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Evaluating of Earthquake Hazard Parameters (EHP) With Bayesian Approach Method in Sakarya and Surrounding, Turkey

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Abstract

In this study, the Bayesian Approach method used to evaluate earthquake hazard parameters (EHP) (maximum regional magnitude ($M_{\max}$), β value, and seismic activity rate or intensity (λ) and their uncertainties) in Sakarya and surrounding. So, Sakarya divided into 3 different seismic source zones based on of tectonic, fault types, epicenter distribution etc. features. Respectively, this zones contained zone 1 (Arifiye and Karadere segments), zone 2 (Tepetarla and Dokurcun segments), zone 3 (Geyve fault). Also, zone 1 associated with the northern branch of the North Anatolian fault zone (NAFZ), while zone 2 and 3 associated with the southern branch of the NAFZ. A compiled earthquake catalog that is homogenous with $M_s \geq 3.0$ completed during the period from 1900 to 2017. The $M_{\max}$ values determined as 6.85 in zone 1, 6.06 in zone 2, 5.77 in zone3. Low values found in the southern part of Sakarya, whereas high values observed in the northern part of Sakarya. The largest value computed in Arifiye and Dokurcun segments zone, comprising the other zones. The quantiles of functions of distributions determined for the true and apparent magnitude in future years. The quantiles of functions of distributions of the apparent and true magnitudes for next time intervals of 5, 10, 25, 50, 75 and 100 years calculated in all seismogenic source regions for confidence limits of probability levels of 50, 60, 70, 80, 90, 95 and 98 %. According to the computed the EHP, Sakarya and surrounding estimated the highest earthquake magnitude (6,91) in the next 100 years with a 98 % probability level and it was the most dangerous zone compared to other zones. The results of this study can be used in earthquake hazard studies for Sakarya.

Key words: Bayesian Approach method, earthquake hazard parameters (EHP), Quantiles, Sakarya and surrounding

1. Introduction

The North Anatolian Fault Zone (NAFZ) was 1600-km-long as an intercontinental dextral strike-slip fault with significant strain localization and demonstrated a major plate boundary between the Anatolian plate in the south and the Eurasian plate in the north. Though collision between the Eurasian (in the east) and Arabian plates was primarily opinion to be the main driving force for the westward motion of the Anatolian plate, last advances in high-resolution GPS data have showed an outdoor role of the southwest-trending rollback of the Hellenic subduction zone in the south Aegean Sea for the rapid deformation of the Aegean-Anatolian region (McClusky et al., 2000; Reilinger et al., 2006). Sakarya and surrounding founded in the central NAFZ.

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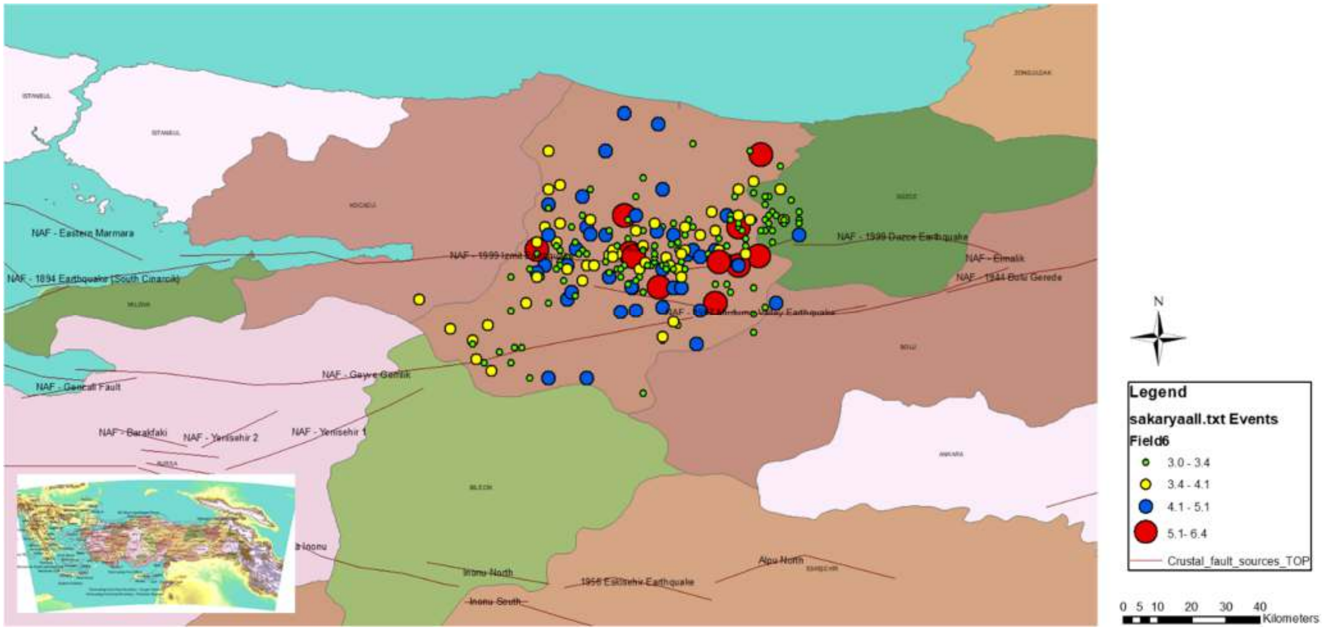


Figure 1. Sakarya and surrounding plotted for $M_s \geq 3.0$ magnitude (Bottom figure and maps plotted for 1/1.000.000 scales).

We divided into 3 different seismic source zones (Fig. 2) (Arifiye and Karadere Segments (Zone 1), Tepetarla and Dokurcun Segment (Zone 2), Geyve Fault (Zone 3)) based on epicenter distribution, tectonic, seismicity, geology, faults etc. in Sakarya and surrounding (Fig. 1). A homogenous earthquake catalog for $M_s \geq 3.0$ magnitude is used at time period between 1900 and 2017. The computed M_{max} values changed between 4.7 and 6.4 (Table 1).

Table 1. The Bayesian analysis estimates for 3 different zones tabulated in Sakarya and surrounding.

Zone	Zone Name	N	$M_{max} \pm \sigma_{Mmax}$	M_{max}^{obs}	$\beta \pm \sigma_\beta$	$\lambda \pm \sigma_\lambda$
1	Arifiye and Karadere Segments (North of the Sakarya)	164	6.85±0.33	6.4	1.45±0.12	0.48±0.37
2	Tepetarla and Dokurcun Segments (Central of the Sakarya)	42	6.06±0.55	5.5	1.10±0.20	0.17±0.25
3	Geyve Fault (South of the Skarya)	22	5.77±0.86	4.7	1.72±0.34	0.11±0.23

Bayrak and Türker (2016 and 2017) estimated earthquake hazard parameters using Bayesian method for different regions in the Turkey.

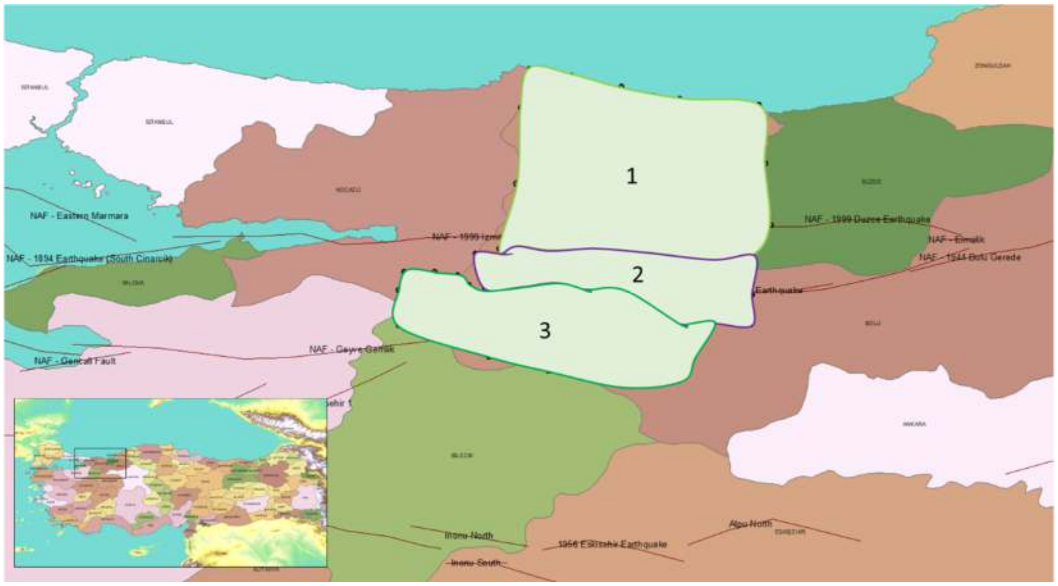


Figure 2. Sakarya and surrounding plotted 3 different sesimogenic zone based on epicenter distribution, tectonic, seismicity, geology, faults etc.

2. METHOD

2.1- Bayesian Method

The theory of Bayesian probability expresses the formulation of the inferences from data straightforward and allows the solution of problems earthquakes occurrences.

Let *R* be some value, which was measured or estimated as a sequence on a "past" time interval (-*τ,o*):

$$\vec{R}^{(n)} = (R_1, \dots\dots\dots, R_n), \qquad R_i \geq R_0, \quad R_t = \max((R_1, \dots\dots\dots, R_n), \quad 1 \leq i \leq n \qquad (1)$$

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

Two main assumptions for Eq. (1) were proposed. Our first assumption is that values of $\vec{R}^{(n)}$ follows by Eq. (1) of the Gutenberg–Richter law of distribution which is expressed:

$$\mathrm{Prob}\{R < r\} = F\left(\frac{x}{R_o}, \rho, \beta\right) = \frac{e^{-\beta R_o} - e^{-\beta x}}{e^{-\beta R_o} - e^{-\beta \rho}} \quad , \qquad R_o \leq x \leq \rho \qquad (2)$$

While the second assumption is that the sequence of Eq. (1) is Poisson process with some activity rate or intensity λ which is an unknown parameter. It is necessary to note that the distribution expressed by Eq. (2) is the Gutenberg-Richter law. If three unknown parameters (ρ, β and λ) can be written, the full vector is:

$$\theta = (\rho, \beta, \lambda) \tag{3}$$

Where, from both Eq. (2) and Eq. (3), 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 b is usually called the 'slope' of the Gutenberg–Richter law, while the intensity or rate value λ is also an unknown parameter.

Let n($x|\delta$) be the probabilistic density of error ε, where δ is some 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. We shall use below the uniform distribution density:

$$n(x|\delta) = \frac{1}{2\delta}, |x| \le \delta \qquad\qquad n(x|\delta) = 0, |x| > \delta \tag{4}$$

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

$$\Pi = \{\lambda_{min} < \lambda \le \lambda_{max}, \beta_{min} \le \beta \le \beta_{max}, \rho_{min} \le \rho \le \rho_{max}\} \tag{5}$$

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

The Bayesian method used in the present method is based on Bayes formula (Rao 1965).

$$F\left(\theta|\vec{R}^{(n)}, \delta\right) = \frac{f\left(\theta|\vec{R}^{(n)}, \delta\right)}{\int_{\pi} f(\overset{\to(n)}{R} | V, \delta) dV} \tag{6}$$

In order to use Eq. (6), we must have an expression for the function $f(\overset{\to(n)}{R} | \theta, \delta)$. The sequence in Eq. (1), with the assumption of a Poisson character and independent of its members, we can obtain:

$$f\left(\vec{R}^{(n)}|\theta, \delta\right) = \bar{f}(R_1|\theta, \delta) \ldots\ldots\ldots\ldots. \bar{f}(R_n|\theta, \delta) * \frac{\exp(-\lambda(\theta,\delta)\tau) * \left(-\bar{\lambda}(\theta,\delta)\tau\right)^n}{n!} \tag{7}$$

We can compute a Bayesian estimate of vector θ:

$$\theta(\vec{R}^{(n)}|\delta) = \int_{\pi} V f(V | \overset{\to(n)}{R}, \delta) dV \tag{8}$$

One of the computations in (Eq. 8) contains an estimate of maximum value of ρ. Using a formula analogous to Eq. (8), we must obtain Bayesian estimate for any of the functions. The most important are estimates of quantiles of distribution functions of true and apparent *R*-values on a given future time interval [*0,T*], for instance for α quantiles of apparent values:

$$\hat{\hat{Y}}\left(\alpha|\vec{R}^{(n)},\delta\right) = \int_{\pi} \overline{Y_T}(\alpha\,|\,V,\delta) * f(V\,|\,\overset{\to(n)}{R},\delta)dV \qquad (9)$$

$\widehat{Y_T}(\delta\,|\,\overset{\to(n)}{R},\delta)$ for α quantiles of true values is written analogously to Eq. (9). Using averaging over the density (Eq. 8, 9) we can also estimate variances of Bayesian estimates (Eq. 9, 10). For example:

$$Var\left\{\widehat{\widehat{Y_T}}\left(\alpha|\vec{R}^{(n)},\delta\right)\right\} = \int_{\pi} (\overline{Y_T}(\alpha\,|\,V,\delta) - \widehat{\widehat{Y}}_T(\alpha\,|\,\overset{\to(n)}{R},\delta))^2 * f(V\,|\,\overset{\to(n)}{R},\delta)dV \qquad (10)$$

Firstly we will set $\rho_{\min} = R_\tau - \delta$. As for the values of $\rho_{\max}$, it is introduced by the user of the method and depends on the specifics of the data series (Eq. 1). Boundary values for the slope β are estimated by the formula:

$$\beta_{min} = \left(\beta_0 .(1-\gamma)\right), \qquad \beta_{max} = \beta_0 .(1+\gamma), \qquad 0 < \gamma < 1 \qquad (11)$$

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

$$\sum_{i-1}^{n} \ln\{\frac{\beta e^{-\beta R_i}}{e^{-\beta R_o} - e^{-\beta R_\tau}}\} \to Max; \beta, \beta\varepsilon(0,\beta_s) \qquad (12)$$

Where, β_S is a rather large value.

For setting boundary values for rate or intensity (λ) in Eq. (5), we use the following reasons. 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 $\sqrt{n} \approx \sqrt{\lambda\tau}$. So taking boundaries at $\pm 3\sigma$, we will obtain:

$$\lambda_{min} = \lambda_o\left(1 - \frac{3}{\sqrt{\lambda_o \tau}}\right), \lambda_{max=}\lambda_0(1 + \frac{3}{\sqrt{\lambda_0 \tau}})$$

$$\lambda_0 = \frac{\bar{\lambda}_0}{c_f(\beta_0,\delta)}, \bar{\lambda}_0 = \frac{n}{\tau} \qquad (13)$$

3. Results and Discussions

The earthquake hazard parameters (EHP) for 3 different seismogenic zones estimated with the Bayesian method in Sakarya and surrounding. In accordance with the $M_{\max}$ values determined changed as 6.85, 6.06 and 5.77. While the highest magnitude value is calculated in the Zone 1 related to Arifiye and Karadere segments (North of the Sakarya), the lowest value is calculated in the Zone 3 related to continuating of Geyve Fault (South of the Sakarya) (Table 1). Addition, we estimated for Sakarya and surrounding the a posteriori probability density and the a posteriori probability distribution function. These parameters estimated for both "apparent" and "true" $M_{max}(T)$ values that will observer in a next time interval of 5, 10, 25, 50, 75 and 100 years. For example, the a posteriori probability density and the posteriori probability distribution function of "apparent" and "true" $M_{max}(T)$ estimated for (Zone 1) Arifiye and Karadere segments (North of the Sakarya) in next years (Fig. 3 and 4).

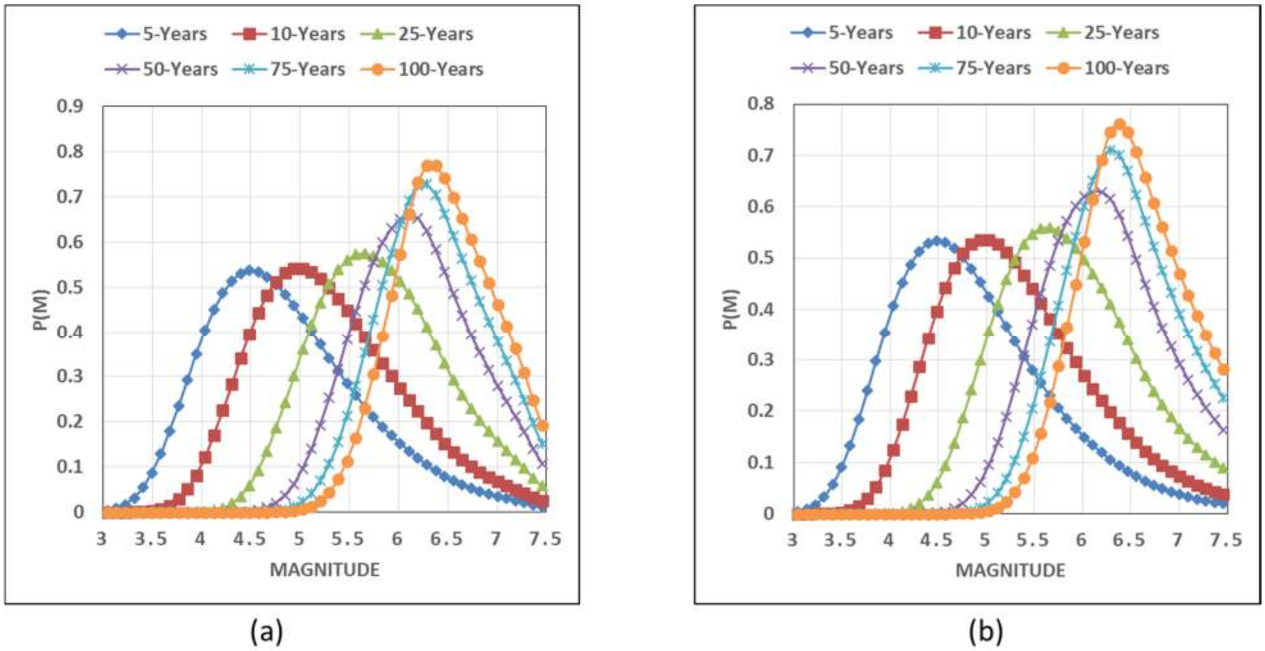
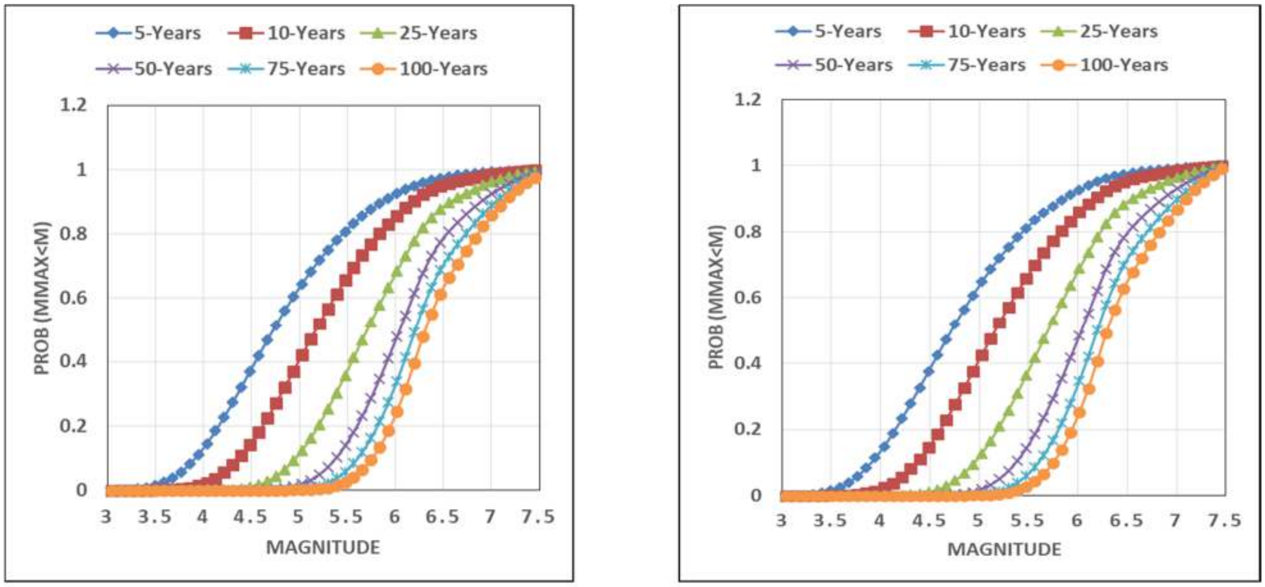


Figure 3. The a posteriori probability density graphs for the apparent (a) and true (b) $M_{max}(T)$ magnitudes estimated for zone 1 in Sakarya.



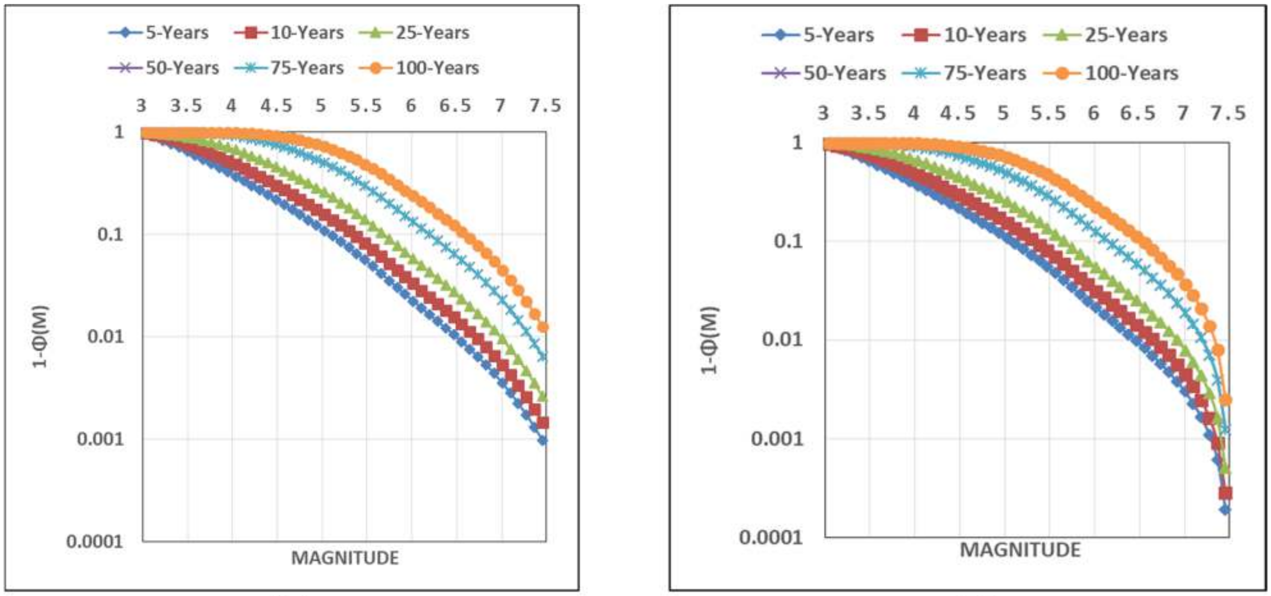
(a) (b)

Figure 4. The a posteriori probability distribution function graphs for the apparent (a) and true (b) $M_{max}(T)$ magnitudes are determined for zone 1 in a next T=5, 10, 25, 50, 75 and 100 years.

Quantiles that estimated the "tail" probabilities $P(Mmax(T)>M)$ for both the apparent and for the true magnitudes (Fig. 5). The quantiles of functions of distributions of the apparent and true magnitudes for next time intervals of 5, 10, 25, 50, 75 and 100 years calculated in all seismogenic source regions for confidence limits of probability levels of 50, 60, 70, 80, 90, 95 and 98 %.

Finally, the α-posteriori *M*-quantiles estimated for the six seismic source zones of " apparent" magnitude and "true" magnitude and for probabilities of 50, 60, 70, 80, 90, 95 and 98 % levels in next periods 5, 10, 25, 50, 75 and 100. The quantiles for both "apparent" and "true" magnitudes $M_{max}(T)$ estimated for 50, 60, 70, 80, 90, 95 and 98 % levels of probability estimated.

According to the computed the EHP, Sakarya and surrounding estimated the highest earthquake magnitude (6,91) in the next 100 years with a 98 % probability level and it was the most dangerous zone compared to other zones. This work will guide scientists in earthquake hazard studies for Sakarya and will be useful for the earthquake hazard of Sakarya and surrounding.



(a)

(b)

Figure 5. The ‘Tail’ probabilities *1-ϕ(M)=Prob(Mmax(T)≥M)* graphs for the apparent (a) and true (b) $M_{max}(T)$ magnitudes are determined for region 1 in a next T=5, 10, 25, 50, 75 and 100 years.

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