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Investigation of the seismicity of East Anatolian fault zone (EAFZ) according to Poisson and Exponential distribution models

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ABSTRACT

Turkey has a high earthquake risk due to include active the North Anatolian Fault Zone (NAFZ) and the East Anatolian Fault Zone (EAFZ). The earthquakes should be detail investigated in order to minimize the damage caused by the earthquakes. Different statistical approaches are used in these estimation studies. The Poisson distribution model is widely used in earthquake studies. The model used for a large number of statistical studies and it gives reliable results. Moreover, exponential distribution model is used in earthquake prediction studies. In this study, EAFZ and its near regions were selected as the study area. The Poisson and Exponential distribution model was applied by using the earthquakes of Ms≥3.0, which occurred in the selected area between 1900 -2016. The probabilities of major earthquakes (Ms≥5.0) and recurrence periods are calculated with the models. According to the results of Poisson model the next 100 year with interval 10 year, the probability of earthquake (Ms≥5.0) is 99,5% in the next 10 years and earthquake recurrence period is estimated as 2 year. Also the probability of earthquake (Ms≥7.0) in same period is 10,7% and recurrence period is 88 year. According to the exponential distribution model results, the recurrence of earthquakes (Ms≥5.2) is 4 year and probability is 28,5%. The two models were compared with same magnitude interval and the results were evaluated. When the seismicity of the region was examined, it was seen that the results were consistent. Active seismicity of the region will continue to be investigated with different statistical studies.

Keywords: Earthquake risk, Poisson model, Exponential distribution model, East Anatolian Fault Zone (EAFZ), Turkey

Doğu Anadolu fay zonu (DAFZ) ve civarının depremselliğinin Poisson ve Üstel dağılım modellerine göre incelenmesi

ÖZET

Türkiye içerdiği aktif Kuzey Anadolu fay zonu (KAFZ) ve Doğu Anadolu fay zonu (DAFZ) nedeniyle yüksek deprem riskine sahiptir. Depremlerin yaratacağı hasarların en aza indirilmesi için depremlerin önceden tahmini üzerine araştırmalar yapılmalıdır. Bu tahmin çalışmalarında farklı istatiksel yaklaşımlar kullanılmaktadır. Deprem çalışmalarında literatürde yaygın olarak Poisson dağılım modeli kullanılmaktadır. Çok sayıda istatistiksel

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çalışmada kullanılan model güvenilir sonuçlar vermektedir. Ayrıca üstel dağılım modelinde deprem tahmin çalışmalarında kullanılmaktadır. Bu çalışmada DAFZ ve civarı inceleme alanı olarak seçilmiştir. Seçilen bölgede 1900- 2016 yılları arasında meydana gelen Ms≥3.0 depremler kullanılarak Poisson ve Üstel dağılım modeli uygulanmıştır. Elde edilen sonuçlarla büyüklüğü Ms≥5.0 olan depremlerin olma olasılıkları ve tekrarlama periyotları hesaplanmıştır. Gelecek 100 yıl için 10 yıl aralıklarla hesaplanan Poisson modeli sonuçlarına göre; 10 yıl içinde büyüklüğü (Ms≥5.0) olan bir depremin olma olasılığı %99,5 ve depremin tekrarlama periyodu 2 yıl olarak hesaplanmıştır. Ayrıca aynı zaman periyodu içinde (Ms≥7.0) bir depremin olma olasılığı %10,8 ve depremin tekrarlama periyodu 88 yıl olarak belirlenmiştir. Üstel dağılım model sonuçlarına göre büyüklüğü (Ms≥5.2) bir depremin tekrarlama periyodu 4 yıl ve olasılığı %28,5 olarak belirlenmiştir. İki model aynı magnitüd aralığında karşılaştırılmış ve sonuçları değerlendirilmiştir. Bölgenin depremselliği incelendiğinde sonuçların tutarlı olduğu görülmüştür. Bölgenin aktif depmremselliği farklı istatistiksel çalışmalarla araştırılmaya devam edecektir.

Anahtar kelimeler*: Deprem riski, Poisson model, Üstel dağılım modeli, Doğu Anadolu fay zonu (DAFZ), Türkiye*

I. INTRODUCTION

Turkey has a high earthquake risk because of the tectonics structure, which involves the active North Anatolian Fault Zone (NAFZ) and East Anatolian Fault Zone (EAFZ). Recent years, intensive seismic activity on EAFZ has necessitated detailed studies in the region. Serious precautions must be taken against earthquakes, especially due to the density of the residential area near Lake Van. Therefore the statistical methods generally use in earthquake prediction studies. The Poisson model is the one of the reliable and useful method in literature. Poisson model represents the probability of earthquake occurrences in a period unbound of the elapsed time since the previous earthquake and the model was applied the different region researches [1, 2, 3]. Also the exponential distribution model is the other models used for earthquake prediction [4]. In addition, Researchers evaluated the model that gives the most appropriate prediction in their earthquake catalogs [5, 6, 7].

The study included two different statistical methods and the correlation of the models results. EAFZ were selected the study region because of the active seismicity. Coordinates of the region are 36.5º – 39.1º N, 35.6º – 43.9º E. The Poisson and Exponential distribution models were applied by using the earthquakes of Ms≥3.0 which occurred in the selected area between 1900 -2016. The probabilities of occurrence and recurrence periods of earthquakes the magnitude of Ms≥ 5.0 are calculated with the obtained model results. The models and results are described in the following sections.

II. THE SEISMOTECTONICS OF STUDY REGION

The world active seismically regions is the Alpine-Himalayan Belt which locate from the Indonesia to Azores. Turkey is a part of this active region, from the Caucasus to the Aegean region, is occurred major earthquakes in regions; the movement of the Hellenic arc is link to the northward movement of the Arabian plate, and the explicated movement of the Anatolian plate to westward direction (McClusky et al. 2000, Taymaz et al. 2004). Anatolia involves several important active fault zone, which are the North

Anatolian Fault Zone (NAFZ), the East Anatolian Fault Zone (EAFZ), The North- East Anatolian Fault Zone (NEAFZ) and the Bitlis Thrust Belt (BTB) shown in Fig.1

Anatolian, African and Arabian plates is generated a triple Karliova junction structure the east part of Anatolia [10, 11]. EAFZ, located between the Gulf of Iskenderun and KJ, is a left lateral, strike-slip fault and constituted by the convergence of the Arabian and Anatolian Plates along the Bitlis Thrust Belt (BTB).

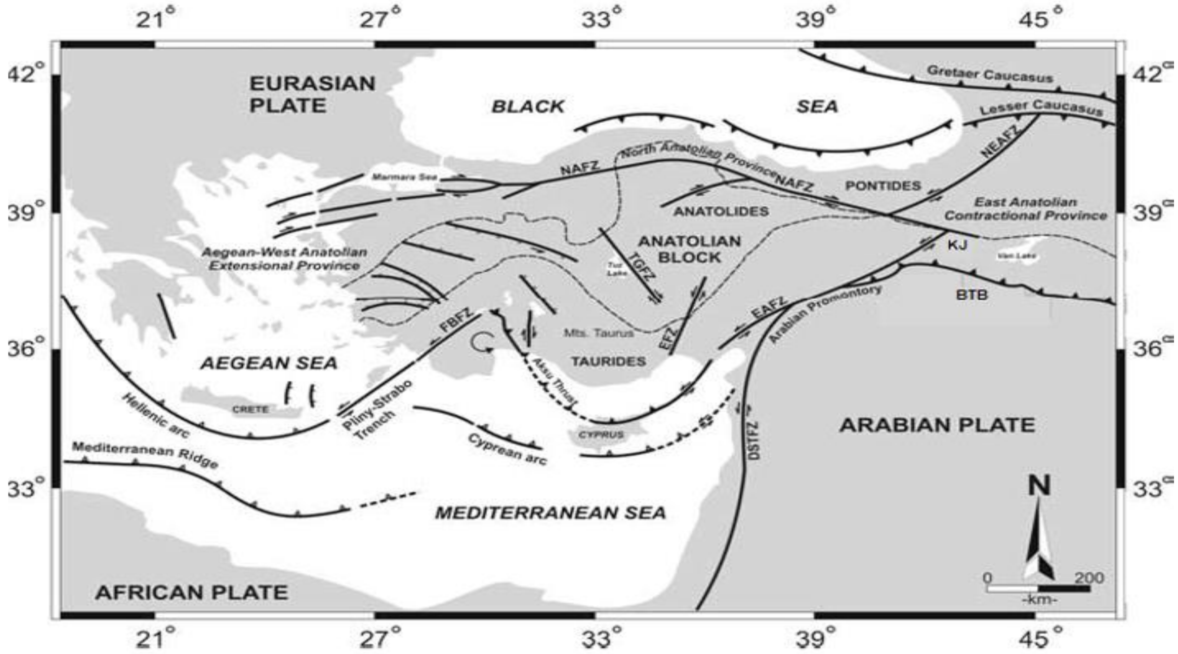
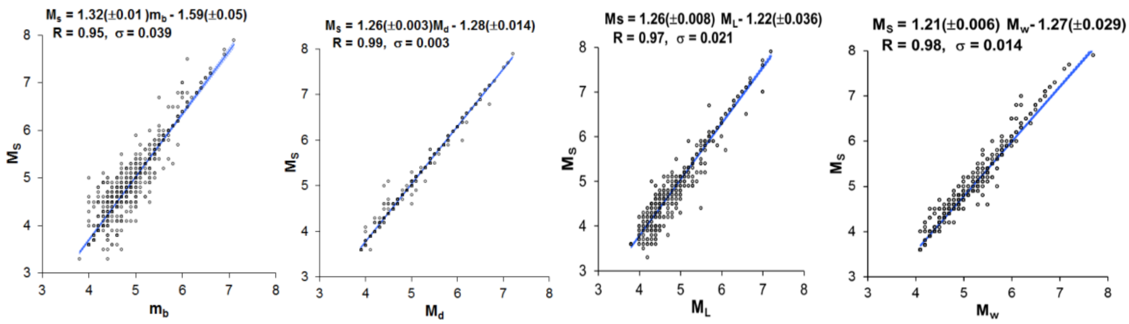


Figure 1. *The tectonics model of Anatolia plate (General directorate of Mineral Research and Exploration)*

III. DATA

The study area was selected between 36.5° – 39.1°N and 35.6°-43.9°E, which include Lake Van and EAFZ. The data was occurred earthquake in the region between 1900- 2016 and magnitude of completeness $M_c \geq 3.0$ (Fig-2.b). The earthquakes was obtained from the catalog of national data center [12].

a)



b)

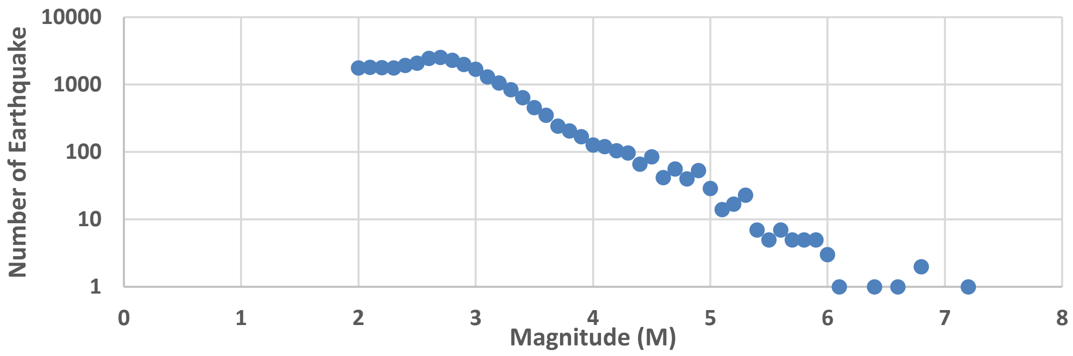


__Figure 2. a)__ The magnitude conversion relations for surface wave magnitude (R; is correlation coefficient σ; standard deviation). ***b)*** *The number of earthquake in the region between 1900- 2016*

The magnitude of earthquakes were converted to surface wave magnitude (Ms) for ensuring homogeneity. The magnitude conversion relations (Ms, mb, ML, Md, Mw) were used, which developed for Turkey show in Fig 2 [13]. Also, the earthquake epicenter distribution was shown in Fig.3.

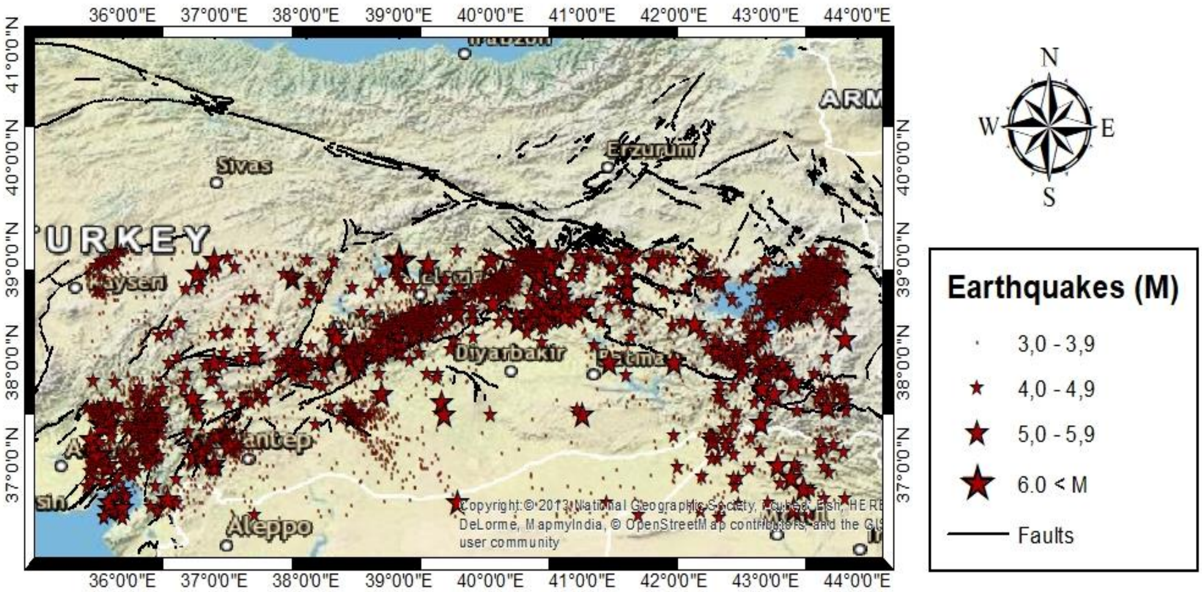


Figure 3. *The epicentral distribution of the earthquakes*

IV. Methods

The Gutenberg-Richter relation is described the number of the earthquakes with related to the magnitude via Eq.1 [14].

$$LogN = a - bM \tag{1}$$

N is cumulative frequency, *M* is the number of earthquakes. The *a*- and *b*-value are real, positive numbers. *a*-value describes the seismic activity. *b*-value is a tectonic parameters. The *a*-value and *b*-

value are generally calculated with the linear least square approaches. The parameters is estimated from Eq. (2),

$$\sum_{i=1}^{n} LogN_i = an - b\sum_{i=1}^{n} M_i$$

$$\sum_{i=1}^{n} M_i.LogN_i = a\sum_{i=1}^{n} M_i - b\sum_{i=1}^{n} M_i^2 \tag{2}$$

The Poisson model generated a random variable that explain the number of occurrences an event in a region within a particular time period. The occurrence probability of earthquake with the certain magnitude in a certain period could be estimated with using *a*- and *b*-values by Eq. (1). Equation (3) is derived from the relation between normal and cumulative frequency. The annual number of n earthquakes ($M \geq M_1$) with magnitude larger or equal M_1 value in a certain time is determined with using Eq. (4):

$$a' = a - Log(bln10) \;\; ; \quad a_1' = a' - LogT_1 \tag{3}$$

$$n(M) = 10^{a_1' - bM} \tag{4}$$

According to the Poisson model R(M), the earthquake occurrences risk in T years with any magnitude M of T_1 year time interval is estimated by Eq. (5) and Q, recurrence period of an earthquake is definite by Eq. (6) [15].

$$R(M) = 1 - e^{-n(M)T} \tag{5}$$

$$Q = \frac{1}{n(M)} \tag{6}$$

X is presumed to be a casual variable having the magnitude of M according to the exponential distribution model. The probability density function of x in the formalize of exponential function is given in Eq. (7) [16].

$$f_M(x) = \lambda e^{-\lambda(x-\theta)} \quad \lambda \rangle 0 \quad \theta \leq x \langle +\infty \;\; (\lambda = (\bar{x} - \theta)^{-1}) \tag{7}$$

here, θ is the smallest magnitude and $\bar{x}$ is the mean magnitude value calculated from occurred earthquake. The distribution function of *x* is estimated with Eq. (8) [17].

$$F_M(x) = \int_0^x \lambda e^{-\lambda(U-\theta)} dU = 1 - e^{-\lambda(x-\theta)} \quad \theta \leq x \langle +\infty \tag{8}$$

V. APPLIED METHODS AND OBTAINED RESULTS

The region earthquake risk were calculated with Poisson and Exponential distribution models from earthquake (Ms≥3.0) in the region between 1900- 2016. The region *a* and *b*-values were calculated from the Gutenberg-Richter relationships according to linear least square method Eq. 1, the used data for Poisson distribution model are shown in Table 1 and graph in Fig.4.

Table 1. *The number of the earthquakes used in Poisson distribution model, which magnitude interval are 0.5*

Magnitude(Ms)	Earthquakes(N)	Cumulative Earthquakes Number (Ni)	LogNi	a	b
3,0-3,4	1691	2855	3,456	6,261	0,836
3,5-3,9	548	1164	3,066		
4,0-4,4	304	616	2,790		
4,5-4,9	191	312	2,494		
5,0-5,4	78	121	2,083		
5.5-5.9	31	43	1,633		
6.0-6.4	8	12	1,079		
6.5-6.9	3	4	0,602		
7.0-7.4	1	1	0,000		

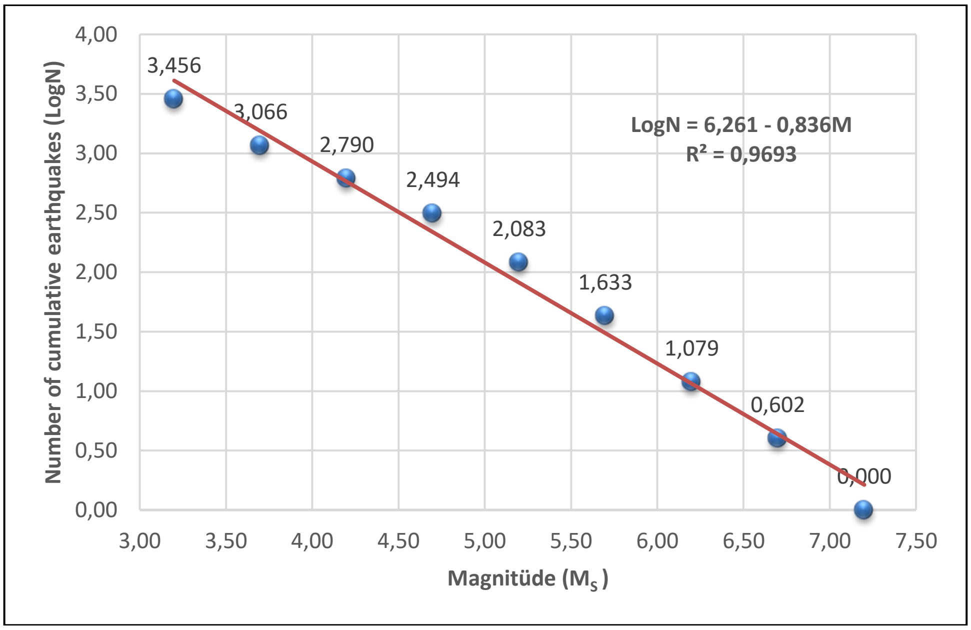


Figure 4. *a and b-parameter according to linear least square method. R is correlation coefficient.*

Earthquake risk and recurrence period values according to the Poisson model were estimated by using a- and b-parameters for the next 100 years with interval 10 year (Table-2).The probability of earthquake (Ms≥5.0) is 99,5 % the next 10 years and earthquake recurrence period is estimated as 2 year. Also the probability of earthquake (Ms≥7.0) the next 100 years is 68 % and recurrence period is 88 year.

Table 2. *Earthquake risk and recurrence periods estimated by using Poisson model for the next 100 years(R*100; Probability, Q Recurrence period)*

T(year)	R(5.0)	R(5.5)	R(6.0)	R(6.5)	R(7.0)	R(7.5)
10	0,995	0,871	0,542	0,258	0,108	0,043
20	1,000	0,983	0,790	0,449	0,204	0,083
30	1,000	0,998	0,904	0,591	0,290	0,122
40	1,000	1,000	0,956	0,697	0,366	0,160
50	1,000	1,000	0,980	0,775	0,434	0,196
60	1,000	1,000	0,991	0,833	0,495	0,230
70	1,000	1,000	0,996	0,876	0,550	0,263
80	1,000	1,000	0,998	0,908	0,598	0,294
90	1,000	1,000	0,999	0,932	0,642	0,324
100	1,000	1,000	1,000	0,949	0,680	0,353
	Q (5.0)	**Q (5.5)**	**Q (6.0)**	**Q (6.5)**	**Q (7.0)**	**Q (7.5)**
Year	2	5	13	34	88	230

Also the earthquake risk was determined according to the exponential distribution model. The results were given in Table 3.The data, which used for the calculation of Exponential distribution model parameter according to Eq.7 and 8, are given in Table 3.

Table 3. *The data used in Exponential distribution model (R; Probability, Q; Recurrence period)*

Magnitude	Number of Earthquakes (fi)	%	Empirical Fmg(x)	fM(x)	Theoretical Fmb(x)	(R*100)	Q (year)
3,2	1691	0,592	0,592	0,395	0,395	11,275	0
3,7	548	0,192	0,784	0,433	0,828	12,358	0
4,2	304	0,106	0,891	0,123	0,951	3,519	0
4,7	191	0,067	0,958	0,035	0,986	1,002	1
5,2	78	0,027	0,985	0,010	0,996	0,285	4
5,7	31	0,011	0,996	0,003	0,999	0,081	12
6,2	8	0,003	0,999	0,001	1,000	0,023	43
6,7	3	0,001	1,000	0,000	1,000	0,007	152
7,2	1	0,000	1,000	0,000	1,000	0,002	533
Sum	**2855**	1,000					

In order to compare the models, the Poisson model was recalculated according to the magnitude intervals in the Exponential distribution model. The results obtained from the models are given in Table 4. Since the Exponential distribution model doesn't give reliable results for minor earthquake, calculations have been made again according to the destructive major earthquakes ($M_s \geq 5.2$) (Table 4).

Table 4. *The Poisson and Exponential Model results. (R; Probability, Q; Recurrence period)*

Magnitude (Ms)	Poisson Model		Exponential Model	
	Probability (R*100)	**Q (year)**	**Probability (R*100)**	**Q(year)**
5,2	0,305	3	0,285	4
5,7	0,130	7	0,081	12
6,2	0,052	19	0,023	43
6,7	0,020	49	0,007	152
7,2	0,008	129	0,002	533

According to models, the probability of the earthquakes with $M \geq 5.2$ gives close results in two models and also give close results for other magnitude values. The maximum difference in probability is found for $M \geq 6.2$. According to the earthquake recurrence periods, the results of the earthquakes with $M \geq 5.7$ and $M \geq 5.2$ are close to each other in two models. The models give different recurrence period for the other magnitude interval (especially for $M_s \geq 7.2$). It is determined that the results of models give consistent with the seismicity of the region (Fig. 5). Detailed investigations should be done for the earthquakes and faults considering the seismic activity of the region. Therefore, the seismicity of the region will be investigated with different statistical studies.

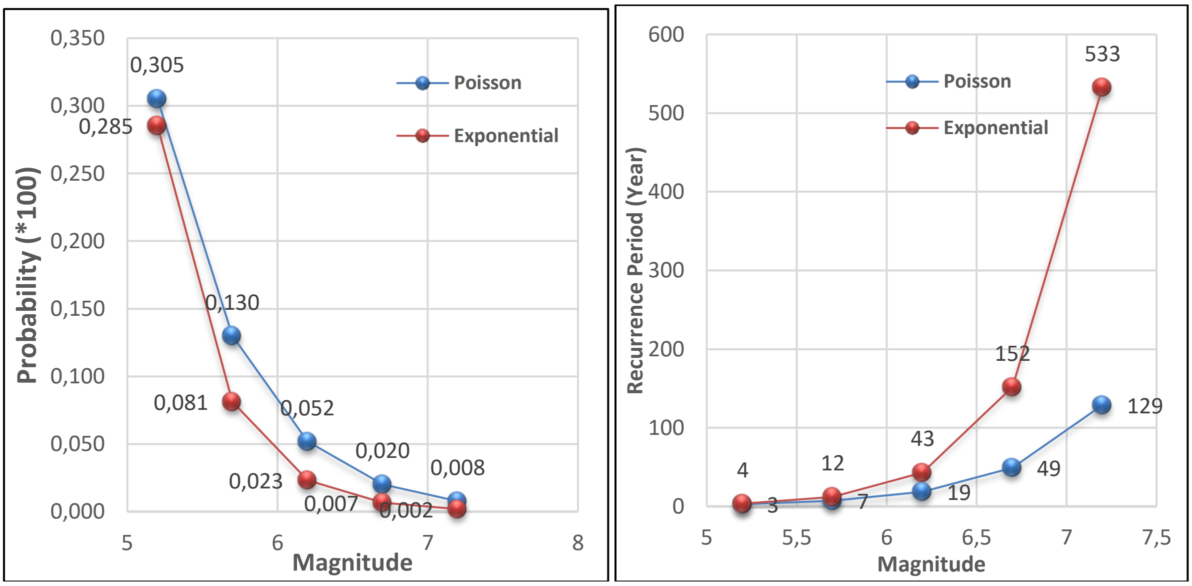


Figure 5. *The comparison results of Poisson and Exponential Distribution Models*

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