+/-0.98	5.20+/-0.11	5.37+/-0.16	5.54+/-0.19	5.77+/-0.23
14	NWZ4	5.28+/-0.10	5.53+/-0.12	5.83+/-0.13	6.01+/-0.15	6.25+/-0.20
15	SZ6	5.69+/-0.13	5.91+/-0.15	6.10+/-0.19	6.18+/-0.21	6.24+/-0.22
16	SZ1	5.23+/-0.10	5.46+/-0.12	5.77+/-0.14	5.95+/-0.17	6.16+/-0.22
17	MZ3	4.40+/-0.16	4.41+/-0.17	4.42+/-0.18	4.43+/-0.19	4.44+/-0.21
18	SZ8	5.06+/-0.85	5.21+/-0.11	5.49+/-0.14	5.69+/-0.16	5.94+/-0.21
19	SZ7	5.52+/-0.12	5.82+/-0.14	6.17+/-0.15	6.38+/-0.16	6.65+/-0.20
20	SZ5	5.16+/-0.10	5.29+/-0.13	5.41+/-0.17	5.45+/-0.19	5.49+/-0.21
21	SZ9	5.74+/-0.11	5.99+/-0.13	6.22+/-0.17	6.33+/-0.20	6.43+/-0.24
22	SZ2	5.71+/-0.21	5.98+/-0.14	6.22+/-0.18	6.33+/-0.20	6.43+/-0.24
23	MZ4	5.36+/-0.14	5.47+/-0.17	5.62+/-0.20	5.70+/-0.21	5.76+/-0.23
24	SZ3	5.34+/-0.12	5.62+/-0.14	6.00+/-0.15	6.25+/-0.16	6.60+/-0.19
25	SH1	5.68+/-0.14	5.79+/-0.16	6.01+/-0.20	6.16+/-0.21	6.33+/-0.23
26	SZ4	5.39+/-0.11	5.59+/-0.14	5.80+/-0.18	5.88+/-0.20	5.97+/-0.23
27	PG1	5.21+/-0.10	5.38+/-0.12	5.62+/-0.16	5.73+/-0.18	5.85+/-0.22
28	PG2	5.62+/-0.15	5.74+/-0.18	5.92+/-0.20	6.00+/-0.22	6.08+/-0.23
29	PG3	4.99+/-0.87	5.07+/-0.10	5.24+/-0.15	5.39+/-0.18	5.59+/-0.22
30	SH2	4.97+/-0.83	5.11+/-0.10	5.32+/-0.14	5.45+/-0.17	5.95+/-0.23
		Quantiles of Probability Level %90				
1	MZ1	5.76+/-0.13	5.98+/-0.14	6.23+/-0.15	6.38+/-0.18	6.59+/-0.21
2	NWZ1	5.26+/-0.12	5.36+/-0.15	5.46+/-0.19	5.51+/-0.22	5.56+/-0.25
3	NWZ7	5.75+/-0.14	5.88+/-0.17	6.18+/-0.21	6.45+/-0.22	6.96+/-0.20
4	NWZ8	5.31+/-0.13	5.37+/-0.15	5.47+/-0.18	5.54+/-0.21	5.61+/-0.24
5	NWZ6	5.63+/-0.15	5.66+/-0.16	5.68+/-0.16	5.69+/-0.16	5.69+/-0.17
6	MZ6	5.53+/-0.12	5.68+/-0.14	5.83+/-0.18	5.90+/-0.21	5.98+/-0.25
7	NWZ2	5.88+/-0.14	6.00+/-0.16	6.10+/-0.19	6.13+/-0.21	6.16+/-0.22
8	NWZ3	5.82+/-0.14	5.92+/-0.18	5.99+/-0.21	6.01+/-0.23	6.04+/-0.24
9	Ah1	5.24+/-0.14	5.27+/-0.15	5.35+/-0.18	5.42+/-0.20	5.53+/-0.24
10	MZ2	5.67+/-0.15	5.85+/-0.18	6.20+/-0.22	6.49+/-0.23	7.06+/-0.20
11	MZ5	5.02+/-0.17	5.03+/-0.18	5.05+/-0.18	5.06+/-0.19	5.07+/-0.19
12	NWZ5	5.28+/-0.14	5.36+/-0.17	5.44+/-0.20	5.47+/-0.22	5.49+/-0.24
13	KH1	5.54+/-0.17	5.59+/-0.18	5.68+/-0.20	5.75+/-0.22	5.84+/-0.25
14	NWZ4	5.72+/-0.13	5.92+/-0.14	6.12+/-0.17	6.21+/-0.19	6.32+/-0.23
15	SZ6	6.05+/-0.17	6.14+/-0.20	6.21+/-0.21	6.23+/-0.22	6.25+/-0.23
16	SZ1	5.70+/-0.13	5.84+/-0.15	6.04+/-0.18	6.13+/-0.21	6.22+/-0.24
17	MZ3	4.53+/-0.20	4.62+/-0.19	4.74+/-0.21	4.83+/-0.19	4.94+/-0.21
18	SZ8	5.51+/-0.12	5.63+/-0.14	5.80+/-0.18	5.91+/-0.20	6.02+/-0.24
19	SZ7	6.04+/-0.14	6.27+/-0.15	6.50+/-0.17	6.61+/-0.19	6.73+/-0.23
20	SZ5	5.78+/-0.17	5.93+/-0.19	6.07+/-0.19	6.19+/-0.20	6.30+/-0.20
21	SZ9	6.14+/-0.16	6.27+/-0.19	6.38+/-0.22	6.41+/-0.24	6.45+/-0.25
22	SZ2	6.14+/-0.16	6.28+/-0.19	6.39+/-0.22	6.42+/-0.23	6.46+/-0.25

Table 7. Continue

Num.	Regions	Future Years				
		10	20	50	100	475
		Quantiles of Probability Level %90				
23	MZ4	5.64+/-0.20	5.68+/-0.21	5.73+/-0.22	5.76+/-0.23	5.78+/-0.23
24	SZ3	5.88+/-0.14	6.12+/-0.16	6.40+/-0.17	6.55+/-0.18	6.72+/-0.22
25	SH1	6.14+/-0.20	6.18+/-0.20	6.26+/-0.22	6.32+/-0.23	6.37+/-0.23
26	SZ4	5.74+/-0.16	5.84+/-0.19	5.93+/-0.22	5.96+/-0.23	5.98+/-0.24
27	PG1	6.29+/-0.18	6.37+/-0.18	6.49+/-0.21	6.55+/-0.20	6.67+/-0.21
28	PG2	5.94+/-0.20	5.98+/-0.21	6.04+/-0.22	6.07+/-0.23	6.09+/-0.23
29	PG3	5.36+/-0.15	5.41+/-0.17	5.50+/-0.19	5.57+/-0.22	5.64+/-0.24
30	SH2	6.11+/-0.14	6.20+/-0.18	6.31+/-0.21	6.40+/-0.22	6.53+/-0.22

6. Conclusion

The Bayesian method is applied to check the potentiality of each source zone in this province for the future occurrence of maximum magnitude $[P(M_{\max}(T)>M)]$. For this aim, $M_{\max}$, β value, and seismicity activity rate or intensity (λ) and their uncertainty are computed. It is estimated that the maximum magnitude is larger than 7.0 for sources 3 (NWZ7) and 10 (MZ2), whereas the lowest value is found in source 17 (MZ3). However, a linear relationship is also established between maximum observed magnitude ($M_{\max}$ obs) and maximum magnitude computed by the Bayesian approach for Zagros seismotectonic province and it will be a useful relation to getting an idea about the maximum magnitude computed by the Bayesian approach in other regions using the maximum observed magnitude. The estimated β values for the 30 different source regions of this province vary between 1.34 and 2.80. The lowest β value is estimated in source 22 (SZ2), whereas the highest value is estimated in source 2 (NWZ1). The probabilistic implements for earthquake hazard assessment are evaluated for 30 source regions in this province. In addition, we estimated the quantiles of the 'apparent and true' magnitudes $M_{\max}(T)$ for the levels of probability 0.70 and 0.90 for 30 source regions of this province in the next T = 10, 20, 50, 100, and 475 years.

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