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# A REEXAMINATION OF EARTHQUAKE PREDICTION ALONG THE SOUTHEASTERN PART OF THE HELLENIC ARC.

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**ABSTRACT**

In this study, the probability distribution of earthquake occurrence along the south-southeastern part of the Hellenic arc is computed by means of Bayesian statistics, and by using different sources of seismological data.

The results show that the probability of zero occurrences in this region ranges between 0.7 and 0.05 for earthquakes with M=6.0-6.5, between 0.9-0.4 for M=6.6-7.0, between 0.95-0.67 for M=7.1-7.5 and between 0.97-0.76 for M=7.6-8.0 for the time period 1984-1993. The statistical analysis showed that the obtained distribution is strongly affected upon the input seismological information.

The probability of zero occurrence of earthquakes in the magnitude range 5.5-7.5 in a distance 100 km around the city of Rodos has been also obtained. Statistically, high seismicity is expected after 1989.

**ΣΥΝΟΨΗ**

Στην εργασία αυτή υπολογίζεται η κατανομή της πιθανότητας εμφάνισης σεισμών με διαφορετικά εύρη σεισμικών μεγεθών κατά μήκος του νότιου-ανατολικού τμήματος τόξου. Η κατανομή της πιθανότητας υπολογίστηκε με βάση τη στατιστική Bayes και χρησιμοποιόντας διαφορετικές πηγές σεισμολογικών δεδομένων.

Από την ανάλυση προέκυψε ότι, η πιθανότητα μηδενικής εμφάνισης σεισμών με μεγέθη M=6.0-6.5 κατανέμεται από 0.74 εως 0.05, για M=6.6-7.0 από 0.90 εως 0.40, για M=7.1-7.5 από 0.96-0.70, και για M=7.6-8.0 από 0.97 εως 0.77 για τη χρονική περίοδο 1984-1993.

Επίσης, υπολογίστηκε η πιθανότητα μηδενικής εμφάνισης σεισμών σε απόσταση 100 χλμ γύρω από την πόλη της Ρόδου και για την ίδια χρονική περίοδο 1984-1993. Η παραπάνω πιθανότητα ελαττώνεται σημαντικά μεταξύ 1989 και 1993, ιδιαίτερα για σεισμούς με μεγέθη μεταξύ 5.5 και 6.0. Για μεγαλύτερα σεισμικά μεγέθη η πιθανότητα μεταβάλλεται από 45% εως 75%.

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ΔΡΑΚΟΠΟΥΛΟΣ Ι., Γ. ΣΤΑΥΡΑΚΑΚΗΣ, Ι. ΛΑΤΟΥΣΑΚΗΣ, Γ.ΔΡΑΚΑΤΟΣ Δ. ΠΑΠΑΝΑΣΤΑΣΙΟΥ - Επανεξέταση της πρόγνωσης των σεισμών κατά μήκος του νότιου-ανατολικού τμήματος του Ελληνικού τόξου.

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# 1. INTRODUCTION

For long-term earthquake prediction and hazard assessment, the well known Hellenic arc has provided a test area in Europe because of its high seismicity. Although the seismotectonic regime along the Hellenic arc seems to be very complex, interesting results have been revealed through numerous studies (PAPAZACHOS and COMNINAKIS, 1971;; MCKENZIE, 1978; Le PICHON et al., 1979; Le PICHON and ANGELIER, 1979).

Different methodologies have also been applied in order to assess the expected time, magnitude and propable location of future strong earthquakes.

WYSS and BAER (1981,a,b) suggest that high seismicity is expected along the Hellenic plate boundary near 22.5° to 23.5°E and 26.5° to 27.5°E between 1980 and 1990. Their expectation is based on seismicity studies along the Hellenic arc.

AMBRASEYS (1981) examined the data available for the Eastern Mediterranean and suggests that the large magnitudes assigned to historical earthquakes in the Hellenic arc are mainly due to the indiscriminate use of different scales and also of second-hand or unreliable macroseismic information. The same author also suggests that the available data is insufficient to support predictions with an acceptable degree of certainty.

PAPAZACHOS and COMNINAKIS (1982) divided the Hellenic arc, on the basis of different seismotectonic characteristics, into two discrete zones. The western zone includes Ionian Islands, South Peloponnesus and west of Crete, where as the south-southeastern zone includes Crete-Karpathos-Rodos. One of the most striking difference of these zones is the state of the stress. The western part is characterized by thrust faulting, the southern part by normal, and the eastern part by strike-slip faulting (PAPAZACHOS and COMNINAKIS, 1982; DRAKOPOULOS and DELIBASIS, 1983; PAPAZACHOS et al., 1986).

FERRAES (1985) used the Bayesian probability theory to obtain a Bayesian discrete distribution in order to predict inter-arrival times for strong earthquakes along the two different parts of the Hellenic arc. He concluded, that in the western zone strong earthquakes are expected after 1992, whereas the probability of occurrence of earthquakes in magnitude range 6.5 - 7.50 are very low in the south-southeastern part of the Hellenic arc. The conclusion, however, is based only on data given in Ambraseys' and in Abe's catalogs (ABE, 1981; AMBRASEYS, 1981).

ZHANG (1986) examined the validity of Ferraes' conclusions and showed that the probability of earthquakes occurring in 15 years, starting from 1976 (when the last large earthquake occurred in the western zone) is of about 83%. Thus, Zhang's results support the suggestion made by Wyss and Baer (1981), that strong earthquakes are expected to occur before 1991.

On October 5, 1987, an unusual seismic activity started in the southeastern part of Hellenic arc. More than 500 shocks of magnitude greater than 1.0 occurred until October 25 .A conclusion whether this seismic activity was a precursory phenomenon for an impending earthquake is still open. This gave us the opportunity to reevaluate the seismic hazard in the south-southeastern part of the Hellenic arc in the framework of the Bayesian statistics and by using different sources of seismological data.

## 2. BAYESIAN PROBABILITIES

In the following, the basic concepts of the Bayesian statistics are used to obtain the probability distribution of earthquake occurrence as given by STAVRAKAKIS and TSELENTIS (1987).

### Earthquake Occurrence

It is assumed that seismic occurrences in a region are Poisson-distributed, with a mean rate $\lambda$ which is treated as random variable. The observed data indicate that in $T_o$ past years occurred $N_o$ earthquakes of magnitude greater than a predetermined level. Then, the corresponding likelihood function $L(\lambda)$ is given by

$$L(\lambda)=P(M_o \text{ events in } T_o \text{ years}/\lambda)$$
$$=(\lambda T_o)e^{-\lambda T}/N_o! \quad \lambda>0 \qquad (1)$$

In the case that, there is any prior information on $\lambda$, it may be assumed prior distribution $f'(\lambda)$ on $\lambda$.
Since $f'(\lambda)$ is independent of $\lambda$, the posterior distribution $f''(\lambda)$ is given by

$$f''(\lambda)=kL(\lambda)$$
$$=k\ (\lambda T_o)^{N_o}e^{-\lambda T_o}/N_o \ .. \quad \lambda>0 \qquad (2)$$

where k is a constant to be determined. After normalization the constant k is obtained to be equal to $T_o$. The probability $P(E)$ of occurring N earthquakes in the T future years is

$$P(E)=\int_0^\infty P(E/\lambda)f''(\lambda)d\lambda$$
$$=\ (\lambda t)^N e^{-\lambda T}T_o(\lambda T_o)e^{-\lambda T_o}d\lambda/N!N_o!$$
$$=[\ (T+T_o)\lambda(T+T_o)^{N+N_o}e^{-\lambda(T+T_o)}d\lambda/(N+N_o)!].$$
$$.(N+N_o)T^N T_o^{(N_o+1)}/N!N_o!(T+T_o)^{N+N_o+1} \qquad (3)$$

The integral in parenthensis equals 1 since the integrated quantity is the density function of the Gamma function. Thus, according to BENJAMIN (1968), the probability $P(E)$ is

$$P(E)=(N+N_o)!T^N T_o^{(N_o+1)}.1/N!N_o!.1/(T+T_o)^{N+N_o+1} \qquad (4)$$

Finally, the probability of no occurrences (N=0)) in the next T years will be given by

$$P(E)=1/(1+T/T_o)^{N_o+1} \qquad (5)$$

This equation will be used to calculate the probability distribution of no earthquake occurrences in the south-southeastern part of the Hellenic arc.

## 3. STATISTICAL ANALYSIS AND RESULTS

Figure 1 shows the region which has been selected along the Hellenic arc in order to compute the probability distribution of zero occurrences for earthquakes of magnitude greater than or equal to 6.0

According to MAKROPOULOS et al., (1986), 30 seismic events of magnitude greater than or equal to 6.0 occurred in this region during the time period 1912 - 1983. The last strong event occurred on January 3, 1986.

By applying eq. (5), the probability distribution of zero accurrences, for the next T years and for different magnitude ranges is obtained. Figure 2 shows the obtained results. In the same region, according to COMNINAKIS and PAPAZACHOS (1986) 38 earthquakes of the same magnitude range have occurred. Following the same procedure, the probability distribution function of zero occurrences is obtained. Figure 3 illustrates the obtained results.

Comparing figures 2 and 3, it is evident that the obtained probability distribution depends upon the input data and cannot be uniquely determined.

It should be emphasized, however, that in both cases the tendency of the distribution of zero earthquake occurrence is almost identical. High probabilities of earthquake occurrence are obtained after 1988 for events of magnitude range 6.0 -6.5 and after 1990 for earthquakes of magnitude greater than 6.6.

The same analysis has been performed for the city of Rodos. The earthquakes of magnitude greater than or equal to 5.5 have been selected in a distance of 100 km around of the city. The probability of zero earthquake occurrence has been computed by using eq. (5). Figures 4 and 5 show the obtained distribution corresponding to the two different earthquake data. In both cases, the probability of earthquake occurrence of magnitude range 5.5 - 6.0 is very high after 1988 whereas for higher magnitudes the probability becomes lower.

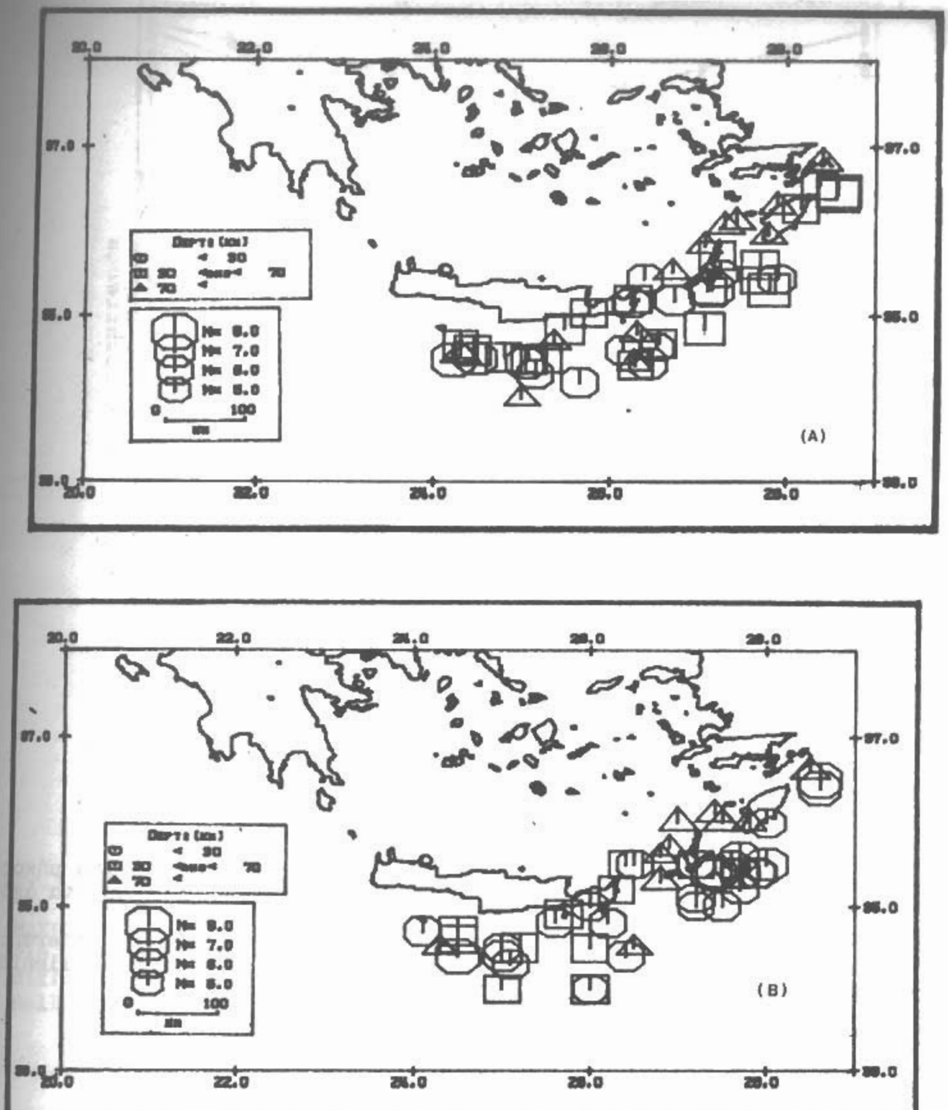
## 4. DISCUSSION AND CONCLUSIONS

The main purpose of this study is to obtain the probability distribution of zero earthquake occurrences of a predetermined magnitude level along the south-southeastern part of the Hellenic arc, within the Bayesian framework.

Assuming that the earthquake occurrence is a Poisson process, the crucial problem is to determine the mean rate of the distribution. In most cases, this parameter is considered to be deterministic and is obtained from historical frequency data. There is, however, statistical uncertainty in the estimation of this parameter, and hence, it should be treated as random variable.

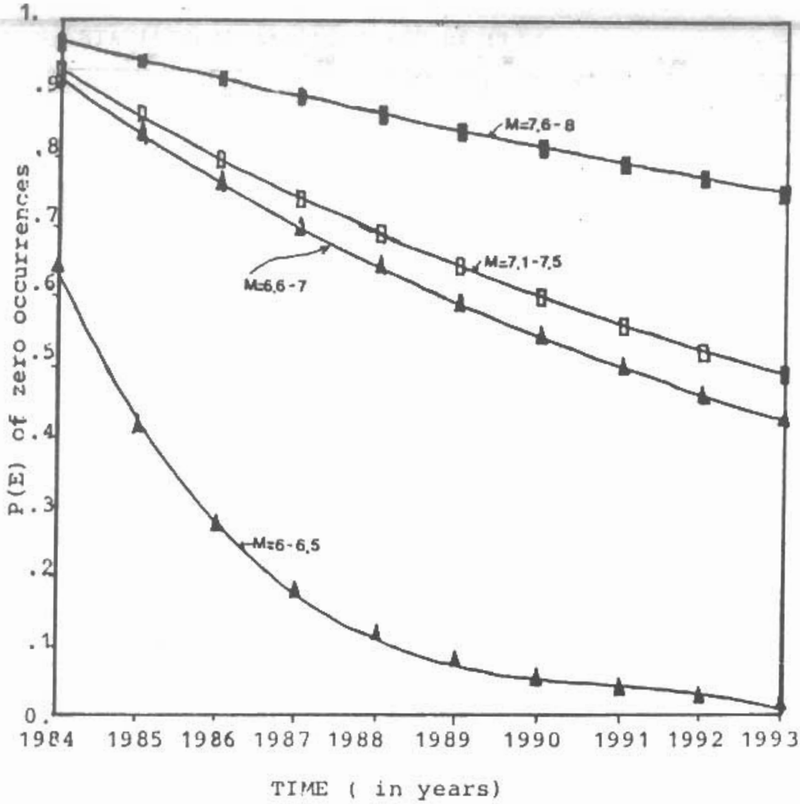
Bu using Bayesian statistics the uncertainties on the mean rate can be reduced and the obtained probabilities are more reliable. In the Bayesian model, the mean rate of earthquake occurrence is defined by

$$\lambda = \lambda f''(\lambda/N,T)d\lambda = N+1/T$$

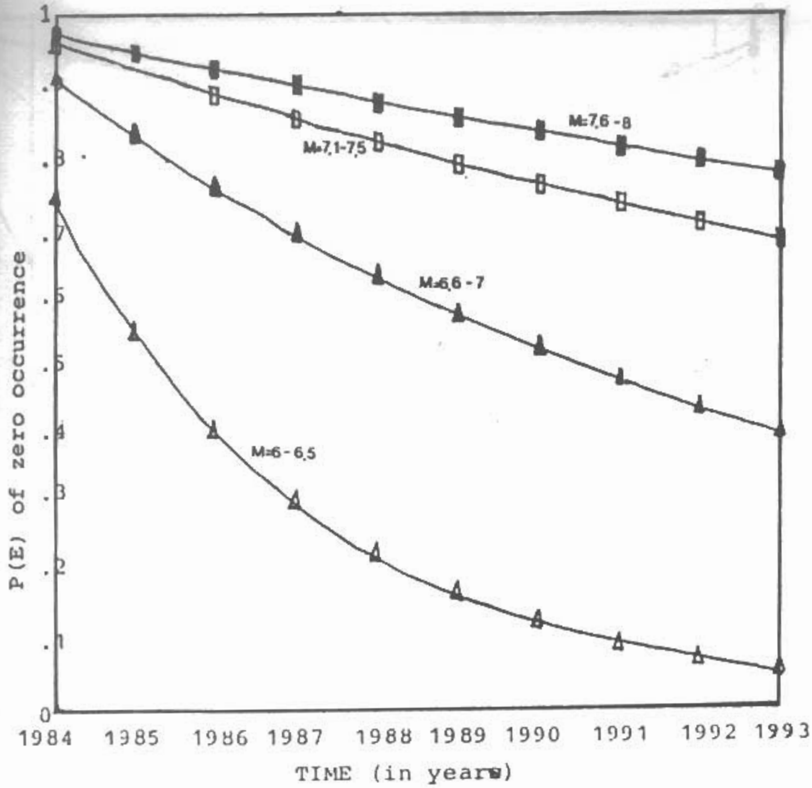



Σχ.1.: (A) Κατανομή σεισμών με M>5,0 κατά μήκος του νότιου-ανατολικού τμήματος του Ελληνικού τόξου. (Δεδομένα από MAKROPOULOS et al., 1986), και (B) με δεδομένα από COMNINAKIS and PAPAZACHOS, 1986).

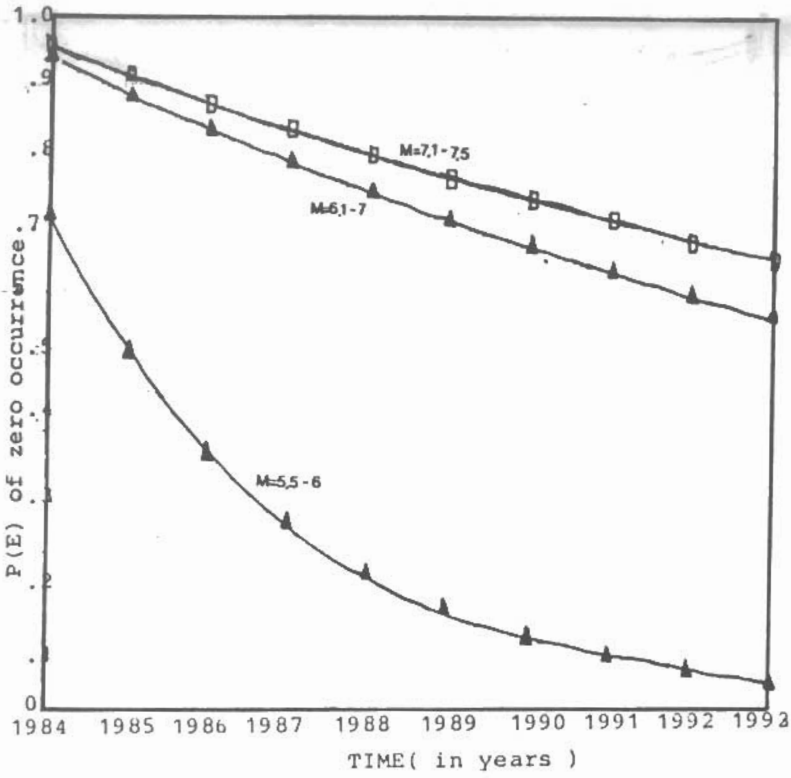
Fig.1.: (A) Distribution of earthquakes with M>5.0 along the south-southeastern part of the Hellenic arc (data from MAKROPOULOS et al., 1986), (B) data from COMNINAKIS and PAPAZACHOS, 1986.




Σχ.2.: Κατανομή πιθανότητας μηδενικής εμφάνισης σεισμών κατά μήκος του νότιου-ανατολικού τμήματος του Ελληνικού τόξου. (Δεδομένα από COMNINAKIS and PAPAZACHOS, 1986).
Fig.2.: Probability of zero earthquake occurrences of different magnitude range along the south-southeastern part of the Hellenic arc (data from PAPAZACHOS and COMNINAKIS, 1986).

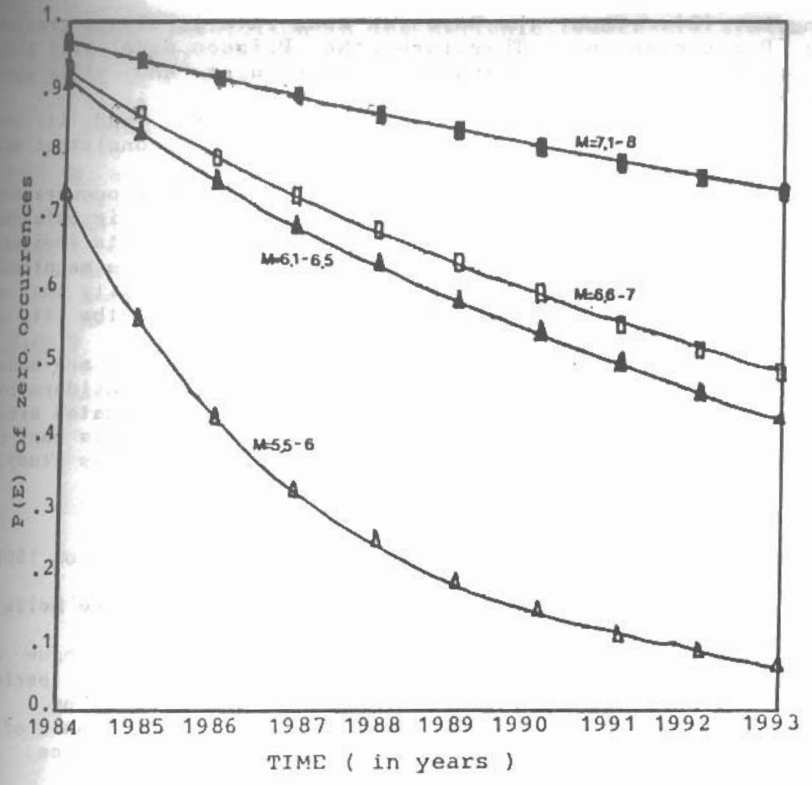



Σχ.3.: Κατανομή πιθανότητας μηδενικής εμφάνισης σεισμών κατά μήκος του νότιου-ανατολικού τμήματος του Ελληνικού τόξου. (Δεδομένα από MAKROPOULOS et al., 1986).
Fig.3.: Probability distribution of zero earthquake occurrences of different magnitude range along the south-southeastern part of the Hellenic arc. (data from MAKROPOULOS et al., 1986).




Σχ.4.: Κατανομή πιθανότητας μηδενικής εμφάνισης σεισμών σε απόσταση 100 χλμ από την πόλη της Ρόδου. (Δεδομένα από MAKROPOULOS et al., 1986).

Fig.4.: Probability of zero earthquake occurrences of different magnitude range in a distance of 100 km around the city of Rodos. (data from MAKROPOULOS et al., 1986).




Σχ.5.: Κατανομή πιθανότητας μηδενικής εμφάνισης σεισμών σε απόσταση 100 χλμ από την πόλη της Ρόδου. (Δεδομένα από COMNINAKIS and PAPAZACHOS, 1986).

Fig.5.: Probability of zero earthquake occurrences of different magnitude range in a distance of 100 km around the city of Rodos. (data from COMNINAKIS and PAPAZACHOS, 1986).

by using eq. (2). Thus, the Bayesian mean rate is always greater than the Poissonian one. Therefore, the Poisson model will give smaller probabilities of earthquake occurrences and will also underestimate the real seismic hazard at a site.

The model developed in this study is general and it can handle any quality and quantity of information in a consistent and eficient manner.

The probability distribution of zero earthquake occurrences along the south-southeastern part of the Hellenic arc is obtained by using two different seismological data. The results indicate that the probability of earthquake occurrence in the magnitude range 6.0 - 6.5 is very high after 1986. The probability that an earthquake of the same magnitude range will be felt in the city of Rodos is also high after 1987.

It should be emphasized that the obtained results are based on a pure statistical analysis without taking into consideration the focal depth, an important factor for the investigated area. However, the conclusion that the seismic hazard of this part of the Hellenic arc is high has been verified throughout this study.

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