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Research Article

A STUDY ON THE CHARACTERISTICS OF GÜMÜŞHANE SEISMICITY: ANALYSES OF REGION-TIME PARAMETERS

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ABSTRACT

The proposed study is focused on the identification of region-time characteristics of earthquakes in Gümüşhane, Turkey. Detailed statistical evaluations were achieved by considering the most frequently used size-scaling parameters such as seismotectonic *b*-value, fractal dimension *Dc*-value, standard normal deviate *Z*-value and recurrence time of earthquakes. Used earthquake catalog is homogeneous for duration magnitude, M_d, and consists of 2902 shallow earthquakes with $1.0 \leq M_d \leq 6.5$ in about 47.76-years period between 1970 and middle of 2018. *b*-value is computed as 1.02±0.02 with a completeness level of 2.8, and this result indicates that frequency-magnitude distribution of seismicity in Gümüşhane is well represented with a *b*-value typically close to 1.0. *Dc*-value is calculated as 1.57±0.03 with a scale invariance between 4.96 and 86.28 km. This *Dc*-value means that seismic activity is more clustered in smaller areas or at larger scales in Gümüşhane. The analysis on the recurrence times of earthquakes implies that Gümüşhane has not a significant earthquake potential for the great earthquakes. Regional variation of *b*-value shows that small *b*-values were observed in and around Kelkit and Köse, and these regions may have a possible earthquake hazard and risk in the future. *Z*-value analysis suggests that there are not noticeable seismicity rate changes in the mid-2018. These statistical results indicate that the seismic hazard is low and seismic risk is minor in the intermediate term in Gümüşhane.
Keywords: Gümüşhane, seismicity, statistics, seismic hazard, seismic risk.

1. INTRODUCTION

Many statistical models have been used for a detailed evaluation of region-time-magnitude distribution of earthquake occurrences [1], [2], [3], [4], [5], [6]. For this purpose, several basic earthquake parameters are preferred by different researchers given above in order to evaluate the earthquake hazard and risk in different parts of the world. Some of these seismotectonic parameters can be given as *b*-value, *Dc*-value, *Z*-value, annual probability and recurrence time of earthquake occurrences. The magnitude-frequency distribution of earthquake occurrences is known as the *b*-value of Gutenberg-Richter relation [7]. The *b*-value reflects the relative numbers of both small and great earthquakes, and is related to the thermal gradient, fracture density, material heterogeneity in the geological complexity or stress distributions in time and space.

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Fractal dimension *Dc*-value defines the heterogeneity degree of earthquake activity on the fault system and some geological, mechanical or structural changes in heterogeneity [8]. Regional and temporal analyses of seismic quiescence have also shown remarkable results in many studies reported by different researchers in the identification of precursory anomalies in and around focal areas several years before great earthquakes [9], [10], [11]. The quiescence hypothesis is firstly formulated by Wyss and Habermann [12] and it postulates that some main shocks are preceded by seismic quiescence, which means an observable decrease in the average earthquake activity rate. It is stated that averag e duration of precursory seismic quiescence before great earthquakes in different parts of the world is expected to be 4.5±3 years. In the scope of this study, these three seismotectonic parameters *b*-value, *Dc*-value and *Z*-value are analyzed as well as recurrence time of earthquake occurrences in order to put forth some important results for the evaluation of seismic hazard and risk in Gümüşhane city of Turkey in the mid-2018.

2. GEOLOGICAL STRUCTURE AND SEISMOTECTONIC PROPERTIES OF GÜMÜŞHANE AND VICINITY

Gümüşhane is located to the east of the Pontide Orogenic belt in the northeast Turkey and to the southern zone of the eastern Pontide tectonic unit [13]. The base rocks of the region consist of Paleozoic-aged metamorphic rocks and Gümüşhane granites rising by cutting them. The geologic structure of Gümüşhane and surrounding region is digitized from the website of the General Directorate of Mineral Research and Exploration (MTA, URL-1) and shown in Figure 1.

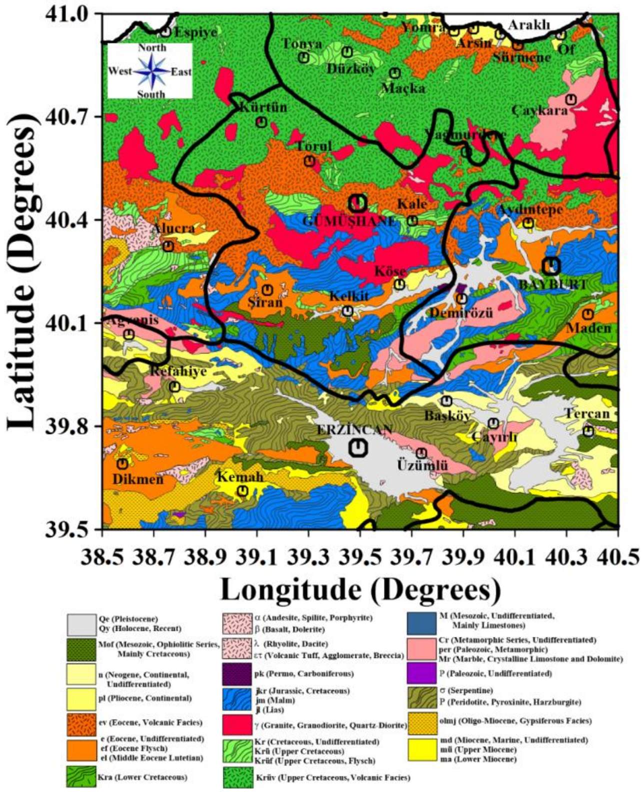

Figure 1. Surface geology in Gümüşhane and surrounding area (modified from MTA).

Geological formation of Gümüşhane c ity center is mainly located on the granitic floor and is generally covered with granite, granodiorite and quartz-diorite (γ), Eosene-volcanic facies (ev), undifferentiated Cretaceous (Kr), upper Cretaceous (Krü) and Flysch (Krüf) as seen from the geological map. Torul and vicinity usually includes granite, granodiorite and quartz-diorite and Eosene-volcanic facies. Granite, granodiorite, quartz-diorite and upper Cretaceous-Volcanic facies (Krüv) are also dominant in and around Kürtün-Özkürtün districts. Şiran and surrounding region covers undifferentiated Eocene (e), Eocene flysch (ef), mid-Eocene lutetian (el), andesite-spilite-porphyrite (α), basalt-dolerite (β), rhyolite-dacite (λ) and volcanic tuff-agglomerate-breccia (ετ). However, Pleistocene (Qe) and Holocene-Recent (Qy) structures, undifferentiated Neogene continental formations (n), undifferentiated Eocene, Eocene flysch, mid-Eocene lutetian floors and partially granite, granodiorite, quartz-diorite structures cover Kelkit and Köse districts.

Gümüşhane is one of the most quiescent region of Turkey in terms of tectonic and seismicity. However, the North Anatolian Fault Zone (NAFZ) passes around 80 km from Gümüşhane, and because of the closeness to the NAFZ, Gümüşhane can be affected from a large earthquake in and around this zone. Fault zones are generally located near the NAFZ and consist of normal, thrust and strike slip faults. The NAFZ is one of the best known right lateral strike slip fault in the world and displays 24-30mm/year rightward movement according to geodetic data [14]. There are several fault segments and fault zones which are related to the NAFZ in Şiran, Kelkit, Köse, Bayburt and Erzincan. These fault segments, basins and fault zones can be given as Kelkit Fault segment (KLFS), Kelkit basin (KLB), Bayburt basin (BYB), Kelkit-Çoruh Fault zone (KÇFZ), Akdağ-Çayırlı Fault zone (AÇFZ), Tercan-Aşkale Fault zone (TAFZ) and Dağyolu fault (DYF). KÇFZ has a length of about 600 km and is left lateral strike slip fault zone. This fault zone consists of four segments as Kelkit, Çoruh, Posof and Borjomi-Kasbeg from the southwest to the northeast. KLFS is separated from the NAFZ with a length of about 100 km. This fault segment is divided into two branches around Kelkit and results in a basin [15]. TAFZ, which is left lateral strike slip fault zone, is about 150 km long and 2-4 km wide. This fault zone passes through the western part of Erzurum near the NAFZ and includes several parallel fault segments of about 2 to 20 km in length [15].

There are not great earthquakes in Gümüşhane in historical and instrumental period. However, two strong earthquakes close to the Gümüşhane border are January 19, 1979 (M_d5.0) and August 12, 1985 (M_d5.0) earthquakes. Considering the earthquakes in which occurred Gümüşhane and vicinity between 1970 and 2018, it can be seen that some of the great earthquakes (March 13, 1992, M_d6.5 and March 15, 1992, M_d5.3) occurred in and around the NAFZ, whereas the other large earthquakes occurred in some parts of Gümüşhane near the NAFZ. Recent earthquakes in and around Gümüşhane are July 30, 2009 (M_d5.0) Erzincan-Çağlayan and September 22, 2011 (M_d5.6) Erzincan-Refahiye earthquakes. Few studies on the geologic, seismic and tectonic structure of Gümüşhane and surrounding area can be found in Taş et al., [13], Bozkurt [15] and Öztürk [16].

3. EARTHQUAKE DATABASE AND STATISTICAL METHODS

The earthquake database for Gümüşhane and surrounding area is compiled from Boğaziçi University, Kandilli Observatory and Earthquake Research Institute (KOERI). Main tectonic environments in Gümüşhane and vicinity were modified from different authors such as Bozkurt [15] and Şaroğlu et al. [17]. Figure 2 shows the simplified tectonic structures in and around Gümüşhane. Earthquake catalog is homogeneous for duration magnitude, M_d, and contains 2902 shallow earthquakes (depth ≤ 75 km) with magnitudes larger than or equal to M_d=1.0 in about 47.76-years period from September 21, 1970 until June 26, 2018. For the detailed analyses, the rectangular region between the co-ordinates 39.5ºN and 41.0ºN in latitude and the co-ordinates 38.5ºE and 40.5ºE in longitude was considered as the study area (Figure 3).

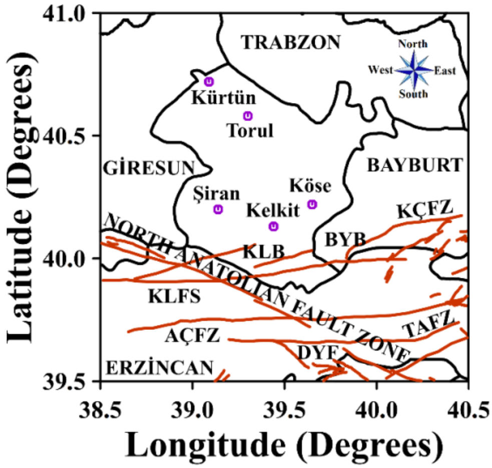

Figure 2. Main tectonic environments in Gümüşhane and vicinity. The names of the faults are given in the text. Some significant city centers are also given on the figure.

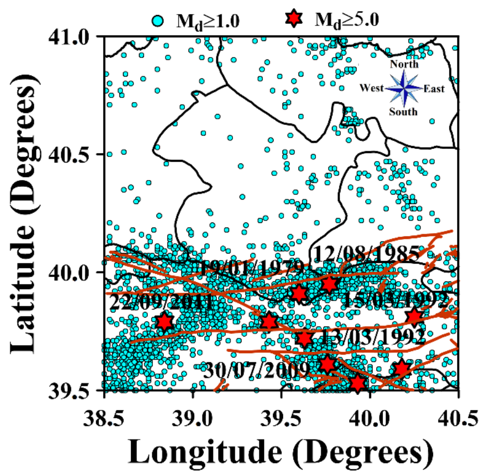

Figure 3. Epicenters of 2902 shallow earthquakes (depth ≤ 75 km) with $1.0 \leq M_d \leq 6.5$ from 1970 to mid-2018. Stars indicate great main shocks with $M_d \geq 5.0$. Dates of some great earthquakes are also shown on the figure.

3.1. Gutenberg-Richter Relationship (*b*-value)

Size-scaling power law of earthquakes occurrences was given by Gutenberg-Richter [18]. This frequency-magnitude distribution of earthquakes was formulated as follows:

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

where *N(M)* is the expected number of earthquakes with magnitudes greater than or equal to *M*, *b*-value gives the slope of the frequency-magnitude distribution, and *a*-value is related to the seismic activity rate. The changes in *a*-value for different regions depend on the extend of the study area, the time interval and also earthquake magnitudes. *b*-value generally changes between

0.3 and 2.0 from region to region [19]. Also, some additional factors such as the number of great and small earthquakes, degree of heterogeneity of cracked medium and geological complexity, stress and strain concentrations are effective in *b*-value changes. However, average *b*-value is accepted as equal to 1.0 [2].

3.2. Fractal Dimension (*Dc*-value)

Fractal distribution implies that the number of events larger than a specified size has a power law dependence on the size. Region-time patterns of earthquakes can be proved to be fractal using the two-point correlation dimension [5]. Fractal dimension, *Dc*, and the correlation sum, *C*(*r*), were defined by Grassberger and Procaccia [20] as follows:

$$Dc = \lim_{r \to 0} \left[\log C(r) / \log r \right] \tag{2}$$

$$C(r) = 2N_{R<r} \ / \ N(N-1) \tag{3}$$

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

$$C(r) \sim r^{Dc} \tag{4}$$

where *Dc* is the fractal dimension, in other words, the correlation dimension. Distance r (in degrees) between two epicenters can be obtained from the following equation:

$$r = \cos^{-1}\left(\cos\theta_i \cos\theta_j + \sin\theta_i \sin\theta_j \cos\left(\phi_i - \phi_j\right)\right) \tag{5}$$

where (θ_i, ϕ_i) and (θ_j, ϕ_j) are the latitudes and longitudes of the i^{th} and j^{th} earthquakes, respectively [5]. *Dc*-value can be estimated by fitting a straight line to a plot of $C(r)$ versus r on a double logarithmic scale, practically from the slop of the graph. Fractal dimension of earthquakes can be calculated for the estimation of possible unbroken zones mentioned as seismic gaps that may be broken in the next [21]. Hence, the changes in fractal features mostly depend on the complexity or quantitative measure of the heterogeneity degree of seismicity in the fault systems. The larger *Dc*-value related to the smaller *b*-value is the dominant structural characteristic in the regions of increased complexity in the active fault system. Also, this result may be interpreted as an indication of stress changes on fault planes of smaller surface area [4], [21].

3.3. Standard Normal Deviate (Z-value)

The standard normal deviate *Z*-test is one of the statistical methods frequently used for imaging the areas exhibiting a seismic quiescence. A continuous image of region and time rate changes in seismicity can be produced by *ZMAP* software [22], creating a grid of geographical co-ordinates, and associating to each grid node a selected number of the nearest events. In order to rank the significance of seismic quiescence, the standard normal deviate *Z*-test is used, generating the LTA (Log Term Average) function for the statistical evaluation of the confidence level in units of standard deviations [9]:

$$Z = (R_1 - R_2) / \sqrt{\left(S_1^2 / N_1\right) + \left(S_2^2 / N_2\right)} \tag{6}$$

where R_2 is the average seismicity rate in the foreground window, R_1 is the average number of earthquakes in the whole background period, S and N are the standard deviations and the number of samples, within and outside the window. The *Z*-value computed as a function of time is called LTA.

3.4. Magnitude Completeness (*Mc*-value) and Declustering Process of Catalog

Magnitude completeness, *Mc*, is one of the most important parameters in many statistical seismicity studies, especially in the analysis of frequency-magnitude distribution. It is very important to use the maximum number of events for the correct and high quality calculations [23]. The Gutenberg-Richter power law distribution against magnitude can be used to estimate *Mc*-value, and the changes in *Mc*-value can be computed with a moving time window approach [23]. Temporal changes in *Mc*-value may have an effect on the seismicity parameters, especially in *b*-value. If *Mc*-value changes systematically as a function of time, the best suitable *Mc*-value must be estimated for reliable statistical analyses, and for this reason, this is very important process.

Some activities such as foreshocks, aftershocks and swarms usually mask the temporal variations of the earthquake numbers and the related statistics. For this reason, it is necessary to remove the dependent events from the catalog for a quantitative analysis of seismicity rate changes. Reasenberg's [24] algorithm can be used to decluster the catalog and dependent events can be separated from independent ones. The cluster algorithm of Reasenberg's [24] "declusters" or decomposes a regional earthquake catalog into the main and secondary events. It also removes all dependent events from each cluster and substitutes them with a unique event. As a remarkable fact, a more reliable, homogeneous and robust earthquake catalog can be obtained after the completion of declustering processes and estimation of *Mc*-value.

4. RESULTS AND DISCUSSIONS

In this study, Reasenberg's [24] algorithm was used to decluster the earthquake catalog and 473 events are removed. *Mc*-value for study region was taken as 2.8 and the number of events exceeding this *Mc*-value is 930. After declustering and the eliminating $M_d<2.8$ earthquakes, approximately 48.35% of events was excluded from the catalog and the number of events for *Z*-test is reduced to 1499. The cumulative number of earthquakes as a function of time for the original catalog (2902 events), for the declustered catalog (2429 events) and for declustered catalog with $M_d\geq2.8$ (1499 events) is shown in Figure 4. Earthquake activity does not show any significant changes from 1970 to 1995, and a little change can be seen between 1995 and 2003. However, there are significant fluctuations in seismicity, especially starting after 2003 since the seismograph network expanded in and around Gümüşhane. Also, many stations have been constructed in Turkey in recent years. Cumulative number of declustered earthquakes with $M_d\geq2.8$ as a function of time has a smoother slope when compared to original catalog ($M_d\geq1.0$). As an important result, one can clearly see from Figure 4 that this declustering process and elimination of $M_d<2.8$ earthquakes has removed dependent events from the original catalog.

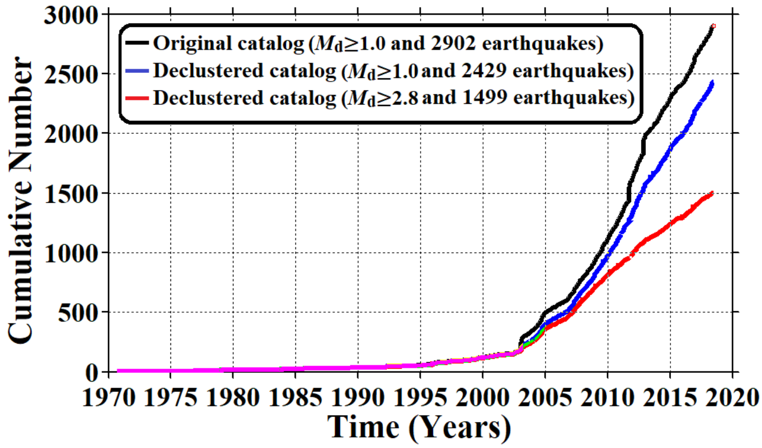

Figure 4. Cumulative number of earthquakes as a function of time for the original and declustered earthquake catalogs including different magnitude sizes.

Figure 5 shows frequency-magnitude relation of Gümüşhane earthquakes. *b*-value is computed as 1.02±0.02 by using *Mc*=2.8. Average *b*-value is accepted as 1.0 in literature and thus, frequency-magnitude distribution is well represented by the Gutenberg-Richter law. Fractal dimension of Gümüşhane earthquakes is given in Figure 6. *Dc*-value is estimated as 1.57±0.03 with 95% confidence. This log-log correlation function exhibits a clear linear range and scale invariance between 4.96 and 86.28 km. *b*-value and *Dc*-values are calculated by using the original catalog including 2902 events. The areas of increased complexity in active fault systems show higher *Dc*-value. The higher *Dc*-value is also quite sensitive to the heterogeneity in magnitude distribution. That means that seismicity is more clustered in smaller areas or at larger scales [4, 21]. Thus, this relatively high *Dc*-value can be a dominant structural feature, and it may be resulted from clusters of seismicity at larger scales or in smaller areas. Also, this result may be interpreted as an indication of stress changes on active fault systems in and around Gümüşhane.

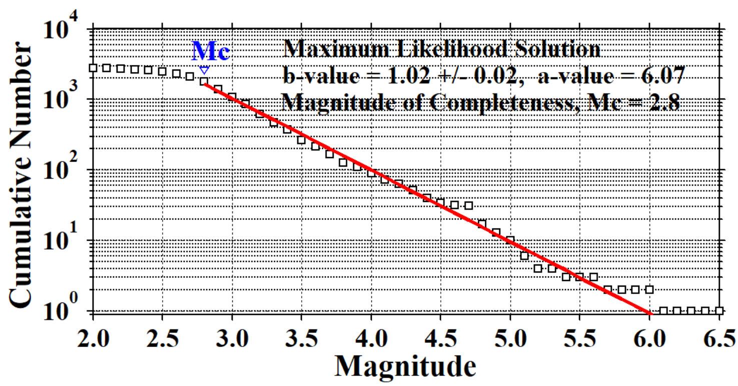

Figure 5. Frequency-magnitude distribution and Gutenberg-Richter *b*-value.

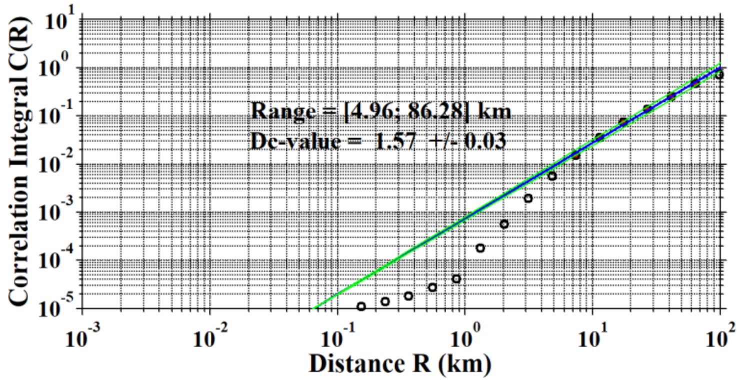

Figure 6. Correlation integral curve against distance and fractal dimension *Dc*-value.

Figure 7 shows the regional changes of *b*-value in and around Gümüşhane in the mid-2018. *b*-value was calculated by using the original catalog and varies from 0.7 to 1.5. The largest *b*-values (>1.3) were observed in the west, northwest and southwest parts of Gümüşhane including Kürtün, Torul and Şiran. The smallest *b*-values (<0.9) were found in the east, south and southeast parts including Keltik and Köse. We could not observe a relation between *b*-value and surface geology of Gümüşhane. But, the regions of small *b*-values observed in and around Kelkit and Köse may be important in terms of the seismic risk. Regional variations of *Z*-value were calculated for every two years between 2000 and 2014 by adding a time window T_W=4.5 years to the cut-at time (Figure 8). Declustered catalog is used for these analyses. The aim of these maps is to test whether a significant seismic quiescence is observed compared to previous years. There are not significant anomalies between 2000 and 2018, and these maps do not show seismic quiescence in the mid-2018. Regional variability of recurrence times for M_d=5.0 and M_d=6.0 earthquakes were calculated by using the original catalog and given in Figure 9. Considering the strong and large earthquakes, there is not a significant hazard and risk in the intermediate term. However, some regions having recurrence years between 15 and 30 may be affected from strong or large earthquakes in the next which occurred nearby regions.

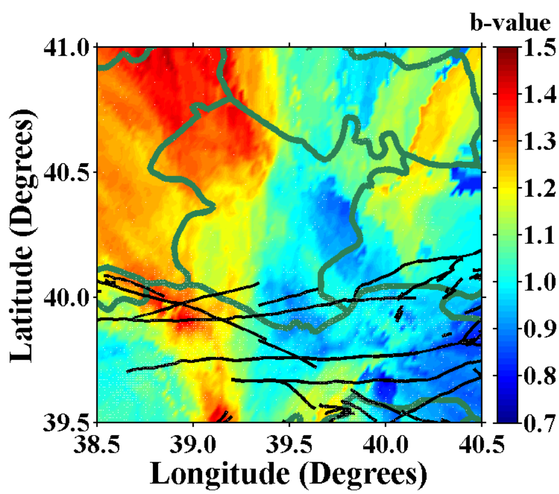

Figure 7. Regional changes in Gutenberg-Richter *b*-value.

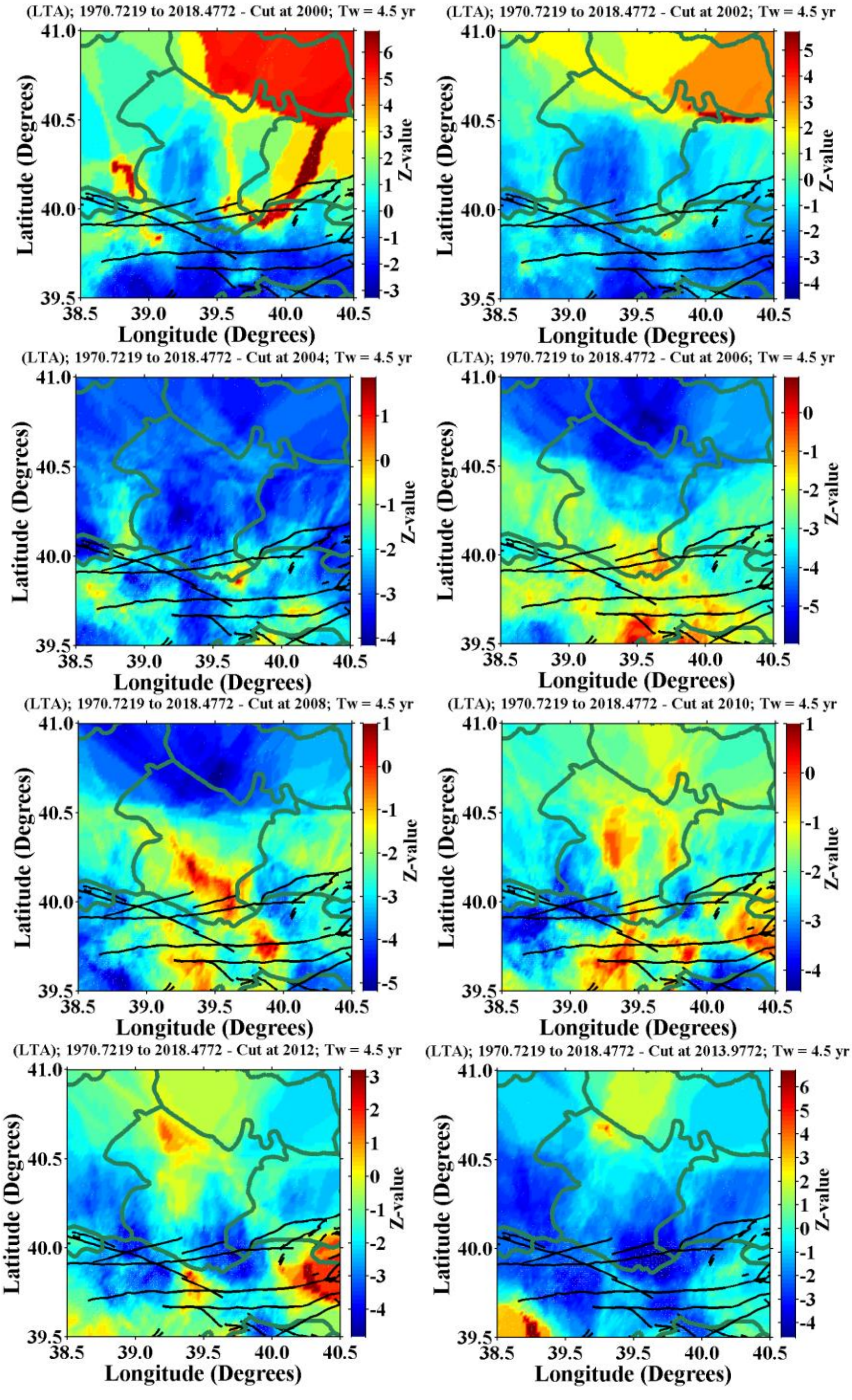

Figure 8. Regional changes of *Z*-value for every two years from 2000 to mid-2018.

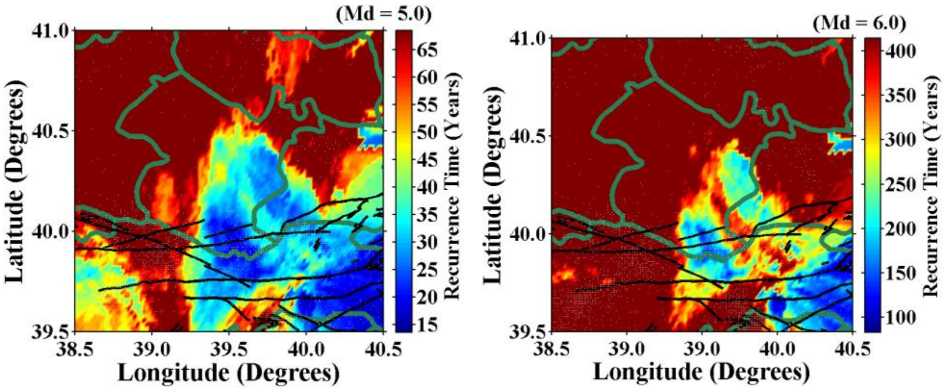

Figure 9. Regional changes of recurrence times for M_d=5.0 and M_d=6.0 earthquakes.

5. CONCLUSIONS

A comprehensive study on the region-time parameters of earthquakes in Gümüşhane and vicinity is provided by considering the most frequently used statistical parameters such as *b*-value, *Dc*-value, *Z*-value and recurrence time of earthquakes. In terms of risk and hazard, there is not a correlation among the geology and other seismotectonic parameters. Detailed region-time analyses show that Gümüşhane has not a significant risk and hazard for great earthquake occurrences in the middle of 2018. This can be interpreted that seismic hazard and risk are minor in the intermediate term in Gümüşhane.

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