PUBLISHED BY THE ACADEMY OF SCIENCES OF ALBANIA

JNTS

JOURNAL OF NATURAL AND TECHNICAL SCIENCES

2018 (2)
XXIII (47)

ACKNOWLEDGEMENT
TO REVIEWERS AND EDITORS

The Editor-in-Chief is very thankful to his Editorial Board team for their continued support and diligent, hard work. But I am especially thankful to our large groups of very faithful and excellent reviewers without whom we wouldn't have a journal of quality. Every paper is reviewed by a minimum of two reviewers and I expect authors of accepted papers to reciprocate by writing really good reviewed version of their manuscripts as well. Reviewing papers is one of the best ways to stay on top of developments in your area of research and it is a necessary component of your career path in Academia. Reviewing is a hard and time demanding process.

Most of the time, for better or worse, we respect the final decisions of the reviewers. In the case of very conflicting reviews, we call for a third reviewer which, of course, prolongs the review process.

Thank you for the time spent and constructive comments on manuscripts to the following reviewers' team:

Abedin Xhomo
Alaudin Kodra
Alda Kika
Alfred Frashëri
Angelo Desantis
Arjan Harxhi
Asti Papa
Blerina Kolgjini
Donika Prifti
Dorian Minarolli
Enea Mustafaraj
Flora Qarri
Frederik Dara
Gafurr Muka
Genc Sulcebe
Gjergji Foto
Ibrahim Milushi
Ilda Kazani
Ilia Mikerezi
Illir Alliu
Indrit Baholli
Indrit Inesi
Irakli Prifti
Isak Shabani
Jul Bushati
Klodian Zaimi
Kostandin Dollani
Luljeta Bozo
Lulzim Hanelli
Matilda Mema
Mentor Lame
Nevton Kodhelaj
Niko Pano
Pëllumb Berberi
Pëllumb Sadushi
Rigena Sema

Rustem Paci
Shaqir Nazo
Shyqyri Aliaj
Spiro Thodhorjani
Steljan Buzo
Theodor Karaj
Vilson Bare
Vilson Silo

With Best Regards from the Editor, the whole Editorial Board and myself,
Yours sincerely,

Salvatore Bushati
Editor-in-Chief

A STATISTICAL ANALYSIS ON THE AFTERSHOCK SEQUENCE FOR JULY 3rd, 2017, BORDER REGION OF MACEDONIA-ALBANIA (M_L=5.0) EARTHQUAKE: AFTERSHOCK PROBABILITY EVALUATION

Rrapo ORMENI

Institute of Geosciences, Energy, Water and Environment, Polytechnic University of Tirana, Albania

Serkan ÖZTÜRK

Gümüşhane University, Department of Geophysics, 29100, Gümüşhane, Turkey

---

ABSTRACT

The aftershock probability method is a powerful way to evaluate the aftershock behaviors in the mainshock-aftershock occurrences and it should be taken into consideration as a significant part of the mainshock-aftershock pattern. There are different physical and statistical processes for the evaluation of aftershock sequences following the mainshock occurrences. In the present paper, the aftershock activity of July 3, 2017 earthquake (M_L5.0) which occurred in the border region of Macedonia-Albania, 14 km of NE of Lin (Albania) and 6 km NW of Jankovec (Macedonia), was statistically analyzed to define the characteristics of aftershock parameters. Aftershock sequence has a time period of 53 days and aftershock catalog is homogenous for local magnitude, M_L. We used 192 aftershocks with local magnitude $M_L \geq 1.9$ for the time interval between July 3, 2017 and August 25, 2017. For the aftershock sequence, magnitude completeness Mc-value was calculated as 2.0 for examples of 10 events/ window by using a moving window approach. Magnitude and time assessments of aftershock distribution show that statistical properties of aftershock sequence may provide some significant scores on the aftershock probability evaluation and earthquake hazard in this part of Macedonia-Albania border region. We used two main aftershock parameters for the probability evaluation and the combination of Gutenberg-Richter and modified Omori laws were utilized. The present paper aims at forecasting the number of strong or large aftershocks that follow the mainshock and calculating the probability of specific magnitude levels of aftershocks. Gutenberg-Richter b-value was calculated as 0.82±0.07 with Mc=2.0 by using maximum likelihood method. The elapse time since mainshock was considered as 0.0201 day, and considering the aftershocks with $M_L \geq Mc=2.0$, temporal decay rate parameters in the modified Omori law were calculated as p=1.22±0.12,

c=0.592±0.285 and K=59.87±19.91 by using the maximum likelihood procedure. The b-value is lower than 1.0 and this small value may indicate a larger stress distribution to build up over time and to be released by future earthquakes. Also, the estimated large p-value shows a fast decay rate of the aftershock activity. Probability for the maximum aftershock magnitude of 4.2 is estimated as 96.94 % and the expected numbers of aftershocks for magnitude size of 3.0 was calculated as about 24. As a remarkable fact, aftershock probability evaluation may support a contribution for disaster prevention measurements in this border region of Macedonia and Albania.
Keywords**:** Macedonia-Albania, aftershock, probability, modified Omori, Gutenberg-Richter

1. INTRODUCTION

The border region of Macedonia and Albania was struck on July 3, 2017 by a moderate earthquake (M_L=5.0), 14 km northeast of Lin (Albania) and 6 km northwest of Jankovec (Macedonia). The epicenter coordinates were given as 41.15°N and 20.96°E, which is being felt in Macedonia and in south and central Albania. Some strong and large earthquakes in and around this part of Macedonia and Albania border region occurred in last century and these earthquakes were resulted in human victims and enormous material loss (Aliaj *et al*, 2010). Earthquakes are the norm in this part of the world as the African Plate moves northward towards Europe by 4-10 mm annually, with regular earthquakes occurring alongside the Eurasia-Africa plate boundary, mainly in Turkey, Greece, Sicily and Italy (Aliaj *et al*, 2001; 2010). An effective evaluation of aftershock hazard would be necessary for the minimization of the human loss, property damage, and social and economic disruption due to earthquakes. Consequently, detailed analyses of aftershock sequences involving a statistical evaluation on the aftershock sequence of July 3, 2017 Macedonia-Albania border region earthquake has been made to provide the necessary results for the next earthquake hazard. The aftershock probability evaluation method is one of the most effective methods to analyze the aftershock sequences. Earthquakes are generally followed by aftershocks and aftershock probability evaluation can be used as a supplementary part of earthquake hazard studies. Many researchers used different statistical and physical models for different aftershock sequences and several important results were obtained (Sulstarova 1983; 1995; Muco 1986; 1993; Guo and Ogata 1997; Wiemer and Katsumata 1999; Ogata 2001; Bayrak and Öztürk 2004; Kociaj 2005; Öztürk *et al*., 2008; Öztürk and Bayrak 2009; Enescu *et al*., 2011; Ormeni *et al.*, 2011; Chan and Wu, 2013; Nemati 2014; Ávila-Barrientos *et al*., 2015; Ormeni *et al*., 2017; Wei-Jin and Jian 2017; Ansari 2017). An evaluation of aftershock probability refers to statistically expressing and appraising the frequency that an aftershock with a specific magnitude will occur. The modified Omori model (Utsu, 1961) forecasts the number of aftershocks that will occur. However, it is necessary to combine this model with the Gutenberg-Richter (Gutenberg-Richter, 1944) formula to provide a probability evaluation of aftershock occurrences. Probability of one or more aftershocks by statistical processing in the mainshock-aftershock pattern can be defined based on the combination of Gutenberg-Richter and modified Omori laws. These types of combined processes for aftershock hazard evaluations estimates not only of the probability of the aftershocks occurrence, but also the number of forecasted aftershocks. After the occurrences of strong or large mainshocks, a number of aftershocks may be triggered in a short period, and additional cumulative damage to structures may be caused by large aftershocks. Strong aftershocks may be dangerous because they are generally not predictable, and they can have a potential to cause extensive structural damage. The structure which is already damaged from the mainshock and is not yet repaired may be collapsed or become completely unusable under mainshock-aftershock seismic pattern. This characteristic is quite significant, and the importance of aftershock sequences cannot be ignored. Therefore, hazard estimation based on the aftershock probability has a great importance and urgency to investigate the influence of as recorded mainshock-aftershock seismic sequences on the dynamic response and accumulated damage of structures (Zhang *et al*., 2013). Consequently, the principally this study aims to provide a probability evaluation on the aftershock occurrence based on the combination of Gutenberg-Richter and modified Omori formulae. We estimated the number of the large aftershocks that might follow the mainshock and achieved an aftershock probability assessment so that a randomly chosen event is larger than or equal to a certain magnitude of aftershock. In this context, we applied an application of aftershock probability evaluation methods to aftershock sequence of July 3, 2017 earthquake (M_L=5.0), which occurred in the border region of Macedonia-Albania.

2. Aftershock data

This study focuses on the aftershock sequence of July 3, 2017 earthquake in the border region of Macedonia-Albania for a detailed evaluation of aftershock probability. The aftershock sequence used in this work were provided by the Albanian, Macedonian and Montenegro seismological stations and by the MEDNET, and AUTH networks. A homogenous and complete data of aftershock catalog was supplied for the mainshock with local magnitude M_L=5.0, occurred at 41.15^{o}N and 20.96^{o}E, and at 11:18:20.1 UTC on July 3, 2017. The aftershock sequence of the mainshock contained about a time period of two months, i.e., from the time of the mainshock (July 3, 2017) until August 25, 2017. The aftershock catalog consists of a total of 192 aftershocks with magnitude $M_L\geq$1.9 in a time interval of 53 days. The epicenter distribution of aftershock data is in the map of the figure 1 illustrated, and the cumulative number of aftershocks in about a time period of two months is in Graph 1 plotted.

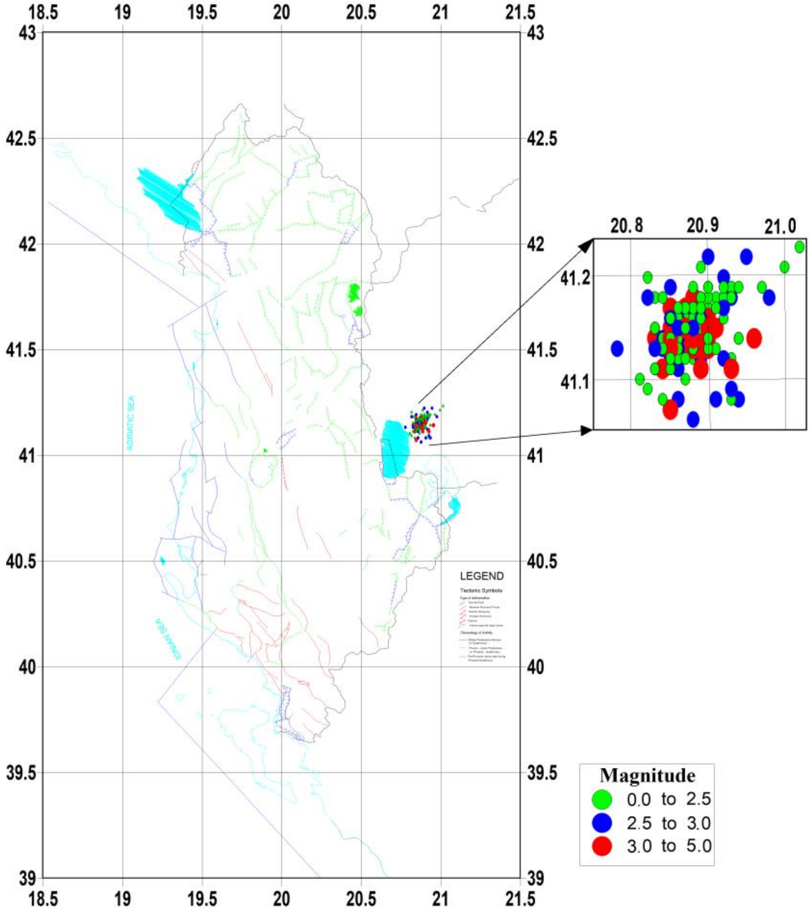
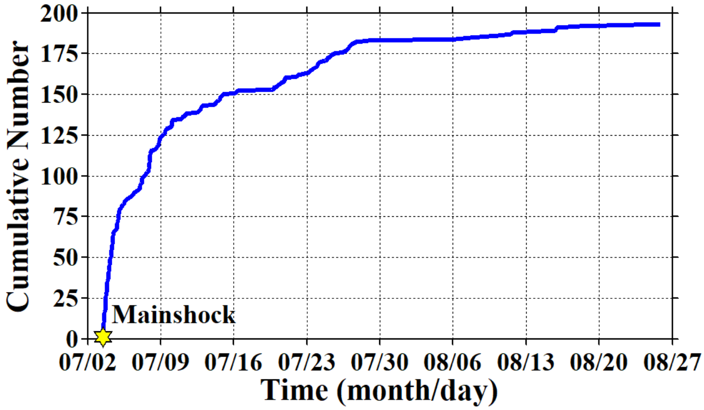


Fig. 1: Seismotectonic map of Albania (Aliaj, 2001), and epicentral distribution of aftershock data of July 3, 2017 earthquake in the border region of Macedonia- Albania. Different color and symbols were used for the data from small to large magnitude levels.



Graph.1: Cumulative number of aftershocks 53 days after the mainshock of July 3, 2017.

3. Brief description of the methods and probability of aftershocks

A number of statistical models have been used to explain the seismic behaviors of earthquakes in space-time-magnitude. There is a significant increase in the modelling of aftershock data in recent years since they occur in a short time period and in a specific region and hence they provide an understanding of source properties of strong or large earthquakes. There are two basic approaches to model the aftershock occurrences: Gutenberg-Richter (G-R) and modified Omori (MO) laws. G-R relation defines the relationship between the frequency of occurrence and magnitude of aftershocks, and MO model defines the occurrence rate of aftershock sequence as a function of time.

The relationship between the magnitude and frequency of occurrence of aftershock sequences can be given as in the following empirical equation:

$$\log_{10} N(M) = a - bM \qquad (1)$$

where $N(M)$ is the cumulative number of aftershocks with magnitudes larger than or equal to M, b-value defines the slope of the frequency-magnitude distribution of aftershocks, and a-value is proportional to the activity level of aftershocks. b-value is one of the most important parameter in earthquake statistics. Utsu (1971) summarized that b-values change roughly in the range 0.3 to 2.0, depending on the different region. Frohlich and Davis (1993) stated that the regional changes of average in an aftershock b-value is accepted as equal to 1.0.

The occurrence rate of aftershock sequence as a function of time can be empirically defined by the modified Omori law (Utsu, 1961) as in the following power law:

$$n(t) = \frac{K}{(t+c)^p} \qquad (2)$$

where *n(t)* is the number of aftershocks per unit time at time *t* after the mainshock. *K*, *c*, and *p*-values are constants. *K*-value depends on the total number of aftershocks in the sequence, *c*-value on the rate of activity in the earliest part of the sequences. There is an opinion that the *c*-value varies from 0.02 to 0.5 and all the reported positive *c*-values result from incompleteness (Hirata, 1969). Of these three parameters, *p*-value is a decay parameter and also the most important one, which varies between 0.6-1.8 (Wiemer and Katsumata, 1999).

It is well known that the number of aftershocks decreases exponentially as the magnitude of aftershocks increases. Expected number of aftershocks $N(T_1, T_2)$ larger than magnitude M during the time from T_1 (beginning time) to T_2 (ending time) is estimated as in the following:

$$N(T_1, T_2) = \int_{T_1}^{T_2} \Lambda(M, s)ds = K \exp\{-\beta(M - M_{th})\} A(T_1, T_2) \qquad (3)$$

where, K is a parameter from MO formula; b is a parameter of G-R formula and M_{th} is the magnitude of the smallest earthquake (Ogata, 1983). $A(T_1, T_2)$ is given as follow:

$$A(T_1, T_2) = \begin{bmatrix} \dfrac{(T_2+c)^{1-p} - (T_1+c)^{1-p}}{1-p} & (p \neq 1) \\ \ln(T_2+c) - \ln(T_1+c) & (p = 1) \end{bmatrix} \qquad (4)$$

Here, c and p-values are constants from MO law. The probability Q for one or more aftershocks with magnitude M or greater occurring since the mainshock, from the time T_1 to T_2 is calculated by Equations 5 and 6 (e.g., Reasenberg and Jones, 1989):

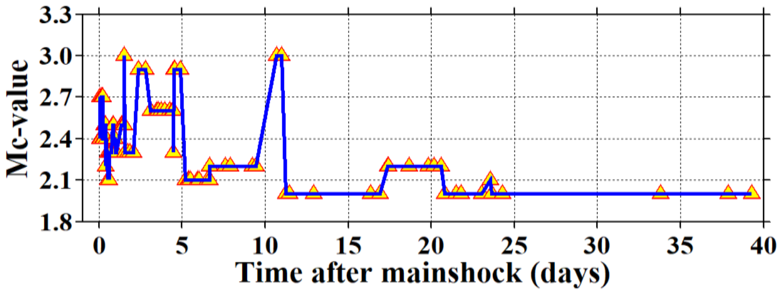
$$Q = 1 - \exp\left\{-\int_{T_1}^{T_2} \Lambda(M, s)ds\right\} = 1 - \exp\{-N(T_1, T_2)\} \qquad (5)$$

$$Q = \begin{cases} 1 - \exp\left[\dfrac{-Ke^{-\beta(M - M_{th})}}{1-p} \left\{ \dfrac{1}{(T_2 + c)^{p-1}} - \dfrac{1}{(T_1 + c)^{p-1}} \right\} \right] & (p \neq 1) \\ 1 - \exp\left[-Ke^{-\beta(M - M_{th})} \left\{ \ln(T_2 + c) - \ln(T_1 + c) \right\} \right] & (p = 1) \end{cases} \qquad (6)$$

In these formulations, p-value describes the extent of time damping; c-value compensates for complex aspects immediately after the main event and K-value is approximately proportional to the total number of aftershocks. The β-value represents the relationship of b and $\beta = b\ln 10$=2.30b in the G-R formula and it is closely related to the number of small aftershocks/that of large aftershocks ratio. Large β-value indicates relatively small number in large earthquakes. M_{th} is the magnitude of the smallest aftershock processed using the MO or the G-R formulas. It is premised that all aftershocks greater than M_{th} are observed without omissions. T_1 and T_2 represent the beginning and the end of the period during the aftershock probability, respectively. This time interval is evaluated, and both represent elapsed time following the mainshock. It must be kept in mind that Equation 6 does not represent the probability of an aftershock that matches conditions occurring exactly once; it represents the probability of it occurring more than one time.

4. Results and discussions on the estimated aftershock parameters

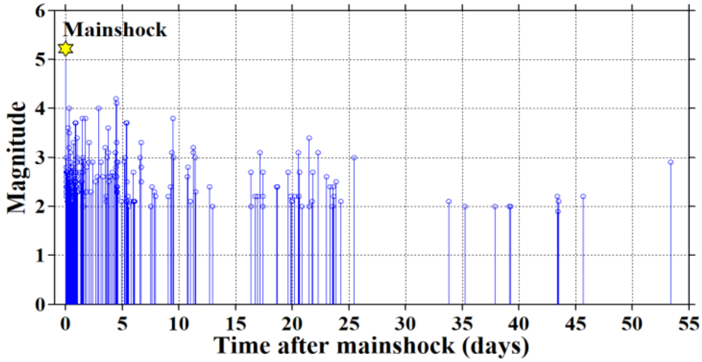
For the high-quality results in the estimation of the aftershock parameters, it is very important to have a completed data set for all magnitude bands. Analysis of completeness magnitude, Mc, is based on the assumption of G-R power-law distribution against magnitude. Completeness magnitude varies systematically in space and time, and particularly the time variations of Mc-value after the mainshock can produce erroneous b and p-value estimations (Wiemer and Katsumata 1999). Mc-value can be larger in the early part of the aftershock sequence since the small shocks fall within the coda of larger events. Thus, small shocks may not be located (Bayrak and Öztürk 2004; Ormeni and Öztürk 2017). The estimation of Mc-value is a very significant stage for all seismicity-based studies since the usage of the maximum number of aftershocks is necessary for reliable results. The changes in Mc-value as a function of time for the aftershock sequence of July 3, 2017 Macedonia-Albania border region earthquake is in Graph 3 plotted. We used a moving time window approach and started at the origin time of the mainshock. Mc-value is estimated for samples of 10 events/window. Mc-value is relatively highest and around 3.0 at the beginning time of the sequences (in the first ten hours). Then, it decreases to about 2.1 between 5 and 10 days after the mainshock. However, it decreases again to about 3.0 within ten days from the mainshock. We can easily see from the Graph 3 that *Mc*-value varies between 1.9 and 2.2 ten days after the mainshock. Therefore, we can say that *Mc*-value generally shows a non-stable value in the aftershock sequence. During the period of 53 days, 192 aftershocks were used for July 3, 2017 earthquake. In order to understand how much the *Mc*-value changes according to the sample size, we tried the different sample sizes such as 35, 45, and 75 events/window. We saw that the selection of the sample size does not change the results. Thus, the fluctuations in completeness seen in Graph 2 does not depend on the small sample size.



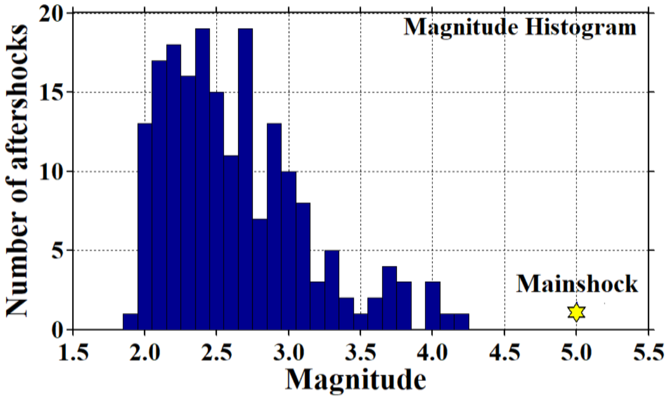
Graph. 2: Completeness magnitude, *Mc*-value, as a function of time for the aftershock sequence of July 3, 2017 Macedonia-Albania border region earthquake. *Mc*-value is estimated for overlapping time windows, including 10 events.

Graph 3 plots the magnitude changes in the time period about two months (53 days) after the mainshock time for July 3, 2017 Macedonia-Albania aftershock sequence. It can be clearly seen from Graph 3 that the greatest aftershock with M_L=4.2 occurred in the five days after the mainshock. However, the occurrences of the aftershocks larger than M_L=3.0 come to an end in 25 days after the mainshock occurrence. There is also a number of aftershocks which magnitudes varies from 3.5 to 4.0 in the first ten days after the mainshock. There is a decreasing trend in the number of aftershocks with magnitude M_L=3.0 after the first 10 days from the mainshock time. Consequently, an average value of magnitude size is densely recorded between 2.0 and 3.0. Graph 4 and 5 show the magnitude histogram and time histogram of the aftershock sequence, respectively. Magnitude level of the aftershock data varies from 1.9 to 4.2, and there is a decrease in the number of aftershocks from the smaller to higher magnitude levels. As seen in Graph 4, the magnitude of the many aftershocks changes between 2.0 to 3.0 and there are some maximums between 2.1 and 2.7. There are 149 aftershocks with

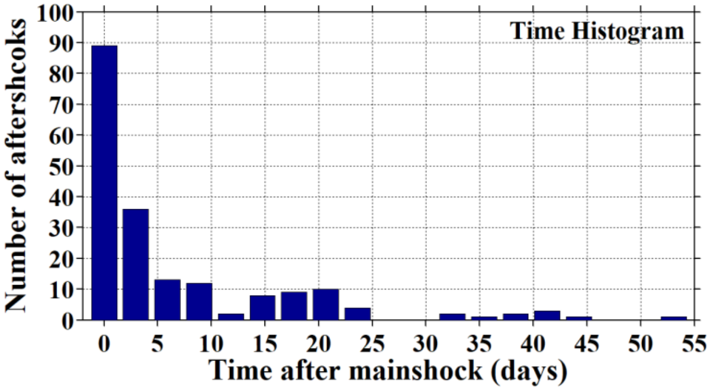
2.0≤M_L<3.0. However, the number of aftershocks with 3.0≤M_L<4.0 is 38, and there are 5 aftershocks with 4.0≤M_L. As a result, the aftershock occurrences with magnitudes 2.0≤M_L<3.0 are more dominant in the aftershock region. Time histogram of aftershock sequence is also given in Graph 5. The aftershock activity is densely distributed in five days and the number of aftershocks in these days is about 140. There is also an increase in the number of aftershocks between the time interval 15 and 25 days. A stableness can be clearly seen after the first month, and the average number of aftershocks after the first month is less than 5. Thus, these types of evaluations can provide a useful perspective for the description of statistical behaviors of aftershocks which is associated with the aftershock probability evaluation and earthquake hazard in this aftershock region of Macedonia-Albania border region.



Graph. 3. Changes in magnitude levels during 53 days after the mainshock time for the aftershock sequence of July 3, 2017 mainshock.

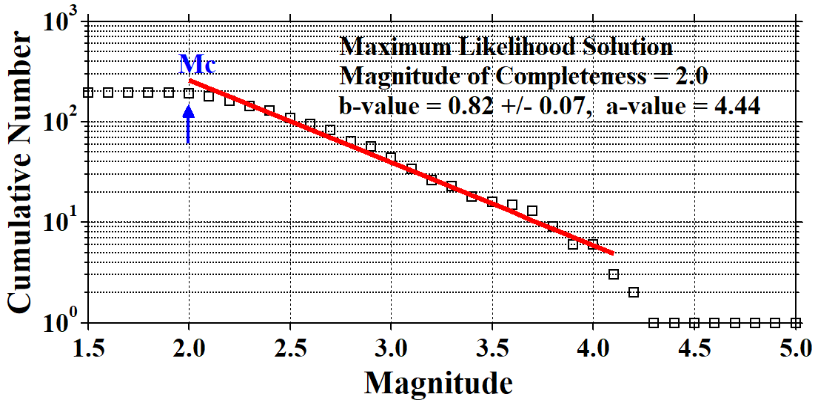


Graph. 4: Magnitude histogram of the aftershock sequence of July 3, 2017 mainshock.

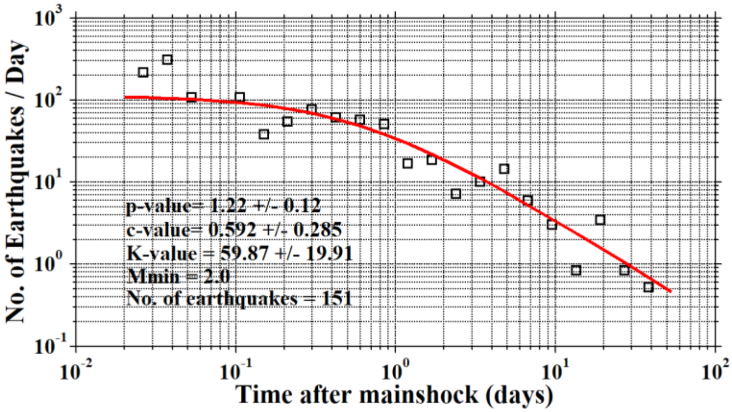


Graph. 5: Time histogram of the aftershock sequence of July 3, 2017 mainshock.

The real implementation of the techniques on aftershock probability evaluation is based on the statistical methods and covers the problem of detecting whether it is possible the exact estimation of the parameters (*K, c, p, b*) for aftershock sequence immediately following a mainshock. If the average values of the aftershock parameters are known, there is a probability that these parameters can be utilized effectively as a preliminary result until the real data is available. For this reason, certain parameters for the aftershock probability evaluation model are compared with the combining of G-R and the MO formulas, and their application range is evaluated. The plot of magnitude-frequency distribution of the aftershocks for July 3, 2017 earthquake is in Graph 6 given. *Mc*-value was calculated as 2.0 for aftershock sequence. The *b*-value and its standard deviation was computed using this *Mc*-value with maximum likelihood method, and *b*-value is estimated as 0.82±0.07. As stated in Frohlich and Davis (1993), this *b*-value is smaller than average value of *b*=1.0 and the smaller *b*-values may be related to the low heterogeneity degree of medium, the higher stress concentration and high strain in this region after the mainshock time. Temporal decay rate of aftershock sequence is in Graph 7 plotted. The *p*, *c* and *K*-values were estimated by using the maximum likelihood method and the occurrence rate was modeled by MO formula. *p*=1.22±0.12, relatively larger, was calculated for aftershock sequence considering minimum magnitude *Mmin*=2.0, T_1=0.0201. The *c*-value was calculated as 0.592±0.285 and *K*-value was calculated as 59.87±19.91. This high *p*-value suggests that aftershock activity after the mainshock shows a fast decay rate as shown also in Graph 1.

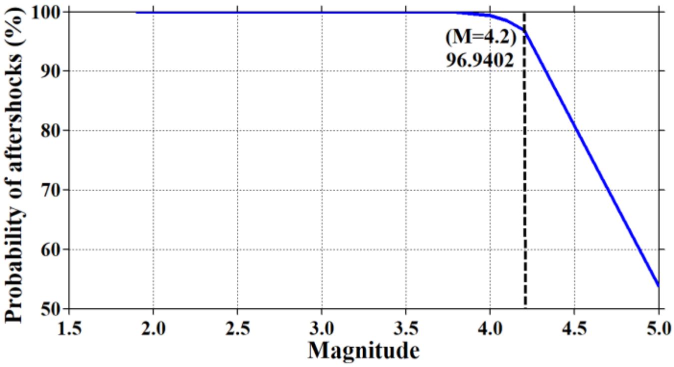


Graph. 6: Gutenberg-Richter relation for aftershocks of July 3, 2017 earthquake. The *b*-value and its standard deviation as well as the *a*-value are given.

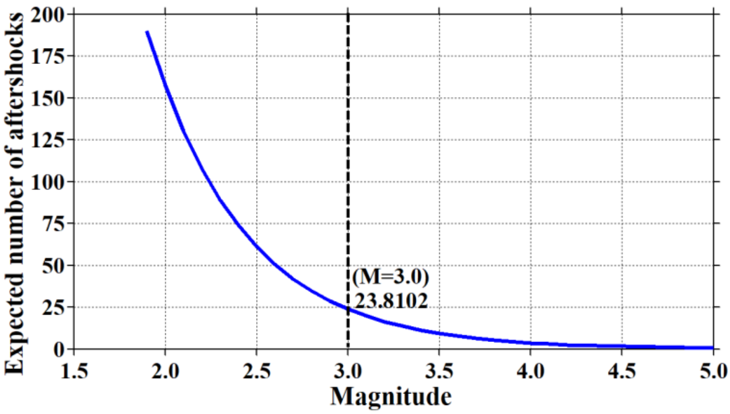


Graph. 7: Aftershock decay rate (per day) in time after mainshock of July 3, 2017 earthquake. *p*, *c* and *K*-values in the modified Omori formula, the minimum magnitude and the number of aftershock used in the estimation are given.

Graph 8 plots the probability of aftershock occurrences against magnitude after the mainshock. Graph 9 plots the expected number of aftershocks versus magnitude after the mainshock. All calculations were considered at the beginning and ending time periods of the aftershock sequence as seen in Equations 4 and 6. The probability of the largest aftershock occurrence for magnitude size of 4.2 was calculated as 96.94 % (Graph 8). The magnitude of randomly chosen aftershock was taken as M_L=3.0 and the estimated number aftershocks for this magnitude level is in Graph 9 plotted. The maximum estimated number of aftershocks for magnitude level of 3.0 was computed approximately 24. For the estimation of *b*-value in G-R relationship maximum likelihood method is preferred because it yields a more robust estimate than least-square regression technique (Aki, 1965). Decay rate parameters in modified OM formula for aftershock data can be estimated correctly by the maximum likelihood method, assuming that aftershock activity follows a non-stationary Poisson process (Ogata, 1983). Some details for the earthquake occurrence of July 3, 2017 are in Table 1 reported. The maximum (Ma_{max}) and minimum (Ma_{min}) magnitudes of aftershock sequence are also given. The number of aftershocks (N), magnitude completeness (Mc), beginning (T_1) and ending (T_2) times for the sequence, b, K, p, and c-values for the aftershock sequence are in Table 2 reported.



Graph. 8. Probability of aftershocks for one or more events. Estimation is carried out by using the beginning and ending times of the aftershock sequence.



Graph. 9. The expected number of aftershocks for one or more events. Estimation is carried out by using the beginning and ending times of the aftershock sequence.

Table 1. Properties of the Macedonia-Albania border region earthquake

Year	Month	Day	Origin Time (GMT/UTC)	Longitude	Latitude	Depth (km)	(M_L)	Ma_{max}	Ma_{min}
2017	07	03	11:18:20.1	20.96	41.15	5.0	5.0	4.2	1.9

Table 2. Aftershock parameters and statistics used in the probability evaluation

Earthquake	N	T_1 (day)	T_2 (day)	Mc	b-value	K-value	c-value	p-value
July 3, 2017	192	0.0201	53.386	2.0	0.82±0.07	59.87±19.91	0.592±0.285	1.22±0.12

5. CONCLUSIONS

The aftershock probability method has been applied for the statistical evaluation of the aftershock sequence of July 3rd, 2017 border region of Macedonia-Albania earthquake. Aftershock dataset was homogenous for local magnitude, M_L, and covered about 53 day-time period. The catalog included 192 aftershocks with magnitude M_L equal to or larger than 1.9. Mc-value is calculated as 2.0 for samples of 10 events/window by using a moving window approach and starting at the origin time of the mainshock. Statistical time-magnitude analyses of the aftershock sequence show that time-magnitude behaviors of aftershock sequence can supply some significant information on the aftershock probability evaluation and aftershock hazard. For this reason, aftershock probability should be accepted as one evaluation method and aftershock hazard must be used as a complementary part of earthquake hazard studies. In this study, a combined model for aftershock probability evaluation based on the combination of Gutenberg-Richter and modified Omori formulas has been used to estimate the number of the large aftershocks following the mainshock and evaluate aftershock possibility that a randomly chosen aftershock is greater than or equal to a certain magnitude of aftershock. b-value for aftershock sequence was calculated as 0.82±0.07 by using the events with Mc=2.0. This small b-value may be resulted from low heterogeneity degree of medium, the higher stress distribution and high strain in this earthquake region after the mainshock time. Aftershock decay parameters were calculated as p=1.22±0.12, c=0.592±0.285 and K=59.87±19.91 by fitting the data $Mc \geq 2.0$. This relatively large p-value shows that aftershock activity from the mainshock time has a fast decay rate. The magnitude of aftershock was randomly chosen, and we selected M_L=3.0 for the estimation of expected number of aftershocks. Also, the largest aftershock M_L=4.2 was used to calculate the probability. Probability for magnitude level of the largest aftershock with M_L=4.2 was estimated as 96.94 % and the expected numbers of aftershocks for magnitude size of 3.0 was computed as 24. Consequently, these types of analyses are necessary for disaster protection studies and a reliable evaluation of earthquake hazard in Macedonia-Albania border region.

REFERENCES

Aki K. 1965. Maximum likelihood estimate of b in the formula $\log N = a - bM$ and its confidence limits. *Bulletin of Earthquake Research Institute., Tokyo University*. **43**; 237-239.

Aliaj Sh, Sulstarova E, Muço B, Koçiu S. 2001. Seismotectonic map of Albania, scale 1:500.000. *Instituti i Sizmologjisë Tiranë.*

Aliaj Sh, Koçiu S, Muço B, Sulstarova E. 2010. Seismicity, seismotectonic and seismic hazard assessment in Albania. *Published by Academy of Science of Albania.*

Ansari S. 2017. Aftershocks properties of the 2013 Shonbe Mw 6.3 earthquake, central Zagros, Iran. *Journal of Asian Earth Sciences.* **147**; 17–27.

Ávila-Barrientos L, Zúñiga FR, Rodríguez-Perez Q, Guzmán-Speziale M. 2015. Variation of b and p values from aftershocks sequences along the Mexican subduction zone and their relation to plate characteristics. *Journal of South American Earth Sciences.* **63**; 162-171.

Bayrak Y, Öztürk S. 2004. Spatial and temporal variations of the aftershock sequences of the 1999 İzmit and Düzce earthquakes. *Earth Planets and Space.* **56**(**10**); 933-944.

Chung-Han C, Yih-Min W. 2013. Maximum magnitudes in aftershock sequences in Taiwan. *Journal of Asian Earth Sciences.* **73**; 409-418.

Enescu B, Enescu D, Ito K. 2011. Values of b and p: Their variations and relation to physical processes for earthquakes in Japan and Romania. *Romanian Journal of Physics*. **56** (**3-4**); 590–608.

Frohlich C, Davis S. 1993. Teleseismic b-values: Or, much ado about 1.0”. *Journal of Geophysical Research*. **98**(**B1**); 631-644.

Guo Z, Ogata Y. 1997. Statistical relations between the parameters of aftershocks in time, space, and magnitude. Journal of Geophysical Research, **102**(**B2**); 2857-2873.

Gutenberg R, Richter CF. 1944. Frequency of earthquakes in California. *Bulletin of Seismological Society of America*, **34**; 185-188.

Hirata T. 1969. Aftershock sequence of the earthquake off Shikotan Island on January 29, 1968. Geophys. *Bulletin-Hokkaido University*. **21**; 33-43.

Koçiu S. 2005, Recent seismic activity in Albania and its features. Martinelli, G and Panahi, B. (eds.). Mud Volcanoes, Geodynamics and Seismicity, NATO Sciece Series, series IV: *Earth and Environmental Sciences, Springer, The Netherlands*, 2005, 123-133.

Muço B. 1986. Tërmetet e serisë së Nikaj-Mërturit dhe karakteristikat e tyre (Nikaj-Merturi earthquake series and their characteristics). v. *Studime Sizmologjike (Journal of Seismological studies)*. 137-155.

Muço B. 1993. On the decay of aftershocks in Albania: *The second Congress of Geophysics of Greece*.

Nemati M. 2014. An appraisal of aftershocks behavior for large earthquakes in Persia. *Journal of Asian Earth Sciences.* **79**; 432–440.

Ogata Y. 1983. Estimation of the parameters in the modified Omori formula for aftershock frequencies by the maximum likelihood procedure. *Journal of Physics of the Earth*., **31**; 115-124.

Ogata Y. 2001. Increased probability of large earthquakes near aftershock regions with relative quiescence. *Journal of Geophysical Research*., **106**; 8729-8744.

Ormeni Rr, Öztürk S. 2017. "Aftershock analysis of October 15, 2016, Greece-Albania border region, Rodotopion-Earthquake based on the Gutenberg-Richter and modifird Omori lows" *International Conference on Applied Sciences and Engineering, FIFM, Polytechnic University of Tirana, Albania,* November 16-17,

Ormeni Rr, Öztürk S, Neritan Sh, Daja Sh. 2011. An application of the aftershock probability evaluation methods for recent Albania earthquakes based on Gutenberg-Richter and modıfied Omori models. *International Balkans Conference on Challenges of Civil Engineering*, BCCCE, 19-21 May 2011, EPOKA University, Tirana, Albania.

Öztürk S, Bayrak Y. 2009. Aftershock probability evaluation for recent Turkey earthquakes based on Gutenberg-Richter and Modified Omori Formulae. *5th Congress of Balkan Geophysical Society*, **6505**; 10-16 May, 2009, Belgrade, Serbia.

Öztürk S, Çınar H, Bayrak Y, Karslı H, Daniel G. 2008. Properties of Aftershock Sequence of the 2003 Bingöl, M_D=6.4, (Turkey) Earthquake. *Pure and Applied Geophysics*, **165**(**2**); 349-371.

Reasenberg PA, Jones LM. 1989. Earthquake hazard after a mainshock in California. *Science*, **243**; 1173-1176.

Sulstarova E. 1995. Some aspects of Albania seismicity: *VI Congress of the Carpatho-Balcan Geological Association*, pp 135-140.

Sulstarova E, Lubonja L. 1983. Karakteristikat e pasgoditjeve te termetit te 5 prillit 1979. Termeti i 15 prillit 1979, *Shtepia Botuese 8 Nentori*, pp. 92-120

Utsu T. 1961. A Statistical study on the occurrence of aftershocks. *The Geophysical Magazine*., **30**; 521-603, Tokyo, Japan.

Utsu T. 1971. Aftershock and earthquake statistic (III): Analyses of the distribution of earthquakes in magnitude, time and space with special consideration to clustering characteristics of earthquake occurrence (1). *Journal of the Faculty of Science., Hokkaido University*, Series VII (Geophys.), **3**; 379-441.

Wei-Jin X, Jian W. 2017. Effect of temporal-spatial clustering of aftershocks on the analysis of probabilistic seismic hazard. Chinese Journal of Geophysics-Chinese Edition, **60** (**8**); 3110-3118.

Wiemer S, Katsumata K. 1999. Spatial variability of seismicity parameters in aftershock zones. *Journal of Geophysical Research.*, **104**(**B6**); 13135–13151.

Zhang S, Wang G, Sa W. 2013. Damage evaluation of concrete gravity dams under mainshock–aftershock seismic sequences. Soil Dynamics and Earthquake Engineering, **50**; 16–27.