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Research Article

Analysis of the b-Values Before the July 21th, 2017 Mw 6.6 Bodrum-Kos, Turkey, Earthquake

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Abstract

In this study, a statistical analysis of regional and time-dependent changes of earthquake activity in Bodrum and its vicinity before the Bodrum-Kos earthquake (Mw 6.6) that occurred on 21 July 2017 was performed and the Gutenberg-Richter b-value change was investigated. The earthquake catalog used in the calculations was taken from Boğaziçi University, Kandilli Observatory and Earthquake Research Institute. This catalog contains 16947 earthquakes with M>2 between 2004 and the time until the Bodrum-Kos earthquake of 21.07.2017. The completeness magnitude for these earthquakes was calculated as 2.6. The b-value was calculated as 0.97 using the maximum probability method. Considering that tectonic earthquakes have b-values between 0.5-1, it is seen that the b-value obtained by Gutenberg-Richter law for the vicinity of Bodrum in this study is a good fit. In addition, it was observed that b-value took high values in the north of Bodrum before the Bodrum-Kos earthquake occurred. Low values are observed in the southeast of Bodrum. Stress accumulation was correlated with b-values for the region.

Keywords: Seismicity, b-value, Bodrum-Kos earthquake

21 Temmuz 2017 Mw 6.6 Bodrum-Kos depremi öncesi b-değerlerinin analizi

Öz

Bu Bu çalışmada 21 Temmuz 2017 tarihinde meydana gelen Bodrum-Kos depreminden (Mw 6.6) önce Bodrum ve civarındaki deprem aktivitesinin bölgesel ve zamana bağlı değişimlerinin istatiksel bir analizi yapılmış ve Gutenberg-Richter b-değeri değişimi incelenmiştir. Hesaplamalarda kullanılan deprem kataloğu Boğaziçi Üniversitesi, Kandilli Rasathanesi ve Deprem araştırma Enstitüsünden alınmıştır. Bu katalog 2004 yılı ile 21.07.2017 Bodrum-Kos depremine kadar olan zaman arasında M>2 olan 16947 depremi içerir. Bu depremler için tamamlılık magnitüdü 2.6 olarak hesaplanmıştır. b-değeri maksimum olasılık yöntemi kullanılarak 1.25+-0.01 olarak hesaplanmıştır. Tektonik depremlerin 0.5-1.5 arasında b-değerine sahip oldukları düşünülürse bu çalışmada Bodrum civarı için Gutenberg-Richter yasası ile elde edilen b-değerinin iyi uyum sağladığı görülmektedir. Ayrıca Bodrum-Kos depremi meydana gelmeden önce Bodrum'un kuzeyinde b-değerinin yüksek değerler aldığı gözlenmiştir. Bodrum'un güneydoğusunda ise düşük değerler gözlenmiştir. Bölge için b-değerleri ile gerilme birikimi ilişkilendirilmiştir.

Anahtar Kelimeler: depremsellik, b-değeri, Bodrum-Kos depremi

1. Introduction

Seismically and tectonically active fault areas are complex natural systems and exhibit fractal behavior between earthquakes in space and time (Öncel and Wilson, 2002). The b-value determined from the Gutenberg-Richter relation (Gutenberg and Richter, 1944), which shows

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the frequency-magnitude relationship in earthquakes (LogN = a-bM), is used as an important parameter in the statistical analysis of earthquakes, as it is related to the physics of earthquake occurrence (Mogi, 1962; Scholz, 1968). One of the most acceptable theoretical ideas related to b-value variations is that an earthquake fault consists of locked segments that resist asperities where stress is concentrated (Schorlemmer and Wiemer, 2005; Wiemer and Katsumata, 1999; Zhao and Wu, 2008). Some researchers stated that the b-value is controlled by stress, stress heterogeneity or the complexity of the fault plane (Enescu and Ito, 2002), and it changes depending on tectonism and seismicity (Frohclich and Davis, 1993). High b-values were found on the earthquake rupture where higher slip during mainshock (Wiemer and Katsumata, 1999; Sobiesiak, 2000). High b-values have also been observed where extensional stress is effective (Frohclich and Davis, 1993) and volcanic regions, near magma chambers and in heavily fractured volumes (Wiemer and McNutt, 1997; Wiemer et al., 1998; Wyss et al., 1997). A statistically significant reduction of the seismicity rate is defined as pioneering seismic stagnation (Wiemer and Wyss, 1994), and region-time seismicity occurrences, including the leading recession events, may be associated with seismotectonic processes that can cause earthquakes. Therefore, potential region-time analyzes of the relationships between seismotectonic parameters can make significant contributions in defining earthquake characteristics (Öztürk, 2017).

According to the report of Disaster and Emergency Management Authority (AFAD) and Bogazici University, Kandilli Observatory and Earthquake Research Institute (KOERI), a large earthquake at a depth of 19.44 km which has a normal faulting mechanism striking about east-west occurred on July 21th, 2017 in Gökova Bay (Aegean Sea) at local time 01:31:09 (UTC) between Bodrum town, Turkey, and Kos island, Greece Figure 1. The moment magnitude was calculated as Mw = 6.6. After the earthquake 525 earthquakes were recorded in the first day, and 1506 aftershocks with magnitudes varying between 1.1 and 5.0 within a week (as of 2017.07.27, 14:30).

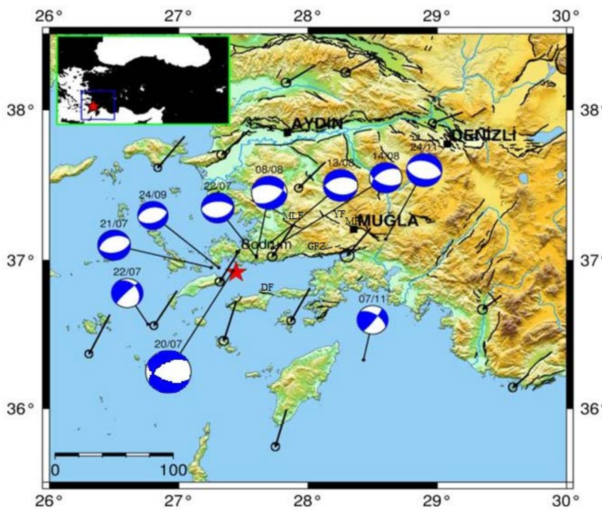
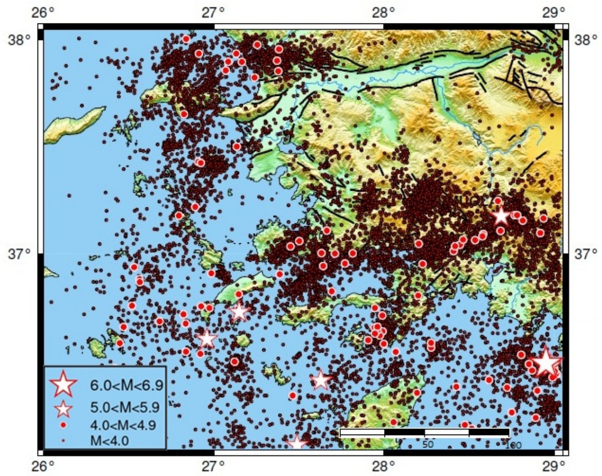


Figure 1. Tectonic map of eastern Turkey. Map showing GPS velocities with respect to Eurasia and 95% confidence ellipses for eastern Anatolia (McClusky et al., 2000; Reilinger et al., 2006). For reference, the centroid moment tensor solutions (KOERI) of the mainshock and

nine aftershocks are plotted Blue and white circles on beach-balls exhibit P and T-axes, respectively. The epicenter of the 2017 Bodrum-Kos EQ is indicated by the red star. GFZ: Gökova Fault Zone, MF:Muğla Fault, YF:Yatağan Fault, MLF: Milas Fault, DF: Datca Fault.



The inset in the above left shows whole Turkey.

Figure 2. The distribution of earthquakes from 2010 to 1 day before the Bodrum-Kos earthquake on the topographic map.

The Gulf of Gökova is one of E-W trending asymmetric depression with 120 km long and widens westward from 5 to 30 km. It is developed on the Lycian nappes, filled with Plio-Quaternary terrestrial and marine sediments (Gurer et al., 2013)

The W-SW directional movement of the Anatolian plate created an expansion regime in Western Anatolia after the Arab-Eurasian plates collided in Southeastern Anatolia along the Bitlis suture belt in the Late Serravalian (Dewey and Sengör, 1979). The Anatolian plate compensated for the compression that occurred after this collision by first thickening and then moving westward along the North Anatolian and Eastern Anatolian faults. Main tectonics have been progressed as a result of the northward The Global Positioning System (GPS) vectors in Figure 1 also show that the Anatolian Block moves counterclockwise (McClusky et al., 2000; Reilinger et al., 2006). Tectonic structures and related complex deformations due to the African-Eurasian convergence are also related to intense earthquake activity which includes many strong or destructive events in and around this region (Yolsal-Çevikbilen et al., 2014). The Aegean region, which also includes Bodrum, shows complex tectonic structures due to the strong heterogeneity in the crust. Earthquakes that occurred in the tectonically active region in the last century are 1933 (Ms = 5.7) Denizli-Çal, 1941 (Ms = 6.0) Ula-Muğla, 1955 (Ms = 6.8) Söke-Aydın, 1961 (Ms = 6.3) Köyceğiz offshore, 1963 (Ms = 5.5) Buldan-Denizli, 2004 (Mw = 5.5) Aegean Sea, 2004 (Md = 5.1) Ula-Muğla, 2016 (Mw = 5.1) Aegean Sea, 2016 (Mw = 5.2) Aegean Sea earthquakes. According to the historical period records between 1400 and 1900, devastating earthquakes up to IX intensity occurred in the region. It is known that in these earthquakes, significant loss of life and property occurred and significant tsunamis were experienced (Altınok and Ersoy, 2000; Aktar et al., 2006; Yolsal et al., 2007; Kalafat and Horasan, 2012; Yolsal-Çevikbilen and Taymaz, 2012).

The aim of this study is to make a statistical evaluation of the earthquakes that occurred in Bodrum and its surroundings from 2004 to 2017 Bodrum-Kos earthquake. For this purpose, regional and time dependent changes of seismotectonic b-value and Mc-value were mapped and region-time-magnitude distributions of seismicity were analyzed. As a result, the seismic activity in the region before the Bodrum-Kos earthquake was evaluated in terms of the earthquake hazard depending on the region and time. In this study, spatial and temporal variations in b-values before the 21 July 2017 Bodrum-Kos Earthquake are investigated. Low b-values can be interpreted as the stress present before the main shock. The low b-values can also be examined as a possible precursor to the arrival of the Bodrum-Kos main shock.

2. Material and Methods

Earthquakes between 21.07.2004-21.07.2017 were used within the scope of this study. Earthquake data were compiled from the catalogs obtained from the web pages of KOERI. This catalog contains 16.947 earthquake data (Figure 3).

Modeling of the magnitude distributions of earthquakes is done with the Gutenberg-Richter law (Gutenberg and Richter, 1944). The relationship between the magnitude of earthquakes and the number of earthquakes can be given with the following empirical equation:

$$\text{Log}_{10}\, N(M) = a - bM \qquad (1)$$

Here N (M) is the cumulative number of earthquakes with magnitudes greater than and equal to M. b-value defines the slope of the size distribution of earthquakes, while parameter a is related to seismicity or the rate of earthquake generation. b-value is the slope of the line obtained from the magnitude (M)-logarithm of the cumulative earthquake number (LogN) (Scholz 1990; Wiemer and Wyss 1997).

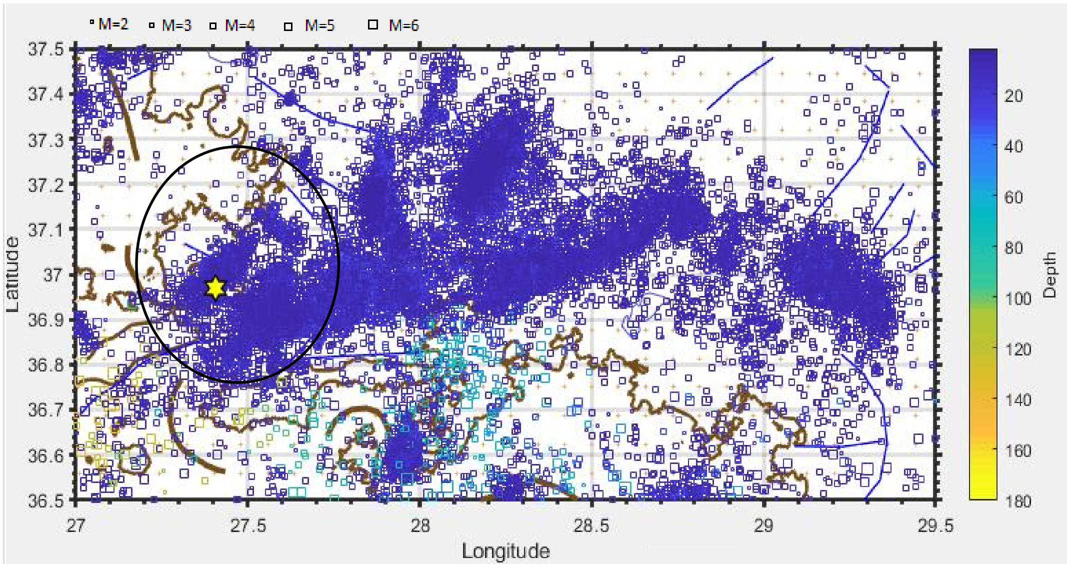


Figure 3. The epicenter distribution map of the original earthquake catalog containing 16942 earthquakes with M≥2.0 between 2004 and 2017 for Bodrum and its vicinity. The magnitude

values of earthquakes are shown with square symbols of different sizes changing with depth and the star represents the 6.6 Bodrum-Kos Earthquake. The earthquakes in the black circle represent the earthquakes used in the b-value calculation.

In a semi-logarithmic plot, the constants a (zero-offset) and b (slope) can be determined. The slope b has been interpreted to indicate the presence of asperity, stress and material heterogeneities along the fault plane (Amitrano, 2003; Mogi, 1962; Scholz, 1968; Schorlemmer et al., 2005). The b-value is calculated using the maximum likelihood method published by Utsu (1966, 1999).

$$b = \frac{\log_{10}(e)}{[M-(M_c-\Delta M_{bin}/2)]} \qquad (2)$$

Here (M) is the mean of the binned magnitudes, Mc is the magnitude of completeness and ΔM_{bin} is the binning width of the catalog.

The b-value in the Gutenberg-Richter relationship is one of the most important parameters in seismology. Besides its importance in seismic assessments and its usability as a leading anamole in earthquake prediction, it is a complement to the mechanical characteristics in seismogenic material such as stress accumulation, crack density and degree of heterogeneity (Voidomatis et al., 1990). There is a correlation between the space variations in b-values and static stress drop, apparent stress, and dynamic stress (Urbancic et al., 1992). The magnitude of the precision (Mc-value) is a very important parameter in statistical seismicity studies. The Mc-value is the minimum magnitude of a complete earthquake record, and the magnitude-earthquake number distribution and changes in the Mc-value of earthquakes can be calculated by the moving time window technique (Wiemer and Wyss, 2000).

2.1. Declustering of Earthquake Data

Earthquakes are considered to be independent events in seismicity studies. In earthquake sequences, the main shocks are independent events. Foreshock and aftershocks are dependent events resulting from stress changes caused by the main shock. Foreshock and Aftershocks negatively affect earthquake statistical analysis. ort his reason, in order to determine the temporal variation of earthquake numbers accurately, interdependent earthquakes should be distinguished from earthquake catalogs and removed from the catalog. The process of distinguishing dependent and independent events from each other is called ‘declustering’. Seismicity parameters to be obtained without declustering may contain various errors. Declustering can be performed using different algorithms such as Reasenberg (1985) model, Savage (1972) model, Gardner and Knopoff (1974) model, Uhrhammer (1986) model, and can be distinguished from dependent events. In this study, the Reasenberg (1985) algorithm is used.

Deep earthquakes were extracted from the catalog before proceeding with the declustering process and Shallow earthquakes have been used. Because the aim of this study is to analyze the b value in the brittle crust. Seismotectonics crust in western Turkey is about 30 km (Akçığ, 1988). According to the AFAD’s Bodrum earthquake report, when the depths of the earthquake after the Bodrum earthquake were examined, it was determined that the earthquakes occurred in the first 30 km. After the elimination of deep earthquakes and declustering, 12849 earthquakes remained.

3. Research Findings

In this study, Mc calculation has been made since the completeness value will be used to calculate the b-value and to apply earthquake prediction methods. Seismicity constants are not affected much by errors in focus determination, but are affected by the completeness magnitude in the catalog (Wiemer and Katsumata, 1999). □igüre□□ reason, completeness (Mc) analysis was performed to increase the accuracy of the b-value maps. Completeness magnitude was determined as 2.6 by examining earthquake data in Bodrum and its vicinity. Figure 4 shows how the Mc level changes over time □igüre□ entire catalog.

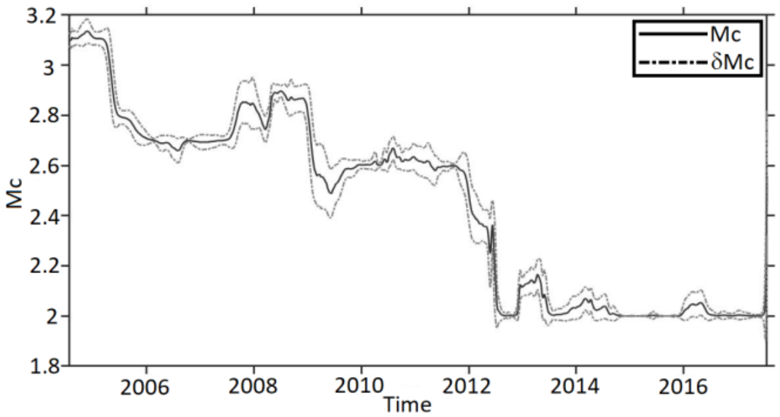


Figure 4. Mc analysis for basement and its vicinity as a function of time. The Mc-value was calculated using 15 events per window and the standard deviation (δMc) is given on the □igüre.

In the analysis of the Mc-value, the earthquake catalog with M $\geq$2 and containing 12849 earthquakes was used and the Mc-value was calculated using 100 samples per window. The magnitude of completeness Mc for all of the data ranges from 2.1 to 3.1.

The catalog was limited to earthquakes with a constant Mc-value (2.6) and above in order to obtain an accurate b-value over the entire space and time range. Figure 5 show the cumulative number of earthquakes for Mc $\geq$2.6. Figure 6 show time histogram for Bodrum and its vicinity between 2004-2017

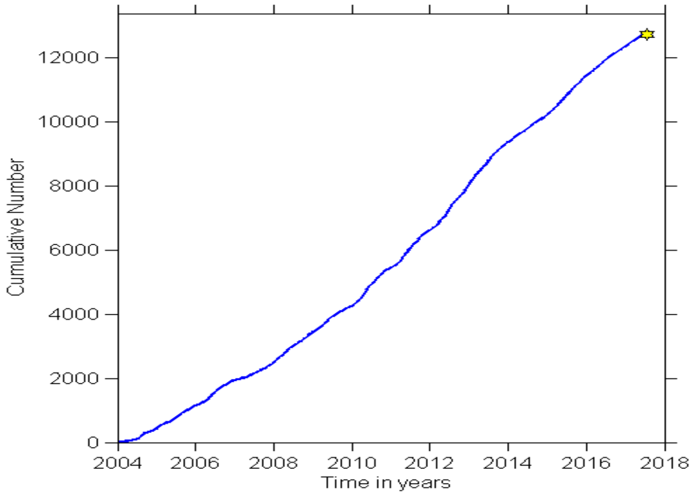


Figure 5. Cumulative number of earthquakes with Mc ≥ 2.6 (blue line, N = 16947) from 2004 to 2017 in the Bodrom region. The yellow star is the 21 July 2017 Mw = 6.6 Bodrum-Kos Earthquake

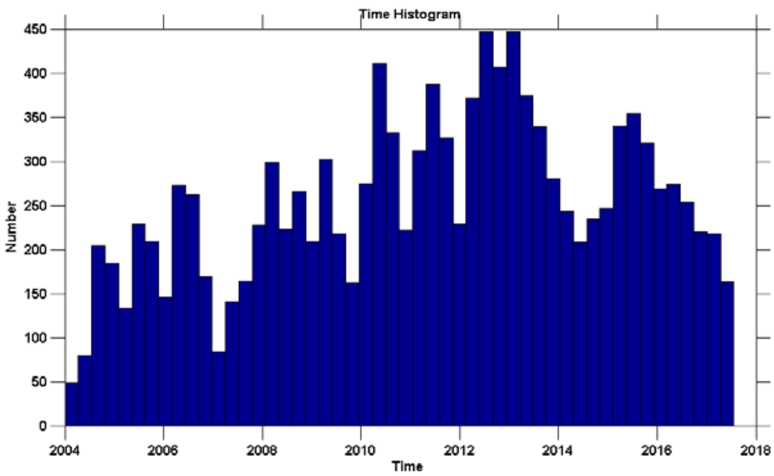


Figure 6.Time histogram for Bodrum and its vicinity between 2004-2017

The b-value and standard deviation in the Gutenberg-Richter relationship were calculated using the maximum probability method (Figure 7). The maximum probability method offers a more accurate approach compared to the least squares method (Aki, 1965).

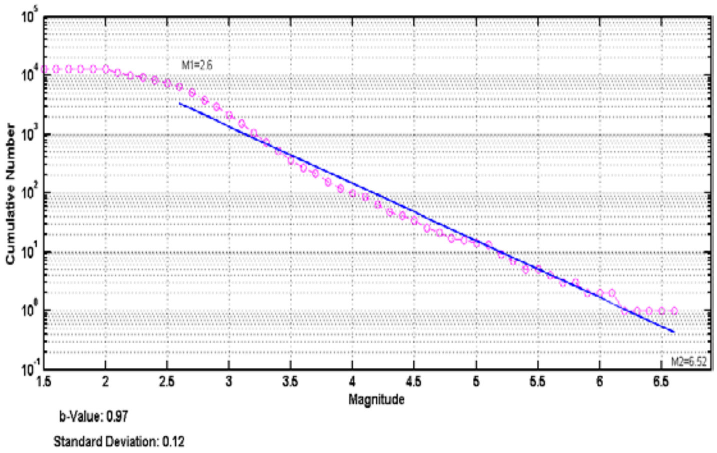


Figure 7. Gutenberg-Richter relationship and magnitude-frequency distribution for all earthquakes between 2004-2017 for Bodrum and its vicinity. The magnitude of completeness, b-value and standard deviation are also given on the □igüre, along with the a-value in the Gutenberg-Richter relationship.

The surface change map of the b-value is shown in Figure 8. The b-value variations are calculated using the public software package ZMAP by Wiemer (2001). The study region is divided into 0.01 ° × 0.01 ° grids. ,

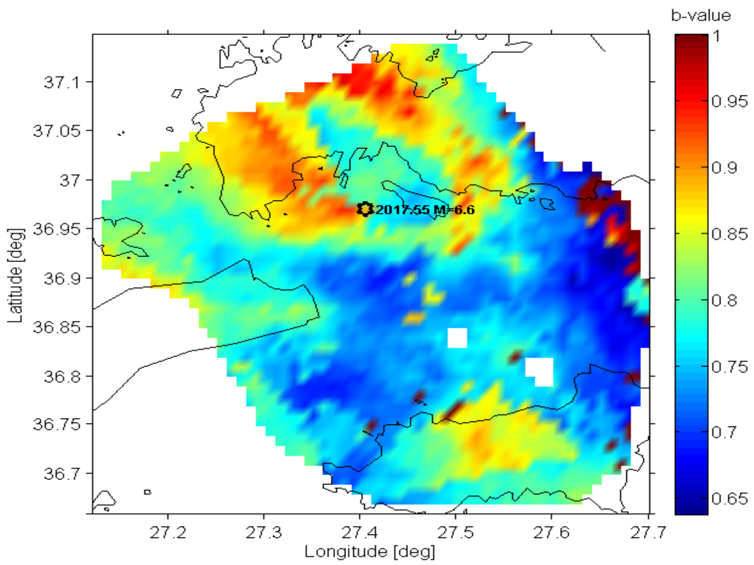


Figure 8. Regional change map of b-value for Bodrum and its surroundings before Bodrum-Kos earthquake

4. Results and Discussion

In this study, the magnitude-scale distributions of earthquakes from 2004 to the Bodrum-Kos earthquake were statistically analyzed and the b-value, an important parameter in earthquake statistics, was calculated. The maximum probability method was used to estimate the b-value. Because this method provides a stronger estimation than the least squares method. The magnitude-cumulative earthquake number graphs for earthquakes in Bodrum and its vicinity are shown in Figure 7. The magnitude of completeness was calculated as Mc = 2.6 and the b-value= 0.97. Frohlich and Davis, 1993 stated that the average b-value for tectonic earthquakes varied around 1.0. It is seen that the b-value obtained for Bodrum earthquakes is well represented by Gutenberg-Richter law. The regional change map of the b-value was created using the moving window technique with a grid spacing of 0.01 ° × 0.01 ° and is given in Figure 4. In the mapping of the b-value, only shallow earthquakes with Mc=2.6 were taken into account and 400 earthquakes were used per window. As seen in Figure 8, b-values vary between 0.5-1. High b-values have been observed in Bodrum and its northwest. At the same time, an increase in b-value was observed towards the northeast (0.85-1). b-values decrease from the south of Bodrum towards north (0.85-0.60).

As can be seen in Figure 1, the source mechanism solutions of the Bodrum-Kos earthquake and several aftershocks after it show that normal fault mechanisms with a small strike-slip component are observed in E-W striking normal fault systems in this region. If this is interpreted the extension is in a north-south direction (Tiryakioğlu et al., 2018), it may be related with the low north-south direction of b-value obtained in this study before the Bodrum-Kos earthquake.

In addition, if we remember that earthquakes up to the Bodrum-Kos earthquake were used in the calculation of the b-value, it can be interpreted as the area where the b-value fell, the area where the stress accumulation occurred, and it is seen that the Bodrum-Kos earthquake occurred in this area and the aftershocks extended to the southeast (Figure 1). This result was found to be consistent with Crampin and Üçer, 1975; Gürbüz et al., 2000; Öncel and Wyss, 2000; Westerhaus et al., 2002; Wyss et al., 2004; Görgün; 2013.When the earthquakes with Mw = 5 and above on the Gökova Fault Zone in the last 100 years are examined (Sözbilir et. Al., 2017), considering that there is an earthquake migration based on energy transfer from east to west in the fault segments, the change in b-value and the stress We can also say that it has increased.

With the release of the stress accumulated in the region for 12 years (Sözbilir et al., 2017) before the basement earthquake, a stress discharge occurred in the region. The fact that b value was relatively low in this region before the earthquake also explains the stress accumulation in this region. As a matter of fact, Öztürk and Şahin (2019) found that the lowest b-values were observed in and around mainshock and these regions are related to high stress regions as well as coseismic deformation regions. The result obtained regarding the b-value in this study, Wiemer and McNutt (1997), Wiemer at all., (1998), Wiemer and Katsumata (1999), Wiemer and Wyss (1997), which is also supported by the general results provided. This region is tectonically very complex as it is a place within the thrust belt where deep earthquakes also occur. It would be better to examine the changes of the b-value with depth and at certain time intervals before mainshock. Thus, the relationship of b-value with the regional stress distribution can be revealed more clearly.

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