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LETTER FROM THE EDITOR-IN-CHIEF

Dear readers,

As the New Year begins, it's heartening to see the numerous issues that we addressed throughout 2018—from mathematics, biology, physics, medicine, earth sciences to environment and nanotechnology. While we strive to become even more attractive to the Albanian scientific enterprise and helpful to the young researchers, very little has been said and done about the underrepresented fields and their subfields like health care policies, environmental policies, civil engineering policies, food security etc.—all affecting our everyday life.

As science and scientific enterprise are dear to anyone of us, revitalizing the Editorial Board seems indispensable. To make a lasting difference in the quality of the Journal, I would encourage each of you to address the less discussed topics in the fundamental fields like mathematics, physics, biology, and chemistry, and their respective subfields.

Expanding our editorial board with eminent personalities both inside and outside the country is crucial.

The members have been selected after a long discussion at the Section's annual report meeting for consultation about future activities and action plans based on their scientific performance both at a national and international level. Other criteria included closer relationships with the state institutions they represent, both inside and outside the country, and their contribution to the selection of the best reviewers of the manuscripts of our journal (JNTS). So, after the long consultation, I would like to introduce all the Members of the Editorial Board team, eminent personalities in the scientific research in various areas like medicine, ecology, environment, genetics, nanotechnology, mathematical engineering etc.

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Sincerely,

Acad. **Salvatore Bushati**
Editor-in-Chief
Chairman, Section of Natural and Technical Sciences,
Albanian Academy of Science

AN APPRAISAL ON THE AFTERSHOCK CHARACTERISTICS OF THE JULY 4, 2018 EARTHQUAKE, M_L=5.1, NEAR DURRËS, ALBANIA

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ABSTRACT

Statistical properties of the aftershock sequence of July 4, 2018 earthquake, M_L=5.1, near Durrës, Albania are here described in time, space and magnitude by means of p-value, Dc-value and b-value, respectively. We used 151 aftershocks with local magnitude $M_L \geq 1.3$ between the time span of July 4, 2018 and September 29, 2018. Aftershock catalog has a time period of about 90 days. A probability model of aftershock sequence based on the combination of Gutenberg-Richter and Modified Omori laws is here described. In addition, fractal analysis was used to investigate spatial properties of the aftershock sequence. Mc-values were taken as 1.8 and b-value was computed as 0.68±0.06 by maximum likelihood method. Temporal decay parameters of sequence were estimated asp=0.94±0.06, c=0.022±0.019, K=15.55±2.09 by considering the aftershocks with $M_L \geq Mc=1.8$ and elapse time since mainshock as 0.0048 day. The smaller than 1.0 b-value might show a higher stress release to be built up over time and be released by next earthquakes. Also, the relatively small p-value might be due to the slow decay rate of the aftershock activity. Dc-value was estimated as 1.86±0.03 and it means that aftershocks show homogeneous distribution. Also, we estimated the number of large aftershocks that might follow the mainshock and we evaluated the probability of specific magnitude of aftershock. Probability for magnitude level of 4.3 was estimated as 67.88 % and the expected numbers of aftershocks for magnitude level of 2.5 was calculated as 19.66. Consequently, we suggested that aftershock hazard evaluation to be developed by considering the space-time-magnitude evaluations of aftershocks in this part of Albania.
Keywords**:** Albania, Gutenberg-Richter, modified Omori, fractal dimension, aftershock hazard

1. INTRODUCTION

A strong, M_L=5.1, earthquake near Durrës, Albania, occurred on July 4, 2018 with epicenter coordinates 41.466^o N and 19.495^o E. The Institute of Geosciences, Energy, Water and Environment (IGEWE) reported that the earthquake occurred at 09:01:07 GMT (11:01:07 a.m. local time) around 18 km underground near the Lalësi Bay, northwest of Durrës and some 30 km west of Tirana. It was followed minutes later by a series of weaker aftershocks, with the strongest measuring magnitude 4.3. In addition, no injuries or damages were reported and there were no initial reports of damage except for small cracks in buildings. High-rise structures were evacuated following the tremor. In recent years, some strong earthquakes occurred in and around Albania,e.g., October 15, 2016 and July 3, 2017 earthquakes. Some strong and large earthquakes in and around Durrësi region occurred historically and in last century and these earthquakes were resulted in human victims and enormous material loss (Aliaj 2012; Aliaj *et al*., 2010; Aliaj and Meço 2018).

The African Plate moves to the northward, towards Europe by 4-10 mm annually and thus, earthquakes occurred in this part of the world which resulted in regular earthquakes alongside the Eurasia-Africa plate boundary, mainly in Turkey, Greece, Sicily and Italy. An accurate and reliable aftershock probability evaluation is of fundamental importance for further studies for the implications on aftershock risk and hazard. Considering human victims, property damage, and social and economic disruption due to earthquakes, analyzing the space-time-magnitude parameters of aftershocks may present a perspective for the seismogenic environment and potential earthquake hazard in the aftershock region.

Almost all major earthquakes are followed by a series of aftershocks and hence, this type of assessment must be used as a complementary part of earthquake hazard studies. Space-time-magnitude analyses of aftershock sequences have been carried out by different authors for different aftershock sequences and, some significant outcomes are obtained (Sulstarova and Lubonja 1983; Sulstarova 1985; Muco 1986; 1993; Guo and Ogata 1997; Wiemer and Katsumata 1999; Aliaj *et al*., 2010; Polat *et al*., 2002; Bayrak and Öztürk, 2004; Kociu, 2005; Öztürk *et al*., 2008; Öztürk and Ormeni, 2009; Ormeni and Öztürk 2017; Öztürk and Bayrak 2009; Aliaj *et al*., 2010; Feng-Chang 2011; Ormeni *et al*., 2011; Zhang *et al*., 2013; Hainzl *et al*., 2016; Liu *et al*., 2017; Öztürk and Şahin 2019). An assessment of aftershock hazard refers to statistically expressing and evaluating the frequency that an aftershock of a certain magnitude will occur. The modified Omori formula (Utsu 1961) forecasts the number of aftershocks that will occur. Also, it is necessary to combine this formula with the Gutenberg-Richter (Gutenberg-

Richter 1944) formula for the probability assessment of aftershock sequences. Also, one of the most effective tools to analyze the space-time-magnitude distribution of the aftershock sequence is to estimate the fractal dimension which may be used as a quantitative measure of the heterogeneity degree of earthquake activity in a region, and it can be controlled by the heterogeneity of the stress field and the pre-existing geological structures (Öncel *et al*., 1996). Probability of one or more aftershocks by statistical processing of the mainshock-aftershock pattern has been defined based on the combination of modified Omori law and Gutenberg-Richter relation. Also, these types of models for aftershock hazard evaluations clarify the number of events forecasted. Thus, the contents of these applications include items for judgments of whether a case is the mainshock-aftershock pattern and a study not only of the probability of the aftershocks' occurrence, but also the number of events estimated.

Aftershocks always followed the occurrence of large shallow earthquakes within a short period. After the main rupture is completed, the mainshock gradually propagates outward into the surrounding small faults (or weak zones) causing the stress change. The interaction of stresses and faults plays an important role in the occurrence of aftershocks (Ansari 2017). Because strong aftershocks are not usually predictable, they may be dangerous, and they can cause an extensive structural damage. The structure already damaged from the mainshock and not yet repaired, which may be incapable of resisting the excitation of the strong aftershocks, may be collapsed or become completely unusable under mainshock-aftershock sequences. Region-time magnitude distributions of aftershocks have significant information about the earthquake nucleation, fault geometry, material properties in the fault zone, as well as the distributions of stress, strength and temperature. Also, strong aftershocks can give an important additional hazard associated with damaging earthquakes (Kisslinger 1996). Therefore, the study of space-time-magnitude distribution of the aftershocks is very significant and interesting for protecting against and mitigating earthquake disasters (Hu *et al.,* 2013).

The present study involved hazard evaluation on the aftershock occurrence based on the combination of Gutenberg-Richter relation and modified Omori law to forecast the number of the large aftershocks that might follow the mainshock and to make an aftershock hazard assessment i.e., a randomly chosen event is larger than or equal to a certain magnitude of aftershock. So, we made an analysis on the aftershock hazard evaluation methods for the aftershock sequence of July4, 2018 strong earthquake (M_L=5.1), in which occurred near Durrës, Albania.

2. Aftershock sequence of July 4, 2018 strong earthquake

In the present study the aftershock sequence of July 4, 2018 strong earthquake near Durrës region, Albania was analyzed to make an appraisal on the characterizing of the seismic cycle and hazard assessment. The data used in this study were compiled from the Albanian seismological stations, Montenegro seismological stations and from INGV, MEDNET, and AUTH networks.

Complete and homogenous catalog of aftershock data were provided for the mainshock with local magnitude M_L=5.1, occurred at 41.466^{o}N and 19.495^{o}E, and at 09:01:07 GMT on July4, 2018. The aftershock catalog includes approximately a period of three months, that is from the time of the main earthquake (July 4, 2018) to September 29, 2018. A total of 151 aftershocks with magnitude M_L larger than and equal to 1.3 were used in a time period of about 90 days. The earthquake of July 4, 2018 and its aftershocks were recorded by permanent broadband seismological stations that are part of the Albanian Seismological Network (bci, puk, dhr, php, vlo, kbn, lsk, bpa1, bpa2 and srn), as well as by the neighbouring seismic networks, namely, AUTH (fna, igt, nest, the, lkd2, mev), MSO (pdg, bey, bry, bdv, hcy, nky, pvy, ulc), INGV (mrvn, noci, scte, sgrt) and MEDNET (tir). The epicentres were located using P and S onsets, a local velocity model (Ormeni, 2011) and the Hypo inverse program (Klein 2002). The smallest magnitude events 1.3 to 3.0 (Richter) are recorded at least by the closest station to the epicenters (dhr, tir, bpa1, bpa2, ulc). Figure 1 depicts the epicenters of aftershocks. Graphic 1 plots the changes in cumulative number of aftershocks in approximately a period of three months.

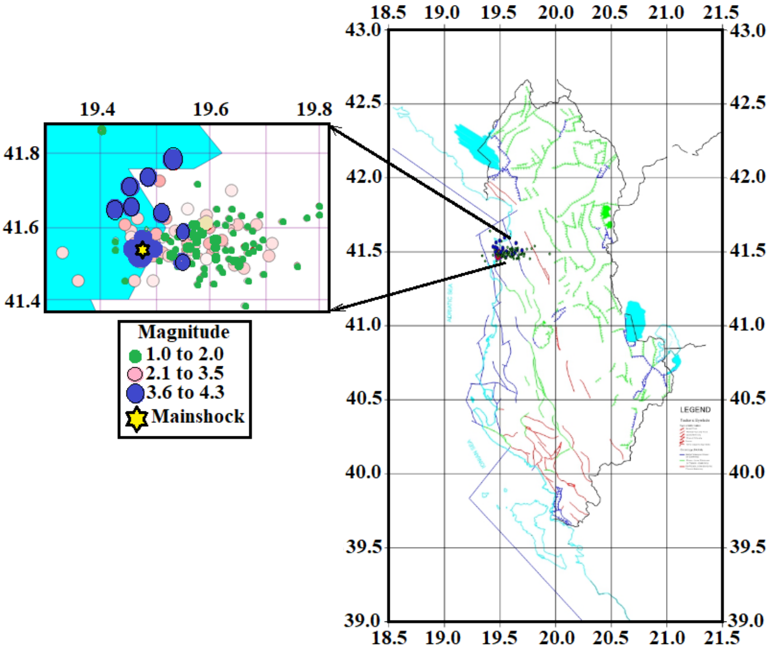
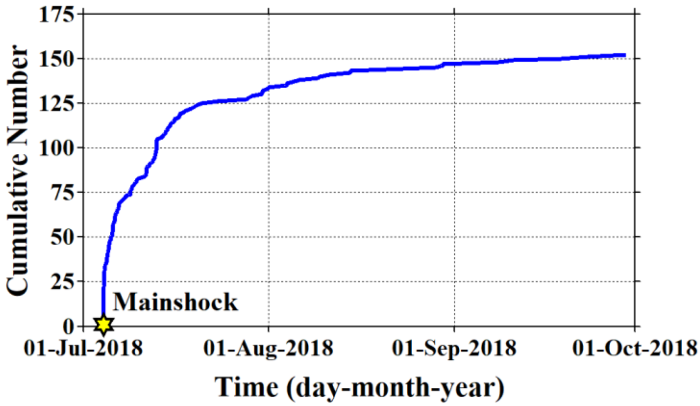


Fig. 3: The tectonic fault map of Albania (Aliaj 2000) and epicentral distribution of aftershock data of July4, 2018 earthquake near Durrës, Albania. Data from small to great magnitude sizes of the aftershocks plotted by different symbols and colors.



Graph. 1: Cumulative number of aftershocks in about 90 days after July 4, 2018 earthquake.

3. Aftershock parameters and aftershock probability evaluation method

Space-time-magnitude distributions of aftershocks provide sufficient information about the Earth's crust, geometry of the fault, stress distribution associated with the earthquake occurrence, physical properties of the materials in the fault zone and source properties of large earthquakes (Öztürk and Şahin 2019). Although there are different techniques to analyze the aftershock activity after the mainshock, aftershock properties can be described in space (fractal dimension, Grassberger and Procaccia 1983), time (modified Omori [MO] law, Utsu 1961) and magnitude (Gutenberg-Richter [G-R] law, Gutenberg and Richter 1944).

The relation between magnitude and frequency of aftershock occurrences was described by Gutenberg and Richter (1944) as following:

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

where N (M) is the cumulative number of aftershocks with magnitudes equal to or larger than M, b-value describes the slope of the magnitude-frequency distribution, and a-value is proportional to the activity rate of aftershocks. The b-value is one of the most significant parameters in seismology and aftershock hazard. It is summarized that b-values change roughly in the range 0.3 to 2.0, depending on region (Utsu 1971). Frohlich and Davis (1993) suggested that the mean b-value in global scale could be given as equal to 1.0.

Temporal distribution of the aftershocks is empirically well described by the modified Omori law (Utsu 1961) as following:

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

where $n(t)$ is the occurrence rate of aftershocks per unit time, t, after the mainshock. K, c, and p-values are empirically derived positive constants. K-value depends on the total number of aftershocks, c-value on the rate of activity in the earliest part of the sequences. The c-value changes between 0.02 and 0.5 and all the reported positive c-values result from incompleteness (Hirata 1969). Among these three parameters, p-value is decay parameter and the most important, which changes between 0.6 and 1.8 (Wiemer and Katsumata 1999).

Fractal dimension of aftershocks distributions can be defined by using two-point correlation dimension, *Dc*, and correlation sum *C*(*r*) given by (Grassberger and Procaccia 1983):

$$Dc = \lim_{r \to 0}\left[\log C(r)/\log r\right] \quad (3)$$

$$C(r) = 2N_{R<r} / N(N-1) \quad (4)$$

where *C*(*r*) is the correlation function, *r* is the distance between two epicenters and *N* is the number of aftershocks pairs separated by a distance *R*<*r*. If the epicenter distribution has a fractal structure, following equation can be given:

$$C(r) \sim r^{Dc} \quad (5)$$

where *Dc* is a fractal dimension, more definitely, the correlation dimension. If the *Dc* value close to 2, the earthquake epicenters are homogeneously distributed over a two-dimensional fault plane. Fractal dimension may be estimated to avoid the possible unbroken fields, and these unbroken regions are suggested as potential seismic gaps to be broken in the future (Öncel *et al*., 1996). Thus, fractal analysis based on the correlation integral can be used to evaluate the regional features of the aftershock sequence.

Quantitatively, when the magnitude of aftershocks increases, their number declines exponentially. The expected number of aftershocks N (T_1, T_2) greater than *M* magnitude during the time from T_1 (beginning time) to T_2 (ending time) is calculated by:

$$N(T_1, T_2) = \int_{T_1}^{T_2} \Lambda(M, s)\,ds = K\,exp\{-\beta(M - M_{th})\} A(T_1, T_2) \quad (6)$$

Here, *K* is a parameter from MO law; *b* is a parameter of G-R relationship and M_{th} is magnitude of the smallest earthquake (Ogata, 1983). *A* (T_1, T_2) can be written as:

$$A(T_1, T_2) = \begin{bmatrix} \dfrac{(T_2 + c)^{1-p} - (T_1 + c)^{1-p}}{1-p} \\ \ln(T_2 + c) - \ln(T_1 + c) \end{bmatrix} \begin{matrix} (p \neq 1) \\ \\ (p = 1) \end{matrix} \quad (7)$$

where c and p-values are constants from MO formula. The probability Q of one or more aftershocks of M magnitude or larger occurring since the mainshock, from the time T_1 to T_2 is found by Equations 8 and 9 (e.g., Reasenberg and Jones 1989):

$$Q = 1 - \exp\left\{ -\int_{T_1}^{T_2} \Lambda(M,s)ds \right\} = 1 - \exp\{-N(T_1,T_2)\} \tag{8}$$

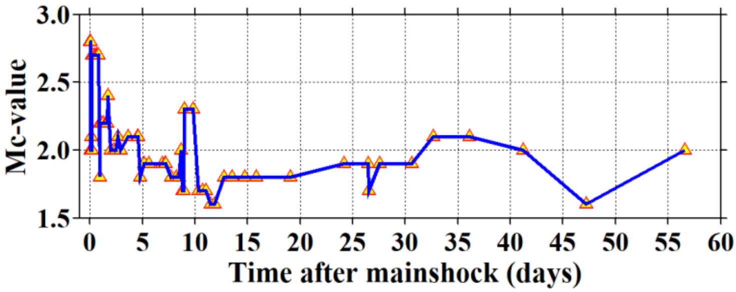
$$Q = \begin{cases} 1 - \exp\left[\dfrac{-Ke^{-\beta(M-M_{th})}}{1-p} \left\{ \dfrac{1}{(T_2+c)^{p-1}} - \dfrac{1}{(T_1+c)^{p-1}} \right\} \right] & (p \neq 1) \\ 1 - \exp\left[-Ke^{-\beta(M-M_{th})} \{\ln(T_2+c) - \ln(T_1+c)\} \right] & (p = 1) \end{cases} \tag{9}$$

In these equations, K-value is approximately proportional to the total number of aftershocks; p-value represents the extent of time damping; c-value compensates for complex aspects immediately after the main shock. The β represents the relationship of b and $\beta = b\,ln10$ =2.30b. β is closely related to the number of small aftershocks/that of large aftershocks ratio and, its great value indicates relatively small number in large aftershocks. M_{th} is the magnitude of the smallest earthquake processed using the MO law or the G-R relation. It is premised that all aftershocks greater than M_{th} are observed without omissions. T_1 to T_2, which represent the beginning and the end of the period during the aftershock probability, is evaluated; both represent elapsed time following the main shock. As a remarkable fact, Equation 9 does not indicate an aftershock possibility that matches the conditions which occurs exactly once; it indicates the possibility of it which occurs more than one time.

4. RESULTS AND DISCUSSIONS FOR AFTERSHOCK PARAMETERS AND HAZARD EVALUATION

Cumulative number of aftershocks in about 90 days after the mainshock is in Graph 1 plotted. If we consider the aftershock activity from the mainshock time to 90 days in which many aftershocks are recorded, Graph 1 could be divided into two sub-regions. The first month could be considered as the first region and the following 50 days as the second region. There were 136 aftershocks in the first month after the mainshock. Fifteen events were recorded in the remaining 50 days. Thus, aftershock activity shows slower decrease in comparison with the activity of the first month.

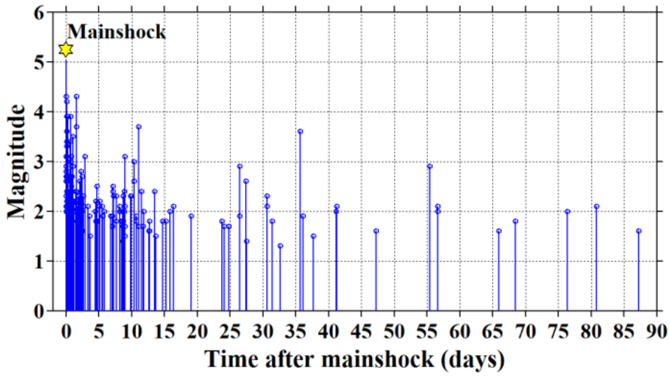
In the analyses related to space-time-magnitude distribution of the aftershocks, especially in the estimation of *b* and *p*-value, the use of complete data set for all magnitude levels is quite important for reliable results in seismicity-based studies. Consequently, using the maximum number of events would be advisable. As one of the most important processes, the minimum magnitude of completeness, *Mc*-value, based on the assumption of G-R power law distribution of magnitudes could be estimated. *Mc*-value can be theoretically described as the smallest magnitude of all the recorded earthquakes. In other words, it can be defined as the minimum magnitude of complete reporting. It means that *Mc* level contains 90% of the events which can be sampled with a power law fit (Wiemer and Wyss 2000). The estimation of *Mc*-value is a very important stage for all seismicity-based studies since the usage of the maximum number of aftershocks is necessary for reliable analyses. The variations in *Mc*-value as a function of time for the aftershock sequence of July 4, 2018 earthquake is in Graph 2 plotted. *Mc*-value is estimated for samples of 10 events/window. *Mc*-value is the largest at the beginning of the sequence (in the first ten hours) and varies from 2.0 to 2.8. Then, it shows a value between 1.8 and 2.2 after two days from the mainshock. *Mc*-value generally changes between 1.7 and 2.1, average *Mc*=1.8, after 10 days from the mainshock. Thus, it can be said that *Mc*-value generally shows a non-stable value in the aftershock sequence and is selected as 1.8 in order to estimate the *b*-value and *p*-value.



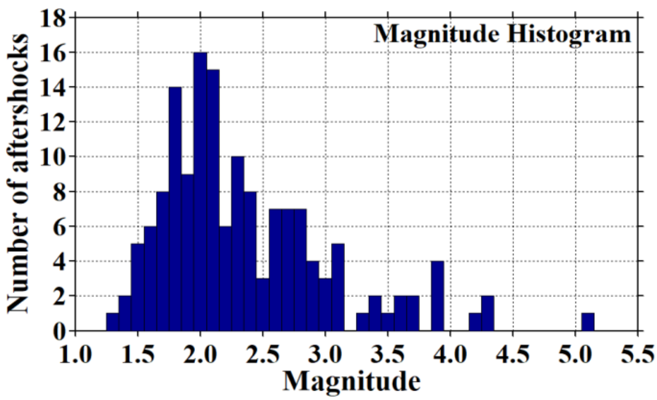
Graph. 2. Temporal variations of magnitude completeness, *Mc*, for the aftershock sequence of July 4, 2018 earthquake. *Mc*-value estimated for overlapping temporal windows, containing 10 earthquakes.

For aftershock sequence, the variations in magnitude levels in the time period about 90 days are in Graph 3 plotted. Clearly, the largest aftershock with M_L=4.3 occurred in the first hour after the mainshock. However, the occurrences of the aftershocks larger than M_L=3.0 come to an end in ten days after the main shock. There are also a few aftershocks whose magnitudes changes between 3.5 and 4.5 in the first four days after the mainshock. There is a decreasing trend in the number of aftershocks with magnitude M_L=3.0 after the first 35 days from the mainshock, and magnitude of aftershocks mostly changes between 1.3 and 2.0. As a result, an average value of magnitude variation is observed between 1.5 and 2.0.

Magnitude and time histograms of the aftershock sequence are plotted in Graph 4 and 5, respectively. Magnitudes of the aftershocks change between 1.3 and 4.3 and shows a decrease in their numbers from the smaller to larger magnitudes. As shown in Graph 4, the size of the many aftershocks varies from 1.5 to 4.0 and a maximum is observed for M_L=2.0. The number of aftershocks with 1.3≤M_L<2.0 are 61. However, there were 79 aftershocks with 2.1≤M_L<3.5, and 11 aftershocks with 3.6≤M_L. Thus, the aftershock occurrences having magnitudes between 1.8 and 2.1 are more dominant in the aftershock region.

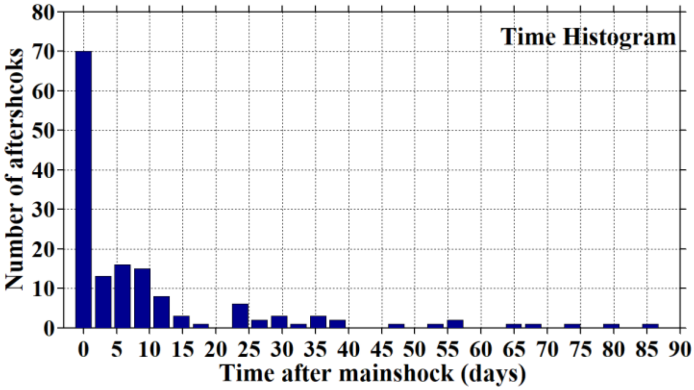


Graph. 3. Magnitude variations as a function of time during 90 days for the aftershock sequence of July 4, 2018 earthquake.



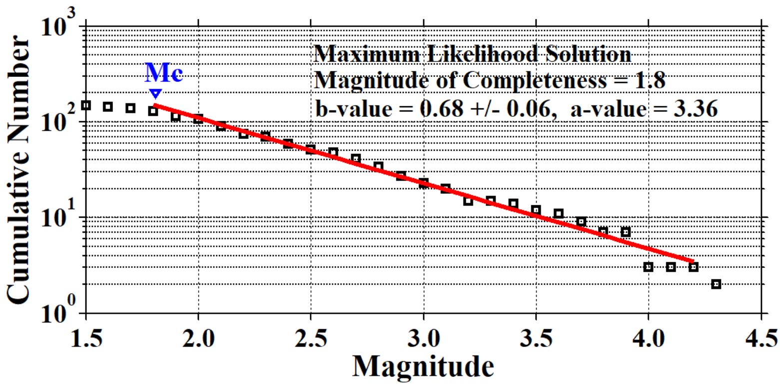
Graph. 4. Magnitude histogram of the aftershock sequence of July 4, 2018 mainshock.

Graph 5 shows the time histogram of aftershocks. There was a large aftershock activity in the first days and the number of aftershocks in the first days was about 70. There was also a decrease in the number of aftershocks after 15 days. A stableness can be clearly seen after the first month and, the average number of aftershocks after the first month was less than 10. Thus, these types of analyses are a means to address the analyses of statistical properties of aftershock sequence which is associated with the aftershock probability evaluation and seismic hazard in this aftershock region of Albania.

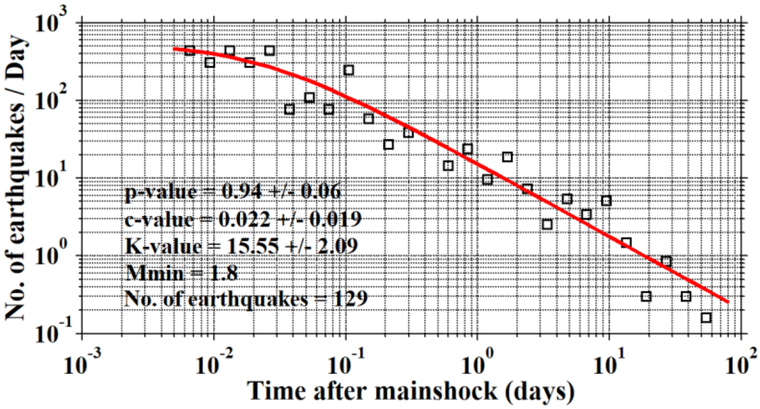


Graph. 5. Time histogram of the aftershock sequence of July 4, 2018 earthquake.

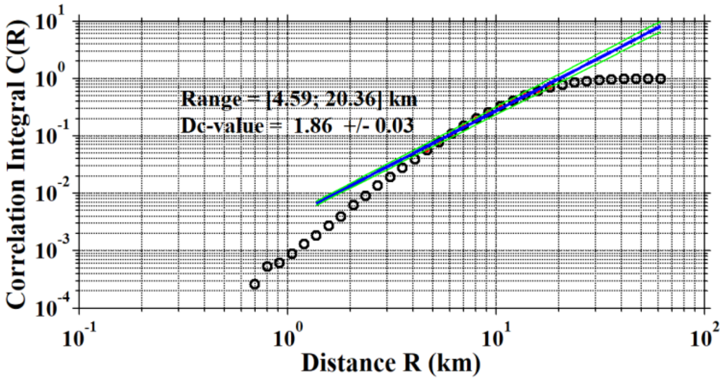
It is well known that application of hazard evaluation methods requires on a statistical base and involves the problem of determining whether it is possible to accurately calculate the parameters such as *K, c, p, b*-values (Ogata 1983). If the average parameters are known for the aftershock activity immediately following the mainshock, there is a possibility that they can be used effectively as preliminary data until the actual data is available. For this reason, specific parameters of the aftershock statistical model including G-R relation, MO law and fractal dimension are compared, and their results are discussed in this study. Cumulative magnitude-frequency of July 4, 2018 aftershock sequence is shown in Graph 6. We used Mc=1.8 considering the temporal variations given in Graph 2. The *b*-value and its standard deviation, as well as the *a*-value of G-R relation, were calculated with the maximum likelihood method. The *b*-value is estimated as 0.68±0.06 and this value is lower than mean value of *b*=1.0. Frohlich and Davis (1993) suggested the smaller *b*-values may be related to the low heterogeneity degree of medium, the higher stress concentration and high strain in the aftershock region in recent years. Graph 7 shows the decay rate of aftershock activity versus time after the mainshock for aftershocks with magnitude *Mc*≥ *Mmin*. In order to estimate the *p*, *c* and *K*-values, the maximum likelihood procedure was used, and the aftershock occurrence was modeled by the modified Omori model. *p*=0.94±0.06, nearly close to the global *p*-value 1, is calculated for the sequence assuming to be *Mmin*=1.8, *Tstart*=0.0048. The *c*-value and *K*-value are 0.022±0.019 and 15.55±2.09, respectively. The small *p*-value for a given aftershock sequence indicates a slow decay of aftershock activity and thus, the occurrence of aftershocks of July 4, 2018 earthquake shows a slow decay rate. Graph 8 plots the fractal dimension of aftershock epicenter distributions for July 4, 2018 earthquake. The *Dc*-value is calculated as 1.86±0.03 for epicenter distribution of 151 aftershocks with 95% confidents interval by the least squares' method. This log-log relation displays a clear linear range and scale invariance in the self-similarity statistics between 4.59 and 20.36 km (indicated in Graph 8 as "Range"). If there is an increasing complexity in the active fault system with higher *Dc*-value and smaller *b*-value, the stress release occurs on fault planes of smaller surface area (Öncel and Wilson, 2002). Also, the larger *Dc*-value is sensitive to heterogeneity in magnitude distribution. The *Dc*-value calculated as 1.86±0.03 in this study suggests that aftershocks are more clustered at larger scales or (in smaller areas) and this large *Dc*-value may be a dominant structural characteristic for aftershock region. Since *Dc*-value is close to 2.0, we can imply that aftershocks of July 4, 2018 earthquake are homogeneously distributed.



Graph. 6: Gutenberg-Richter relation of aftershock sequence. *B*-value, its standard deviation, *Mc*-value, *a*-value in the Gutenberg-Richter relation.



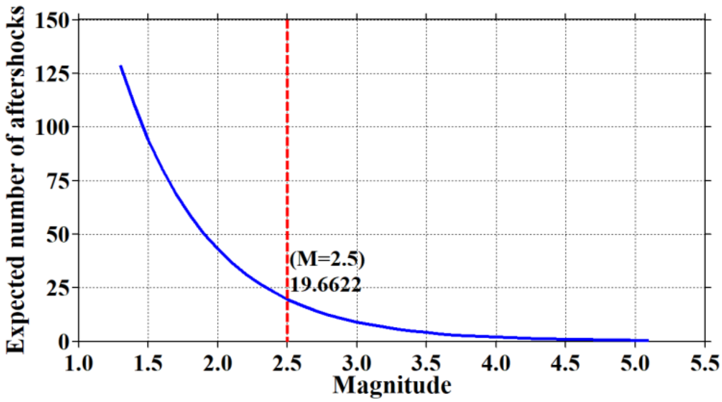
Graph. 7. Modified Omori model and decay parameters aftershock activity of July 4, 2018 earthquake, aftershock parameters such *p, c* and *K*-values in the modified Omori formula, the minimum magnitude, starting time for the data and the number of aftershocks.



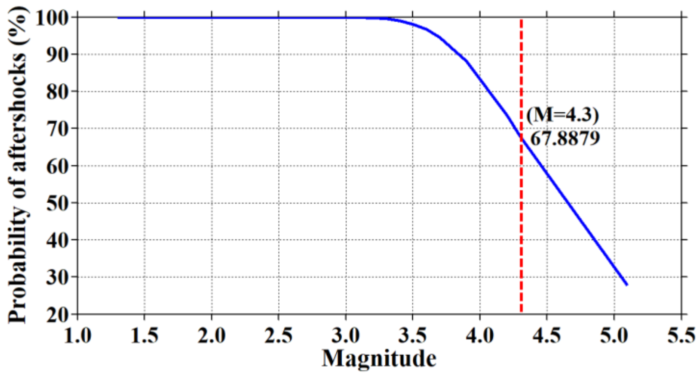
Graph. 8. Fractal dimension of aftershock epicenter distributions for July 4, 2018 earthquake.

The expected number of aftershocks and aftershock occurrence probability versus the magnitude are plotted in Graph 9 and 10, respectively. As seen in the Equation 7 and 9, all aftershock parameters were considered for the estimations, in addition to the starting and ending time intervals of the aftershock sequence. The magnitude of randomly chosen aftershock is considered as M_L=2.5 and expected number of this magnitude band is in Graph 9 plotted. The maximum expected number of aftershocks for M_L=2.5 was computed as 19.66. The probability of aftershock occurrence was calculated for the largest aftershock M_L=4.3 (Graph 10). Probability of the largest aftershock was estimated as 67.88 %. Thus, one can calculate any other probability and numbers for a specific size of aftershocks.

The *b*-value in G-R relationship is estimated by maximum likelihood method, because it yields a more robust estimate than least-square regression method (Aki 1965). The parameters in MO law can be estimated accurately applying the maximum likelihood method, assuming that the seismicity follows a non-stationary Poisson process (Ogata 1983). General information for the earthquake occurrence of July 4, 2018 is in Table 1 provided along with the maximum (Ma_{max}) and minimum (Ma_{min}) magnitudes of aftershock sequence. The number of aftershocks (*N*), completeness magnitude (*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 provided.



Graph. 9: Expected number of aftershocks for one or more events. Estimation made by using all aftershock parameters as well as beginning and ending times of the aftershock sequence.



Graph. 10: Probability of aftershocks for one or more events. Estimation made by using all aftershock parameters as well as the beginning and ending times of the aftershock sequence.

Table 1. Characteristics of the July 4, 2018 near Durrës, Albania earthquake.

Year	Month	Day	Origin Time (GMT)	Longitude	Latitude	Depth (km)	(M_L)	Ma_{max}	Ma_{min}
2018	07	04	09:01:07	19.495	41.466	18.4	5.1	4.3	1.3

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

Earthquake	N	T_1 (day)	T_2 (day)	Mc	b-value	K-value	c-value	p-value
July 4, 2018	151	0.0048	80.8396	1.8	0.68±0.06	15.55±2.09	0.022±0.019	0.94±0.06

5. CONCLUSIONS

A statistical space-time-magnitude analysis for the aftershock sequence of July 4, 2018 M_L=5.1 near Durrës, Albania, earthquake was carried out. Here, the b-value from Gutenberg-Richter law, p-value from the modified Omori law, Dc-value from fractal dimension were estimated along with the expected number of aftershocks and aftershock occurrence probability for specific magnitude levels. Aftershock catalog was homogenous for local magnitude, M_L, and contained about 90 day-time period. The catalog with magnitude $M_L \geq 1.3$ contained 151 aftershocks. By using a moving window approach and starting at the origin time of the mainshock, Mc-value was estimated as 1.8 for samples of 10 events/window. The b-value was computed as 0.68±0.06 with this Mc level. The small b-value might be related to the low heterogeneity degree of medium, the higher stress concentration and high strain in this region in recent years. The decay parameters of aftershock activity were calculated as p=0.94±0.06, c=0.022±0.019 and K=15.55±2.09 by fitting the data $Mc \geq 1.8$. This relatively small p-value shows that aftershock activity after the main shock shows a slow decay rate. From the estimated fractal dimension, Dc=1.86±0.03, it could be concluded that aftershocks of July 4, 2018 earthquake are homogeneously distributed over a two-dimensional fault plane.

A model for aftershock occurrence probability based on the combination of Gutenberg-Richter relation and modified Omori law is used to predict how many large aftershocks may follow main shocks and in order to evaluate aftershock probability that a randomly chosen earthquake is greater than or equal to a certain magnitude of aftershock. As an example, we used M_L=2.5 for the expected number of aftershocks and M_L=4.3 for the probability of the largest aftershock occurrence. Probability for magnitude level of the largest aftershock with M_L=4.3 was estimated as 67.88 % and the expected numbers of aftershocks for magnitude level of 2.5 was computed as 19.66. We suggested that all other possibilities or numbers for a specific magnitude values in the aftershock sequence could be estimated from these applications. Reliable and accurate space-time-magnitude analyses and hazard evaluations of the aftershock sequence are a means to address the future studies on the implications on seismic risk and hazard, and a perspective for the seismogenic environment and the potential aftershock hazard in this aftershock region of Albania.

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