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An Application Of The Aftershock Probability Evaluation Methods For Recent Albania Earthquakes Based On Gutenberg-Richter And Modified Omori Models

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ABSTRACT

In this study, an assessment on the aftershock occurrence probability based on the combination of Gutenberg-Richter and modified Omori formulae is made in order to forecast how many large aftershocks should follow small main shocks and in order to evaluate aftershock probability that a randomly chosen event is greater than or equal to a certain magnitude of aftershock. For this purpose, we made an application of aftershock probability evaluation methods to nine aftershock sequences in which occurred Albania between 2004 and 2009 with magnitude level between 4.5 and 5.0.

1. INTRODUCTION

The aftershock probability evaluation method must be used as a part of earthquake evaluations and it is an effective way to evaluate aftershock activity of the main shock-aftershock pattern. The occurrence of aftershocks has been investigated statistically and physically by many seismologists and some principal results are obtained (Kisslinger and Jones, 1991; Guo and Ogata, 1997; Telesca *et al*., 2001; Öztürk and Bayrak, 2007; Ormeni *et al*., 2009). An aftershock probability evaluation as it is used here refers to statistically expressing and evaluating the frequency and occurrence probability that an aftershock of a certain magnitude will occur. The modified Omori formula (Utsu, 1961) forecasts the number of aftershocks that will occur, but in order to perform a probability evaluation of aftershocks, it is necessary to combine this formula with the Gutenberg-Richter (Gutenberg-Richter, 1944) formula. In this study, a model that clarifies the number of events forecasted and probability of one or more aftershocks by statistical processing of the main shock-aftershock pattern has been defined based on the combination of modified Omori and Gutenberg-Richter models.

2. THE QUALITY OF THE DATA

The data used in this study are taken from the Albanian Seismic Network (ASN), integrated with data from the Montenegro, Thessalonica and Macedonia networks. In order to improve the signal of noise ratio a preliminary spectral analysis was performed and seismograms were filtered in Butterworth filter. *P*, *S*-wave arrivals and

durations from six main earthquakes and their aftershocks which occurred within Albania and surrounding area were accurately re-picked to obtain a high quality data set and were formatted for the Neweve program of Seisan package.
Complete and homogenous catalogs of aftershock sequences are provided for the main shocks with M_D from 4.5 to 5.0, between 2004 and 2009. Aftershocks in this data set have a magnitude ranking between 1.5 and 4.0. This criterion represents most energy released by aftershocks of main earthquakes with M_D between 4.5 and 5.0 in Albania for the analyzed period.

3.METHOD AND RESULTS OF THE PROBABILITY EVALUATION

An evaluation of the aftershock probability for six Albania earthquakes with magnitude level M_D between 4.5 and 5.0 including Leskoviku earthquake of 23 November 2004, Thethi (Tropoja) earthquake of 10 July 2005, Piluri (Vlora) earthquake of 8 August 2006, Bene (Elbasan) earthquake of 16 April 2007, Kuturman (Elbasan) earthquake of 24 October 2008 and Ulqini (Adriatic sea) earthquake of 21 August 2009 is made. Expected number of events $N(T_1,T_2)$ larger than M magnitude of the earthquakes during the time from T_1 to T_2 is calculated by:

$$N(T_1,T_2) = \int_{T_1}^{T_2} \Lambda(M,s)ds = K\,exp\{-\beta(M - M_{th})\}A(T_1,T_2) \qquad (1)$$

Here, K is a parameter from modified Omori (MO) law; b is a parameter of Gutenberg-Richter (GR) formula and M_{th} is magnitude of the smallest earthquake (Ogata, 1983). $A(T_1,T_2)$ is given as:

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

(2)

where c and p are constants from MO formula. The probability Q of one or more aftershocks of M magnitude or greater occurring since the main shock, from the time T_1 to T_2 is found by Equations 3 and 4 (Reasenberg and Jones, 1989):

$$Q = 1 - \exp\left\{-\int_{T_1}^{T_2} \Lambda(M,s)ds\right\} = 1 - \exp\{-N(T_1,T_2)\} \qquad (3)$$

$$Q = \begin{cases} 1 - \exp\left[\dfrac{-Ke^{-\beta(M-M_{th})}}{1-p}\left\{\dfrac{1}{(T_2+c)^{p-1}} - \dfrac{1}{(T_1+c)^{p-1}}\right\}\right] & (p \neq 1) \\ 1 - \exp\left[-Ke^{-\beta(M-M_{th})}\{\ln(T_2+c) - \ln(T_1+c)\}\right] & (p = 1) \end{cases} \qquad (4)$$

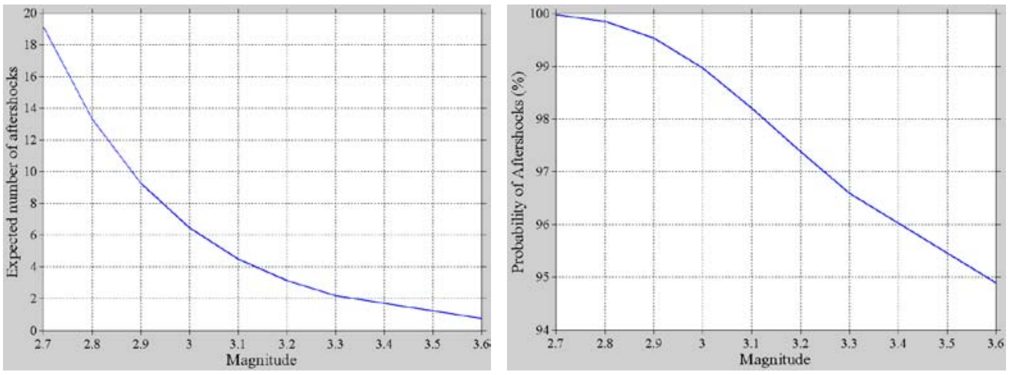
In these equations, K is approximately proportional to the total number of aftershocks; p represents the extent of time damping; c compensates for complex aspects

immediately after the main shock. β represents the relationship of b and $\beta = b\,ln10 = 2.30b$ in the GR formula. b is a value that is closely related to the number of small aftershocks/that of large aftershocks ratio, and its large value indicates relatively small number of deal with in large earthquakes. M_{th} is the magnitude of the smallest earthquake processed using the MO or the GR formulae. It is premised that all aftershocks larger 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. It must be kept in mind that Equation 4 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.
The actual application of the probability evaluation methods based on the statistical models involves the problem of determining whether it is or is not possible to stably find the parameters (*K, c, p, b*) for aftershock activity immediately following a main shock. If the average parameters for the aftershock activity are known, there is a possibility that these can be used effectively as preliminary data until the actual data is available. For this reason, specific parameters for the aftershock statistical model combining the GR and the MO formulae are compared, and their application range is studied. All calculations are considered for the starting and ending time intervals of each aftershock sequence. Also, *b*, *K*, *p*, and *c*-values are very important parameters in the evaluation of aftershock probability and these parameters are given for all aftershock sequences in Table 1.

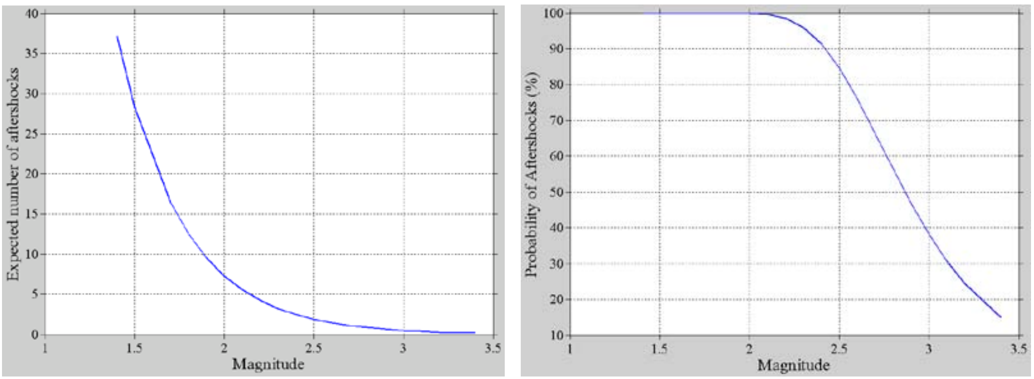
Table 1. Earthquakes and their aftershock statistics used in the probability evaluations

Earthquake	*b*-value	*c*-value	*p*-value	*K*-value
Leskoviku, 2004	1.57±0.10	0	0.72±0.13	1.39±0.62
Thethi, 2005	1.18±0.20	0.002±0.021	1.02±0.1	4.37±0.39
Piluri, 2006	1.55±0.30	0	0.64±0.21	3.71±1.66
Bene, 2007	1.56±0.10	0	0.58±0.24	1.27±0.99
Kuturman, 2008	1.68±0.30	0	0.81±0.27	1.09±0.71
Ulqini, 2009	0.83±0.20	0.394±0.393	1.45±0.38	11.27±8.31

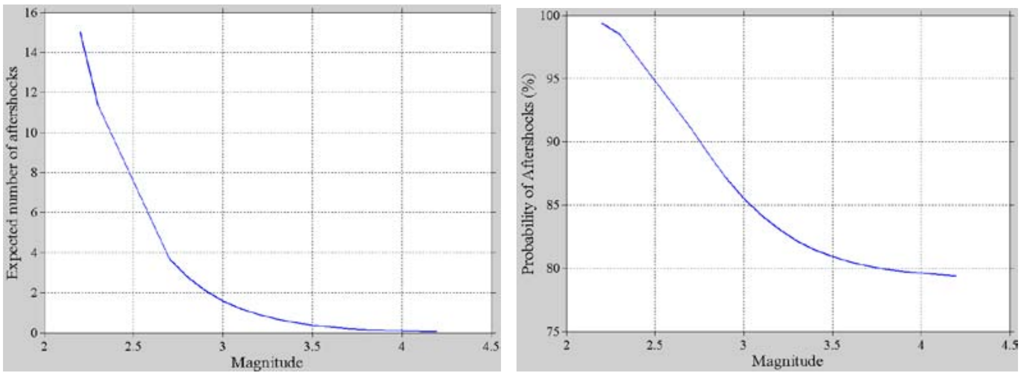
Figure 1 shows the number of aftershocks forecasted and the aftershock occurrence probability versus the magnitude of aftershocks for six aftershock sequences. The largest aftershock occurrence probabilities for magnitude level of 3.5 are calculated as 97.3% for Bene (Elbasan) earthquakes of 16 April 2007, as 95.58% for Leskoviku earthquake of 23 November 2004 and as 94.3% for Ulqini earthquake 21 August 2009. The maximum expected numbers of aftershocks for magnitude level of 2.7 are computed as 19 for Leskoviku earthquake of 23 November 2004 and 13 ($M_{D=}$2.5) for Ulqini earthquakes of 21 August 2009.



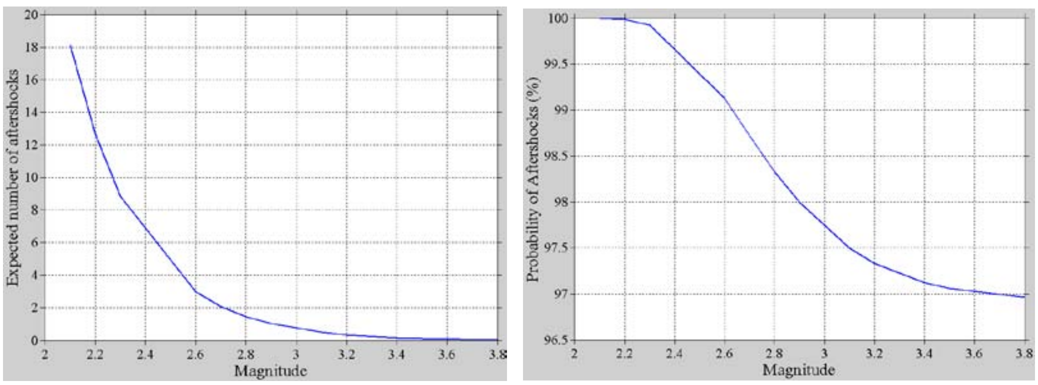
a) Leskoviku earthquake, 23 November 2004.



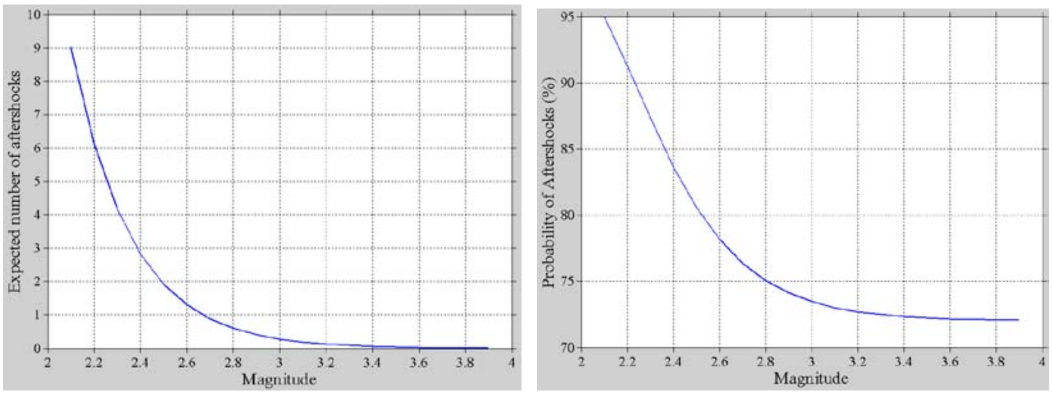
b) Thethi earthquake, 10 July 2005



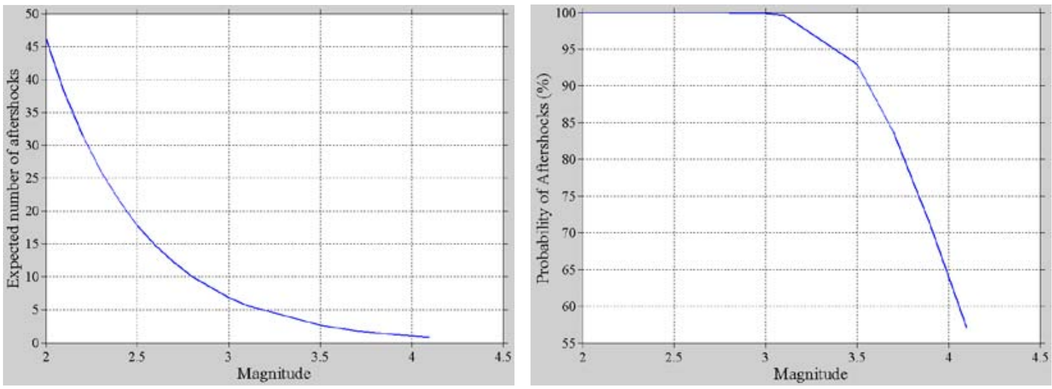
c) Piluri earthquake, 8 August 2006.



d) Elbasan (Bene) earthquake, 16 April 2007.



e) Elbasan (Kuturman) earthquake, 24 October 2008.



f) Ulqini earthquake, 21 August 2009.

Figure 1. The number of aftershocks forecasted and aftershock occurrence probability for six aftershock sequences of recent Albania earthquakes.

3. CONCLUSIONS

Aftershock probability is one evaluation method and it must be used as a part of earthquake evaluations. In this study, an example of statistical analyses of applying the aftershock probability evaluation method to recent six Albania earthquakes between 2004 and 2009 is carried out. The number of events forecasted and the probability of aftershock activity is evaluated by combining the Gutenberg-Richter and the modified Omori models. Thus, such kind of evaluations can make a contribution to the success of disaster protection measures in an earthquake region.
The probabilities of the largest aftershock occurrences for magnitude level of 3.5 are calculated as 97.3% for Bene (Elbasan) earthquakes of 16 April 2007, as 95.58% for Leskoviku earthquake of 23 November 2004 and as 94.3% for Ulqini earthquake 21 August 2009. The maximum expected numbers of aftershocks for magnitude level of 2.7 are computed as 19 for Leskoviku earthquake of 23 November 2004 and 13 (M_D2.5) for Ulqini earthquakes of 21 August 2009.

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