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September 25, 2024 Yumrukaya-Tatvan (Bitlis, Türkiye) earthquake and a seismo-tectonic evaluation of its impact on the earthquake hazard in the region

25 Eylül 2024 Yumrukaya-Tatvan (Bitlis, Türkiye) depremi ve bölgedeki deprem tehlikesine etkisi üzerine sismo-tektonik bir değerlendirme

Serkan ÖZTÜRK[1], **Hamdi ALKAN***[2]

[1]*Gümüşhane University, Faculty of Engineering and Natural Sciences, Department of Geophysics, 29100, Gümüşhane*

[2]*Van Yüzüncü Yıl University, Faculty of Engineering, Department of Geophysics, 65080, Van*

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Abstract

The current and future earthquake hazard in and around Bitlis were tired to reveal by utilizing the September 25, 2024, Yumrukaya-Tatvan earthquake (*Mw*=4.5) and its aftershocks, *b*-value and Z-value distributions, occurrence probabilities and recurrence periods of earthquakes and variations in Coulomb stress within the scope of this study. Also, it was tried to determine which fault systems in the study area is related to the Yumrukaya-Tatvan mainshock, characterized by strike-slip faulting. *b*-value in G-R relation was computed as 0.84±0.06 and small *b*-values (<1.0) were imaged in the north-northwest-southeast directions throughout the South East Anatolian Thrust Zone and Muş Fault Zone, and west of Lake Van. At the beginning of 2025, significant seismic quiescence was observed near the Muş Fault Zone and the south and southeast of the South East Anatolian Thrust Zone. Recurrence periods for the events with the magnitudes of *Mw*=5.0, 5.5 and 6.2 were computed as ~10, ~26 and ~100 years, respectively. Additionally, occurrence probabilities of earthquakes with these magnitudes in the intermediate-term (~10 years) were calculated as ~64%, ~32% and ~10%, respectively. Positive Coulomb stress changes carry out a movement from the Kavakbaşı Fault zone in the west and the Beğendik segment in the east toward the South East Anatolian Thrust Zone in the east-southeast. In this region, there is no active fault/fault system according to the General Directorate of Mineral Research and Exploration. Thus, these findings are significant clues showing that multiple parameter seismo-tectonic analyses are important in determining the earthquake hazard for the September 25, 2024 earthquake, and that regions with small *b*-values and seismic quiescence and regions with positive Coulomb stress changes may indicate current hazard and possible earthquake zones in the future.

Keywords: *b*-value, Coulomb stress, Probability, Recurrence period, Yumrukaya-Tatvan earthquake, *Z*-value

Öz

Bu çalışma kapsamında, 25 Eylül 2024 depremi (Mw=4.5) ve artçı şoklarından, b-değeri ve Z-değeri dağılımlarından, depremlerin oluşma olasılıkları ve tekrarlama periyodlarından ve Coulomb gerilmesindeki değişimlerden yararlanılarak Bitlis ve civarındaki güncel ve gelecek deprem tehlikesi ortaya konulmaya çalışılmıştır. Ayrıca, doğrultu atımlı faylanma ile karakterize edilen Yumrukaya-Tatvan ana şokunun çalışma alanındaki hangi fay sistemleri ile ilişkili olduğu belirlenmeye çalışılmıştır. G-R ilişkisinin b-değeri 0.84±0.06 olarak hesaplanmış ve düşük b-değerleri (<1.0), Güneydoğu Anadolu Yitim Zonu ve Muş Fay Zonu boyunca kuzey-kuzeybatı-güneydoğu yönlerinde ve Van Gölü'nün batısında görüntülenmiştir. 2025 yılı başlangıcında, Muş Fay Zonu civarı ile Güneydoğu Anadolu Yitim Zonunun güney ve güneydoğusunda önemli sismik durgunluklar gözlenmiştir. Mw=5.0, 5.5 ve 6.2 büyüklüğündeki depremlerin tekrarlama periyodları sırasıyla ~10, ~26 ve ~100 yıl olarak hesaplanmıştır. Ayrıca, bu büyüklükteki depremlerin orta vadede (~10 yıl) oluşma olasılıkları sırasıyla ~%64, ~%32 ve ~%10 olarak hesaplanmıştır. Pozitif Coulomb gerilme değişimleri batıda Kavakbaşı Fay zonundan ve doğuda Beğendik segmentinden doğu-güneydoğuda Güneydoğu Anadolu Bindirme Zonuna doğru bir hareketi ortaya koymaktadır. Bu bölgede Maden Tetkik ve Arama Genel Müdürlüğü'ne göre hiçbir aktif fay/fay sistemleri bulunmamaktadır. Sonuç olarak bu bulgular, 25 Eylül 2024 Yumrukaya-Tatvan depremi için, çok parametreli sismo-tektonik analizlerin deprem tehlikesinin ortaya konulmasında önemli olduğunu, düşük b-değerleri ve sismik durgunluğun izlendiği bölgeler ile pozitif Coulomb gerilme değişimlerinin gözlendiği bölgelerin güncel tehlikeyi ve gelecekteki olası deprem bölgelerine işaret edebileceğini gösteren önemli ipuçlarıdır.

Anahtar kelimeler: *b-değeri, Coulomb gerilmesi, Olasılık, Tekrarlama periyodu, Yumrukaya-Tatvan depremi, Z-değeri*

*Hamdi ALKAN; hamdialkan@yyu.edu.tr

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1. Introduction

The Anatolian Plate is located on the Alpine-Himalayan Orogenic Belt and is the most active belt following the Pacific Seismic Belt, and it is recognized for its earthquakes characterized by transform faulting mechanisms. In recent years, especially on the NAFZ (North Anatolian Fault Zone), EAFZ (East Anatolian Fault Zone), NEAFZ (North East Anatolian Fault Zone), DSFZ (Dead Sea Fault Zone), BZSZ (Bitlis-Zagros Suture Zone) and WAEP (Western Anatolian Extension Province), large/destructive earthquakes such as the August 17, 1999 İzmit earthquake (*Mw7*.6), the October 23, 2011 Van earthquake (*Mw7*.2), the October 30, 2020 Samos earthquake (*Mw6*.9) the January 24, 2020 Elazığ earthquake (*Mw6*.8), and February 6, 2023 Kahramanmaraş earthquake doublets (*Mw7*.7 and *Mw7*.6) have occurred according to USGS. Also, the relative movements of the Eurasian-Anatolian-Arabian Plates in the East Anatolian region and the deformation occurring along the BZSZ cause additional tectonism and earthquake activity in this region. In particular, the 2011 Van earthquake and its ongoing aftershocks are important tectonic activities that occurred in the eastern part of the Lake Van basin and which is related to a compression regime. Although not as prominent as the eastern part of the Lake Van basin, the western part of it still contains faults and fault zones that will produce significant medium-magnitude earthquakes. In this context, the recently occurred September 25, 2024 Yumrukaya-Tatvan earthquake (*Mw*4.6) can be considered as a critical indicator to understand the seismicity of Bitlis province and its vicinity.

KOERI (Boğaziçi University, Kandilli Observatory and Research Institute) records show that a mid-size (*Mw*4.6) and shallow (depth=5.4 km) earthquake occurred near Yumrukaya-Tatvan location of Bitlis on September 25, 2024. This earthquake occurred southeast of the Kavakbaşı Fault Zone (KFZ) and just north of the South East Anatolian Thrust Zone (SEATZ). Bitlis province is located north of the SEATZ and south of the northwest-southeast oriented Muş Fault Zone (MFZ). Some important tectonic structures in Bitlis and its surroundings can be given as Kavakbaşı Fault Zone consisting of Kaleköy, Kayalısu, and Ilıcaköy segments in the west, Lake Nazik, Malazgirt, Bulanık and Akdoğan Faults in the north, the segments of SEATZ in the south, and Nemrut fault in the east (Emre et al., 2018). However, on the active tectonic map of the General Directorate of Mineral Research and Exploration, there exist no active faults/fault zones in the epicenter region of the Yumrukaya-Tatvan mainshock. According to focal mechanism solutions made by KOERI and AFAD (Disaster and Emergency Management Presidency), this earthquake has a strike-slip fault mechanism. The directions of the aftershocks which are thought to be related to this earthquake are in the northeast-southwest direction. Shortly after this earthquake, on November 2, 2024, two more events with the same magnitude (*Mw*4.3) occurred in a region closer to city center of Bitlis. These earthquake doublets have a strike-slip mechanism and their aftershocks are in the northeast-southwest direction as in the Yumrukaya-Tatvan earthquake. Therefore, these recent earthquake doublets in the region have shown once again that Bitlis and its surroundings, located in the Lake Van basin, is a seismo-tectonically active region of Türkiye.

Many large/devastating earthquakes occurred in this area throughout the main faults and fault zones in the historical and instrumental period. According to the catalogs of KOERI and AFAD, the seismicity of the region is still active and hence, faults and fault zones in this region produce small/strong earthquakes. Also, the western shores of Lake Van are within the borders of Bitlis and the Lake Van is the other significant tectonic structure in the region. Lake Van, which has undergone strong north-south deformation of the Arabian-Eurasian Plates and has produced large earthquakes, has significant faults and fault zones in and around the lake (Işık et al., 2012). SEATZ, MFZ and KFZ have a significant effect on the tectonics of Bitlis and right/left lateral strike-slip faults which are parallel to NAFZ and EAFZ are dominant tectonic elements (Figure 1a). As seen in Figure 1b, some of these tectonic structures can be given as Akadoğan Gölü, Nazik Gölü, Haçlı Gölü faults, Bulanık, Malazgirt, Yenisu and Cizre faults. Also, some segments such as Karlıova, Kaleköy, Kayalısu, Ilıcaköy (on the KFZ), Kulp, Kozluk, Şirvan and Beğendik control the movements of these main faults. Fault mechanisms of these main tectonic structures show generally strike-slip and normal faulting in northwest-southeast and northeast-southwest directions (Emre et al., 2018). The Lake Van basin, including Bitlis province, is located just north of the BZSZ and is also located between the Zagros Fault zone and the Karlıova Triple Junction (KTJ). All the mentioned faults are active and hence, many large/damaging mainshocks occurred in and around Bitlis from historical time to the present day. Some of them can be given as; 1208 Ahlat-Van-Bitlis-Muş (*Mw*6.5, moment magnitude), 1696 Çaldıran-Bitlis (*Mw*6.8), 1705 Bitlis (*Mw*6.7), 1903 Bitlis-Ahlat (*Mw*5.2), 1914 Bitlis (*Mw*5.8), 1915 Bitlis-Ahlat (*Mw*5.6), 1934 (Mw6.2), 1966 Bitlis-Hizan (*Mw*5.1), 1982 Bulanık-Varto-Muş (*Mw*5.6), 2012 Bulanık-Muş (*Mw*5.1) and 2020 Kurtalan-Siirt (*Mw*5.1) earthquakes (KOERI; Işık et al., 2012). Thus, recent September 25, 2024 Yumrukaya-Tatvan (*Mw*=4.6) earthquake is one of the significant evidence of this active seismicity.

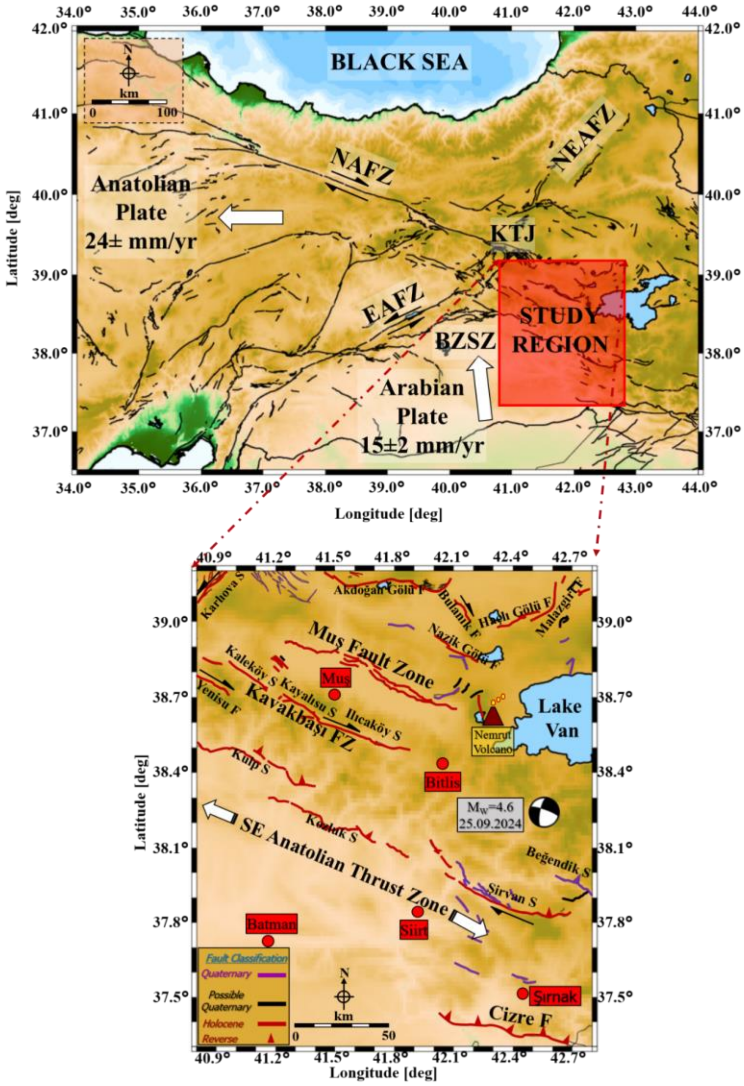


Figure 1. (a) Main faults and fault zones in the East Anatolian region of Türkiye (modified from Emre et al., 2018). Abbreviations of fault names are given in the text as well S: Segment, F: Fault, FZ: Fault Zone. Large white arrows indicate plate motion directions (Reilinger et al., 2006). Study region is shown in red color. (b) Main tectonics in the region (modified from Emre et al., 2018). City locations are given with red circles.

There exist many studies that use different scaling laws as well as statistical and physical models to evaluate the time-region-magnitude behaviors of earthquake occurrences both in Türkiye and the world. For a quantitatively evaluation of the earthquake occurrences in seismo-tectonically active regions and for providing preliminary useful information, well-known and frequently preferred scaling tools such as *b*-value which is the basis of earthquake statistics in seismology, *Z*-value describing standard normal deviate (seismic rate change), *Mc*-value (completeness magnitude) analyses, recurrence period and occurrence probability of the earthquakes and stress changes are generally preferred. With the detailed analyses of these parameters, remarkable results have been obtained about the earthquake behaviors (e.g., Hirata, 1989; Matsumura, 1993; Wiemer & Wyss, 2000; Öncel & Wilson, 2004; Katsumata, 2011; Ulukavak et al., 2020; Sinaga et al., 2022; Öztürk & Alkan, 2023; 2024a, b; Yang et al., 2024; Alkan et al., 2025). For the comprehensive statistical and seismo-tectonic analyses within the aim of this research, time-region-magnitude analyses of the earthquake behaviors in and around Bitlis province were achieved by using (*i*) completeness magnitude, (*ii*) *b*-value, (*iii*) *Z*-value, (*iv*) earthquake occurrence probability, (*v*) recurrence periods and (*vi*) Coulomb stress changes. For the statistical analyses, ZMAP (Wiemer, 2001), Coulomb 3.4 (Toda et al., 2011), and Generic Mapping Tools (GMT, Wessel et al., 2019) software were used. The obtained results will not only be important for defining the earthquake behaviors, but will also contribute to the understanding of earthquake occurrences in the study region. Thus, these parameters will also provide valuable findings for the real-time investigation of the future earthquake potential for this part of Türkiye and its vicinity.

2. Statistical methods

Magnitude-frequency distributions of the earthquakes are defined by Gutenberg-Richter (G-R) relationship (Gutenberg & Richter, 1944) and this physical power law is represented by *b*-value. It is one of the most frequently used tools in earthquake statistics and hazard studies since it is necessary for the calculation of occurrence probabilities and recurrence periods of future earthquake occurrences. Another valuable parameter for describing spatio-temporal behaviors of earthquake occurrences is the evaluation of changes in earthquake activity. Precursory seismic quiescence (*Z*-value) is defined by Wyss & Martirosyan (1998) as "*an important decrease in the average seismicity rate compared to background activity*". Therefore, determination of seismicity rate changes may be significant in determining the earthquake hazard since quiescence period strongly depends on the seismo-tectonic events. In addition to these parameters, Coulomb stress analysis is very important in order to observe the amount of stress increase imposed by previous earthquakes in a region. Static stress changes from an earthquake may affect the present stress state and trigger subsequent occurrences of earthquake on nearby faults. Thus, observation of the stress changes is valuable for explaining the interaction between earthquakes and can contribute to the earthquake hazard and prediction (Alkan et al., 2023).

2.1. Gutenberg-Richter relation (*b*-value), completeness magnitude (*Mc*-value), occurrence probability and recurrence period

An empirical scaling law for the magnitude-frequency relationship of earthquake occurrences was described by Gutenberg & Richter (1944). This is the main equation of earthquake statistics and is given as follows:

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

In this equation, $N(M)$ is the cumulative number of the events in a given period with magnitudes bigger than or equal to M. *a*-value and *b*-value are given as positive coefficients. *b*-value is computed from the slope of magnitude-frequency curve, whereas *a*-value is estimated from earthquake activity rate. Changes of *a*-value for any areas are related to some factors such as duration of the earthquake database, dimension of the seismic zone and the number of events. Literature researches show that *b*-value changes between 0.3 and 2.0 for different active zones in the Earth (Utsu, 1971) and that average *b*-value equals 1.0 (Frohlich & Davis, 1993). Changes in *b*-value can be used to define the properties of seismo-tectonic medium, region-depth variations of stress and relative proportions of small or great events. In general, if *b*-value has a decreasing trend for a seismo-tectonically active zone, it can be commented as the possibility of an earthquake occurrence in this zone. Also, many factors such as seismic, tectonic and geologic properties, stress heterogeneities, anisotropic structure, fault length, crack density, thermal gradient, seismic attenuation, changes in seismic wave velocity, slip distribution or strain circumstances influence the changes on *b*-value (e.g., Scholz, 1968; Öztürk et al., 2008; Nanjo, 2020). As a result, it is considered that *b*-value is considered to be very important parameter in appraising the earthquake hazard in a seismic zone.

For the correct and reliable results in earthquake statistic, the usage of the maximum number of events is quite significant for the determination of seismo-tectonic variables such as *b*-value or seismic quiescence. Hence, completeness magnitude, *Mc*-value, is an important tool and this calculation should be performed as the first step. *Mc*-value is given as the smallest magnitude of all records and level of this magnitude contains 90-95% of the events that can be represented by a scaling law. The estimation of *Mc*-value depends on the magnitude-frequency distribution and the calculation of the maximum value of the first derivative of this distribution (Wiemer & Wyss, 2000). *Mc*-value may be estimated with the maximum likelihood method by using a moving time window approach. By considering the earthquakes with each window including a certain number of events, an average magnitude level is considered for the earthquakes in this window. After that, this magnitude level computed for each window is taken as the average completeness magnitude for the time period of that window. Since *Mc*-value changes in time, variations in *Mc*-value may affect the statistical results and therefore, estimation of completeness magnitude as a function of time should be achieved carefully.

Taking into consideration G-R relationship, occurrence probabilities of earthquakes in different magnitude (M) sizes and certain periods (Tr) are given by following equation (Tabban & Gençoğlu, 1975):

$$P(M) = 1 - e^{-N(M)*Tr} \quad (2)$$

In this eqution, $P(M)$ is the probability of occurrence that at least one event may occur in Tr years (such as 10, 20, 30, …., 100) and $N(M)$ is estimated from G-R distribution in Equation (1). Second equation is the result of Poisson distribution. Recurrence period of any earthquake with the certain magnitude sizes is computed from the formula as follow (Tabban & Gençoğlu, 1975):

$$Q = 1/N(M) \quad (3)$$

where, $Q(M)$ is the recurrence period of an event and is known as the estimated time interval for an event with a magnitude $\geq M$.

2.2. Declustering procedure and seismic rate change (*Z*-value, standard normal deviate)

Elimination of the dependent (secondary) shocks like aftershocks, foreshocks, earthquake swarms and explosions from the earthquake database is one of the most fundamental steps in statistical seismology for earthquake hazard appraisal and evaluation of rate changes in earthquake activity. In the clustering approach, a catalog is declustered (decomposed) into dependent and independent events and this cluster analysis removes all dependent events from each cluster (Arabasz & Hill, 1996). Therefore, to obtain a uniform earthquake data for the seismic quiescence analysis, declustering process should be applied to the catalogs. In this study, declustering algorithm defined by Reasenberg (1985) and available in *ZMAP* software package was preferred in order to decluster the catalog.

Hypothesis of seismic quiescence is firstly recommended by Wyss & Habermann (1988) and according to it, there exists a significant decrease in earthquake activity in a limited part of a seismogenic zone and this decrease in ongoing seismicity compared to background level can be described as seismic quiescence (Wiemer & Wyss, 1994). This quiescence in seismicity rate can be observed in the earthquake focal region and its vicinity for several years before the occurrence of the mainshock, or this decrease can be distinguished by relatively short time period due to the increasing trend in seismicity (Wyss & Habermann, 1988). Seismic quiescence method used in *ZMAP* is suggested by Wiemer & Wyss (1994) and standard normal deviate (*Z*-test) is frequently preferred techniques in these types of applications. *Z*-test uses $LTA(t)$ function (Long Term Average) for the statistical appraisal of the confidence level in standard deviation units (Wiemer & Wyss, 1994):

$$Z(t) = \frac{R_{all} - R_{wl}}{\sqrt{\frac{\sigma_{all}^2}{n_{all}} + \frac{\sigma_{wl}^2}{n_{wl}}}} \quad (4)$$

In this equation, R_{all} is the main seismicity rate (number of earthquakes) in the overall period, R_{wl} is the main seismicity rate in the considered time interval. σ_{all} and σ_{wl} are the standard deviations in these two periods, while n_{all} and n_{wl} are the parameters related to the number of samples in the calculated seismic activity rate. Thus, *Z*-value is calculated as a function of time and is defined as $LTA(t)$.

2.3. Coulomb stress analysis

An earthquake occurrence and stress distribution related to a failure along a fault and it can be clarified by variations in Coulomb failure stress. These types of variations are affected by the slip and geometry of the source fault and effective coefficient of friction. Coulomb stress analysis is a very useful tool to determine the stress conditions when a rupture occurs at the source fault. Variations in Coulomb failure stress ($\Delta\sigma_{cfs}$) on the receiver fault is given by following formula (King et al., 1994):

$$\Delta\sigma_{cfs} = \Delta\tau_s + \mu'\Delta\sigma_{n'} \quad (5)$$

In this equation, $\Delta\tau_s$ is the shear stress variations related to positive direction of the receiver fault slip. , $\Delta\sigma_{n'}$ represents the normal stress change along the fault plane and μ' is the effective coefficient of friction on the fault (Toda et al., 2011). μ' includes the effects of pore-pressure changes and varies from 0 to 1. For the computation of stress changes, μ'-value can be considered as 0.4 as stated in King et al., (1994). The dimensionless Poisson's ratio (v) is accepted as 0.25 and Young modulus (E) is taken as 8×10^5 bars. Stress may increase or decrease rapidly during the loading cycle before the large earthquakes. Therefore, crustal deformation from an earthquake causes stress changes in the seismic source zone and its surroundings. In terms of earthquake physics, the expected location of the future strong/large earthquake depends on the state of stress loaded by the past events and the current seismic and tectonic situations. Recent studies have shown that stress accumulation is caused by earthquakes in the crust and this movement may trigger the future events on nearby faults (King et al., 1994; Toda et al., 2011; Nanjo, 2020; Alkan et al., 2023; Öztürk et al., 2024a, b). Since negative and positive changes in Coulomb stress from -0.1 to 0.1 (bar) are thought to record the forthcoming earthquake hazards (Yadav et al., 2012), regional changes of Coulomb stress distribution are imaged in this criteria.

3. Database for the statistical analyses and Coulomb stress variations

In the scope of this study, a homogeneous earthquake database for the moment magnitude (*Mw*) compiled from Tan (2021) for the time interval from 1905 to 2019 was used to achieve a detailed time-region-magnitude appraisal of the earthquake activity. A uniform, detailed and homogeneous database was prepared by Tan (2021) and it is stated that *Mw* should be considered for the earthquake hazard evaluation. For Türkiye and its surroundings, there exist 377.429 earthquakes in this catalog from 1905 to 2019. Also, the earthquakes with local magnitude (M_L) from 2019 to 2025 are taken from KOERI and there are 164.743 earthquakes in and Türkiye and its vicinity in these time intervals. To obtain a homogeneous database for *Mw* from 2019 to 2025, a relationship given by Tan (2021) for *Mw*-M_L conversion (Mw=1.017*M_L-0.012) is used. For Türkiye and its vicinity, 542.172 events are obtained from 1905 to 2025. Then, the events in the study region covering 37.3°N-39.2°N in latitudes and 40.8°E-42.8°E in longitudes are selected. After this process, a catalog including 7056 earthquakes with 1.0≤*Mw*≤6.2 from November 12, 1934 to December 29, 2025, about 90.13 years, is prepared for the statistical analysis. Earthquake epicenters and great mainshocks with *Mw*≥5.0 are plotted in Figure 2a. Also, 25 events with *Mw*≥4.0 that recorded in the study area by AFAD after 2012 are used to determine the variations in Coulomb stress (Figure 2b). Figure 2b shows the focal mechanisms and epicenter locations, exhibiting generally strike-slip fault characteristics. Also, the parameters (dip, strike, rake, etc.) of focal mechanisms for earthquakes are taken from AFAD, and some details are listed in Table 1. As a result, the changes in Coulomb stress is mapped according to the strike-slip fault mechanism.

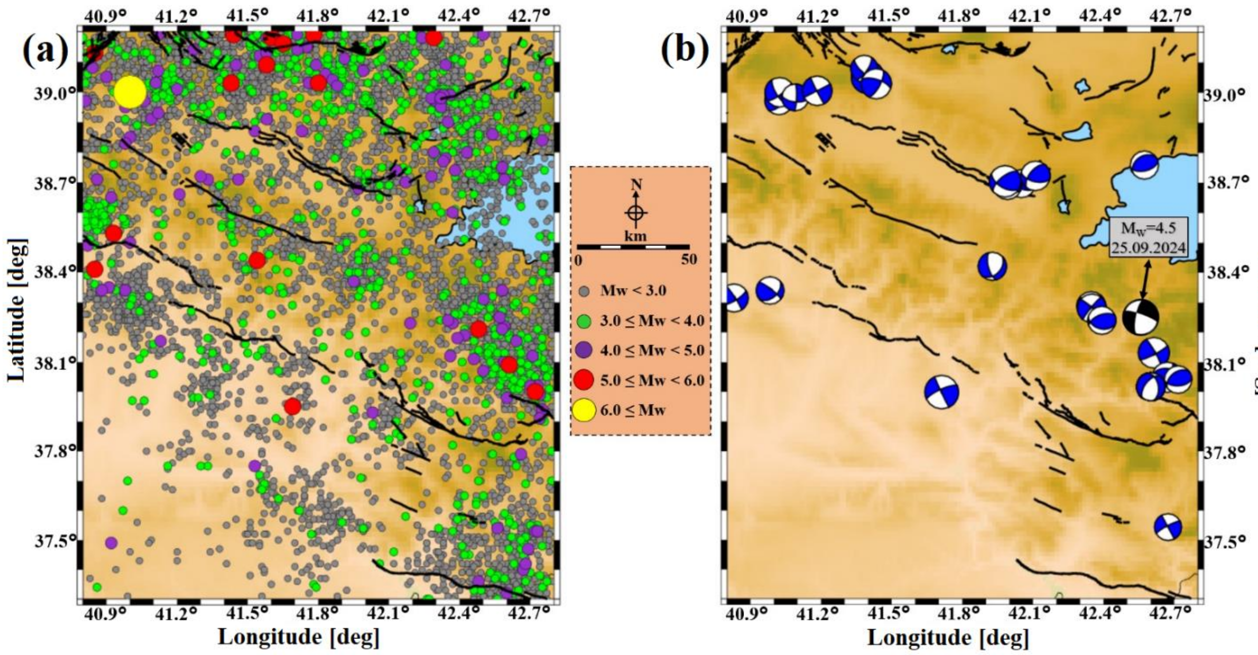
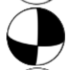
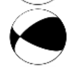
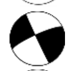
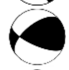
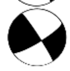
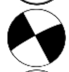
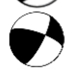


Figure 2. (a) Epicenter locations of 7056 events with *Mw*≥1.0 in and around Bitlis in the time interval between 1934 and 2025. Magnitudes of earthquakes are drawn with different symbols. (b) Blue and black beach balls show the fault plane solutions. The geometry (strike/dip/rake) of these earthquakes is used to calculate Coulomb failure stress variations. The fault-plane solutions (see Table 1 for details) are taken from the AFAD website (https://deprem.afad.gov.tr/event-catalog).

Table 1. Solutions of fault mechanism for earthquakes used to calculate Coulomb stress changes (All details of earthquakes were provided from the website of AFAD (https://tdvms.afad.gov.tr/).

No	Date	Latitude (°N)	Longitude (°E)	Depth (km)	Magnitude (Mw)	Strike/Dip/Rake (°)	Location	Fault Type
1	2024-11-27T02:56:43	38.288	42.347	10.53	4.3	42/89/-38	Bitlis	
2	2024-11-27T02:50:07	38.280	42.350	8.71	4.3	219/83/-5	Bitlis	
3	2024-09-25T11:50:03	38.252	42.555	8.67	4.5	289/73/-153	Tatvan	
4	2023-03-06T04:57:33	38.973	41.021	13.29	4.2	45/62/11	Solhan	
5	2023-02-25T00:28:09	39.001	41.024	12.5	4.4	148/70/-166	Solhan	
6	2023-02-06T19:51:18	38.984	41.090	10.72	4.0	96/62/-171	Solhan	
7	2022-11-10T04:57:32	38.759	42.573	5.84	4.2	237/36/74	Van Lake	
8	2021-04-07T08:47:22	38.697	42.050	11.15	4.2	233/49/40	Korkut	
9	2020-12-03T05:45:19	37.999	41.712	14.02	5.0	155/88/166	Kurtalan	
10	2020-09-18T00:15:10	38.691	41.991	13.14	4.2	232/48/39	Korkut	
11	2020-09-16T14:48:19	38.705	41.981	17.08	4.7	231/64/40	Korkut	
12	2020-08-07T19:20:13	38.131	42.613	6.99	4.6	331/83/171	Hizan	
13	2019-08-12T13:34:27	38.315	40.830	6.41	4.2	327/84/164	Hazro	
14	2018-05-23T22:10:43	38.240	42.392	3.69	4.2	105/39/119	Hizan	
15	2018-03-24T15:04:06	38.340	40.983	12.01	4.1	308/80/134	Kulp	
16	2017-04-18T22:40:54	37.543	42.673	14.16	4.0	152/90/171	Şırnak	
17	2016-10-23T08:22:01	38.421	41.927	1.63	4.2	165/67/-123	Mutki	
18	2016-01-23T07:53:44	38.049	42.670	15.21	4.5	279/42/163	Hizan	
19	2015-02-04T02:48:04	38.041	42.716	5.66	4.1	87/52/113	Bahçesaray	
20	2014-10-30T14:35:44	38.723	42.110	12.23	4.4	104/57/140	Güroymak	
21	2013-09-17T20:40:50	39.051	41.398	19.01	4.9	289/51/-178	Muş	
22	2013-09-17T23:14:28	39.079	41.383	21.97	4.0	132/68/-159	Varto	
23	2013-09-16T10:31:39	39.029	41.434	19.46	4.5	288/66/157	Muş	
24	2013-05-15T07:09:58	39.006	41.183	15.64	4.4	153/88/180	Solhan	
25	2012-01-06T02:06:52	38.017	42.600	22.67	4.2	218/56/-57	Hizan	

4. Results

The main purpose on this study is to define the time-region-magnitude behaviors of earthquake occurrences and to present valuable preliminary findings for the current earthquake hazard and future earthquake potential in and around Bitlis at the beginning of 2025 by analyzing the seismic and tectonic variables such as *Mc*-value, *b*-value, occurrence probabilities and recurrence periods of the earthquakes, *Z*-value and Coulomb stress.

In the earthquake statistics, the selection of *Mc*-value is very important and it should be the first stage since the minimum magnitudes in earthquake catalogs changes over time. Also, the aim is to use the maximum number of events for the correct results in these types of studies. As mentioned in method section, variations of *Mc*-value in time with its standard deviation were computed by using moving time window method and given in Figure 3. For the estimation of *Mc*-value, all catalog containing 7056 events with 1.0≤*Mw*≤6.2 between November 12, 1934 and December 29, 2025 were considered and *Mc*-value was computed with its standard deviation for every 500 events/window. It is shown that *Mc*-value is between 2.5 and 2.9 until 2013, whereas it changes between 1.8 and 2.5 from 2013 to 2015. Then, it has a value around 1.8 from 2015 to 2018 and it varies from 1.8 to 2.0 between 2018 and 2020. However, it fluctuates around 2.0 after 2020. This results show that changes of *Mc*-value in time are not constant and that *Mc*-value is between 1.8 and 2.6 from 2013 to 2025. As a result, since some statistical calculations such as *b*-value, *Z*-value, occurrence probabilities and recurrence periods will be performed within the scope of this study, determination of *Mc*-value was realized as the first step and an average *Mc*-value was assumed to be 2.3.

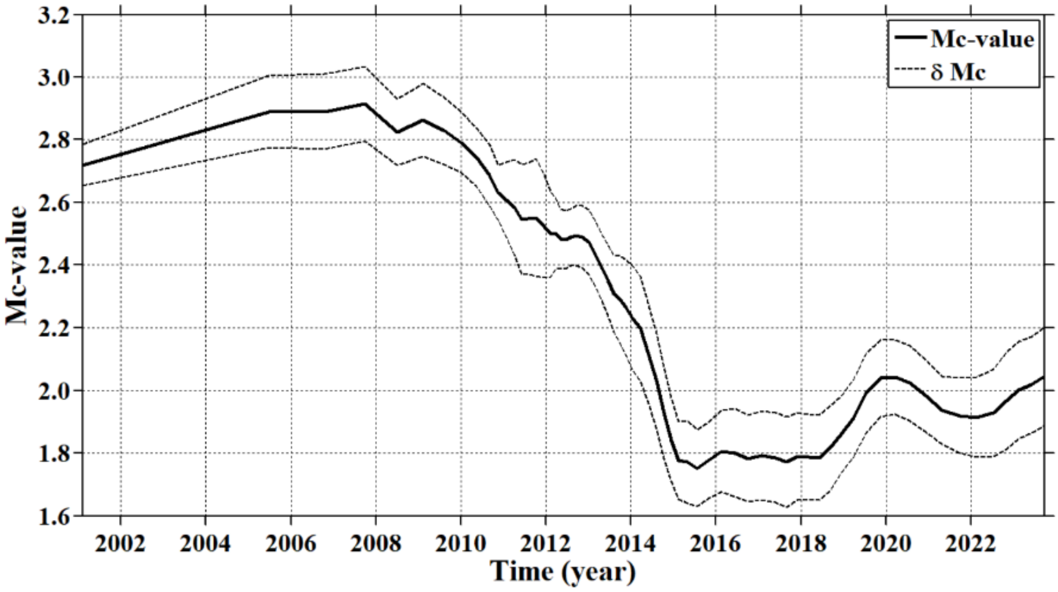


Figure 3. *Mc*-value change as a function of time. Dashed lines (δ*Mc*) show the standard deviation. *Mc*-value was computed by using moving time window estimation by using 500 earthquakes/window.

As mentioned in Data section, there are 7056 earthquakes with *Mw*≥1.0 from November 12, 1934 to December 29, 2025 in the original catalog including all events. After declustering process, 934 earthquakes (%13.24) were removed from the catalog. Accepting to be *Mc*=2.3, 2987 events with *Mw*<2.3 in declustered catalog were also eliminated from the catalog. After declustering and elimination processes, and considering *Mc*-value as 2.3, a total of 3921 events (%44.43) were removed from the original catalog. Thus, a more independent and uniform earthquake catalog, which do not include any dependent events, was obtained for the analysis of seismicity rate. Figure 4 shows the cumulative number of events in time for different magnitude values with the original and declustered catalogs. As seen in Figure 4, the original catalog with *Mw*≥1.0 includes 7056 events (black line), declustered catalog with *Mw*≥1.0 contains 6122 events (blue line) and declustered catalog with *Mw*≥2.3 has 3135 events (red line). There is not any significant seismic activity between 1934 and 2000, and there are very few events between 2000 and 2010. However, there exist a significant earthquake activity increasing after 2010. From Figure 4, the cumulative number curve of declustered catalog with *Mw*≥2.3 has a smoother slope in comparison with the other two catalogs. Literature studies suggest that declustering process using *Mc*-value is necessary to remove dependent events such as foreshocks, aftershocks or earthquake swarms from the catalog. Therefore, this processes should be made as the first step in order to estimate *b*-value and to evaluate the seismicity rate changes (Katsumata & Kasahara, 1999; Joseph et al., 2011). Thus, in this study, by applying these processes to the catalog, a more homogeneous and reliable dataset was obtained for statistical analyses.

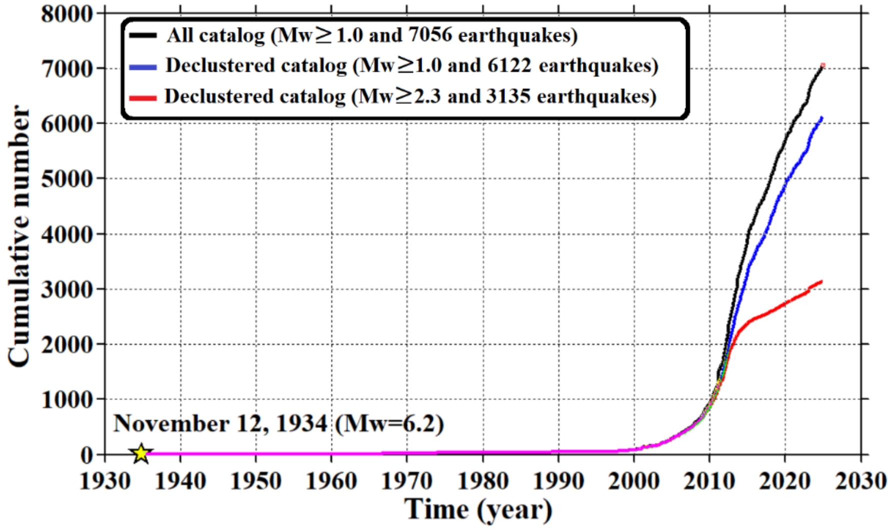


Figure 4. Cumulative number of earthquakes as a function of time. Black line is for all data with $Mw \geq 1.0$, blue line is for the declustered data with $Mw \geq 1.0$ and red line is for the declustered data with $Mw \geq 2.3$.

Magnitude and time histograms of 7056 earthquakes with magnitude $1.0 \leq Mw \leq 6.2$ in Bitlis and its vicinity were plotted in Figure 5. As shown in Figure 5a, magnitudes of the many earthquakes are between 1.5 and 3.0, and the number of events reaches a maximum at $Mw=2.5$. There exist 6206 earthquakes for $1.0 \leq Mw \leq 3.0$, 725 events for $3.0 \leq Mw \leq 4.0$, 108 events for $4.0 \leq Mw \leq 5.0$, 16 events for $5.0 \leq Mw \leq 6.0$, and 1 events for $Mw \geq 6.0$. As a result, it can be said that events with magnitudes between 2.0 and 2.5 occur more frequently in and around study region. This increase in the number of earthquakes with small magnitudes can be interpreted as an evidence of the increasing stress in and around Bitlis at the beginning of 2025. Time histogram of the earthquakes in a period of approximately 90.13 years between 1934 and 2025 was given in Figure 5b.the seismicity between 1934 and 2010 changes very little and there are 917 events in this period. Although the number of earthquakes between 2010 and 2015 indicates both strong decreases and increases, there has been a decreasing trend in the earthquake activity after 2015. There exist 2945 earthquakes from 2010 to 2015 whereas 3193 earthquakes are recorded from 2015 to 2025. Also, the increase in the number of earthquakes reached its maximum level between 2012 and 2013 as 1438 events. As an important result, these types of statistical appraisal may provide valuable information for the evaluation of changes in earthquake activity and these types of changes may also be used for the comprehensive spatio-temporal assessment of seismic quiescence in Bitlis and its surroundings.

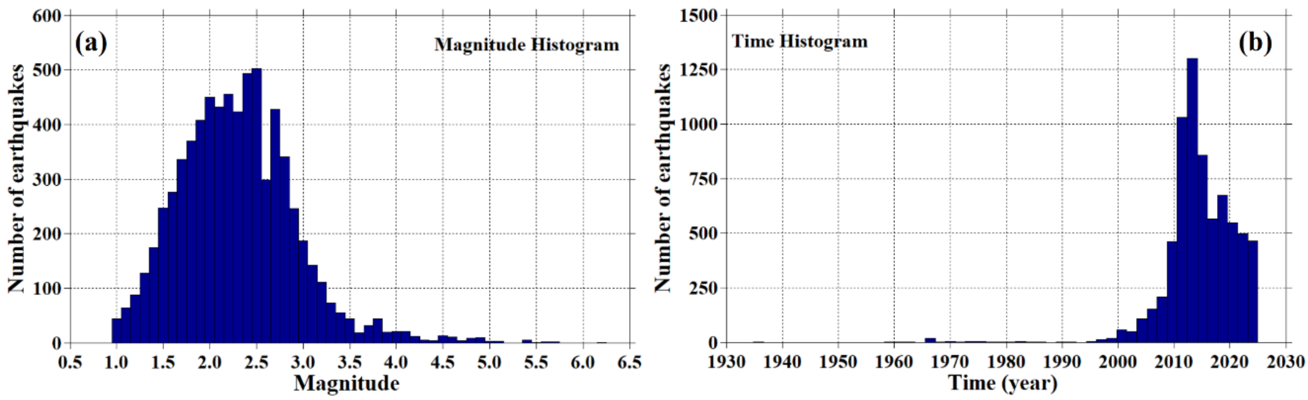


Figure 5. (a) Magnitude histogram and (b) Time histogram for the seismic activity including 7056 events with $Mw \geq 1.0$ in and around Bitlis from 1934 to 2025.

Magnitude-frequency distribution of the earthquakes and *b*-value of G-R relation and spatial distribution of *b*-value at the beginning of 2025 were plotted in Figure 6. *b*-value was estimated as 0.84±0.06 with the maximum likelihood method by using the original catalog including all earthquakes and $Mc=2.3$ (Figure 6a). It is well known that *b*-value changes between 0.3 and 2.0 on global scale and average *b*-value is suggested as ~1.0.

However, *b*-values for tectonic earthquakes vary from 0.5 to 1.5. As seen in Figure 6a, magnitude-frequency distribution of the earthquake occurrences in the region is well represented by G-R relationship and hence, it can be said that *b*-value of 0.84 is a relatively small compared to average value. Thus, this result can be interpreted as an increased stress situation in this part of Türkiye. Regional changes in *b*-value was computed using the moving window technique by using 750 earthquakes/window with a grid spacing of 0.05°×0.05° in latitude and longitude. As shown in Figure 6b, *b*-value variations are between 0.61 and 1.57. As mentioned above, *b*-value for global earthquakes is suggested by G-R relationship with a mean value of 1.0. According to this definition, large *b*-values (b>1.0) were observed in and around Siirt, Batman and Şırnak provinces and in the south, southeast and southwest parts of these provinces (southern parts of SEATZ), on the Bulanık, Malazgirt and Haçlı faults (including Malazgirt and Adilcevaz). However, there exist strong decreases (b<0.9) in *b*-value in and around MFZ (covering Muş, Bitlis, Hizan, Bahçesaray, Çatak and Pervari), KFZ (including Kaleköy, Kayalısu and Ilıcaköy segments), Akdoğan and Nazik Gölü faults, Yenisu fault, Kulp, Şirvan and Beğendik segments as well as in and around Nemrut Volcano. Also, small *b*-values were calculated in the eastern part of the study region covering west of the Lake Van (including Tatvan and Ahlat). The regions with low *b*-values especially cover MFZ, KFZ with all segments and Akdoğan Gölü and Yenisu faults, as well as Kulp, Şirvan and Beğendik segments. These regions with small *b*-values are associated with strong and large earthquake occurrences (Figure 2a) and as a result, *b*-value distribution is in a well consistent with earthquake activity in the study region.

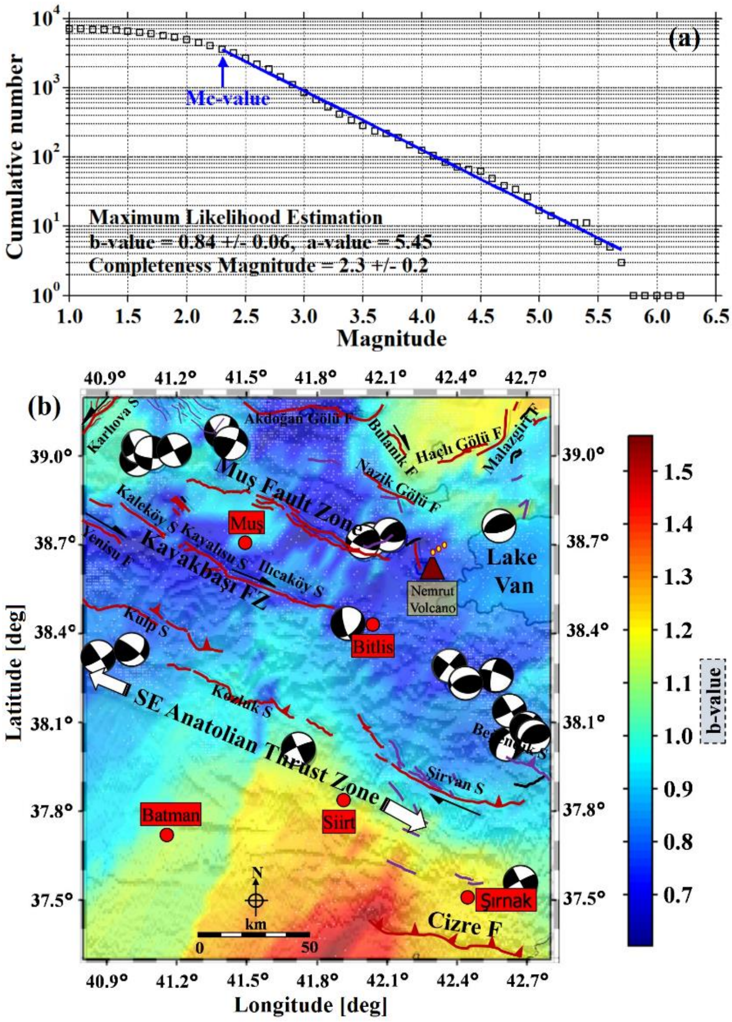


Figure 6. (a) G-R relation and *b*-value. *b*-value and its standard deviation, *a*-value and *Mc*-value with its standard deviation are also given. (b) Regional change map of *b*-value at the beginning of 2025.

Another significant tool for the statistical evaluation of earthquake potential and hazard of a seismo-tectonically active region is the estimation of occurrence probabilities and recurrence periods of expected earthquake magnitudes. These types of calculations for all earthquake magnitudes in the database were plotted in Figure 7. As shown in Figure 7a, the highest occurrence probabilities, which changes between 65-100% for different *Tr* values (*Tr*=10, 20, 30, …., 100), was estimated for the magnitudes of 1.0≤*Mw*≤5.0. Occurrence probability of an event with *Mw*=5.5 in *Tr*=10, 20, 50, 70 and 100 years were calculated as ~32%, ~54%, ~86%, ~93% and ~98%, respectively. Also, occurrence probability for *Mw*=6.0 in different *Tr* values varies from ~15% to ~75%. However, occurrence probabilities of the largest earthquake with *Mw*=6.2 in *Tr*=10, 20, 50, 70 and 100 years were estimated as ~10%, ~18%, ~39%, ~50% and ~63%, respectively. Besides these specific magnitude levels, occurrence probabilities for all earthquake magnitudes in all *Tr* periods can be observed in Figure 7a. Recurrence periods of the events for all magnitude levels were drawn in Figure 7b. As seen in Figure 7b, relatively low recurrence periods (<~2 years) were computed for earthquake magnitude between 1.0 and 4.2, whereas recurrence periods for magnitudes ranging from 4.3 to 5.0 were calculated between 2 and 10 years. Recurrence periods from 10 to 30 years can be expected for magnitudes 5.1≤*Mw*≤5.6, while recurrence periods from 30 to 65 years were estimated for magnitudes varying from 5.7 to 6.0. According to the results, recurrence periods of events with *Mw*=5.0, 5.5 and 6.0 were computed as ~10, ~26 and ~65 years, respectively. Also, recurrence period of the largest events with *Mw*=6.2 were calculated as ~100 years. In addition to these specific magnitude levels, recurrence period for all magnitudes can be seen in Figure 7b. The findings for occurrence probabilities and recurrence periods show that earthquake magnitudes in the range of *Mw*=5.0-6.0 in the intermediate-term (~10 year) are more likely than those of the other magnitude levels. Thus, these estimations may provide primary and significant perspectives in revealing the earthquake potential and hazard in the study region or other active parts of Türkiye.

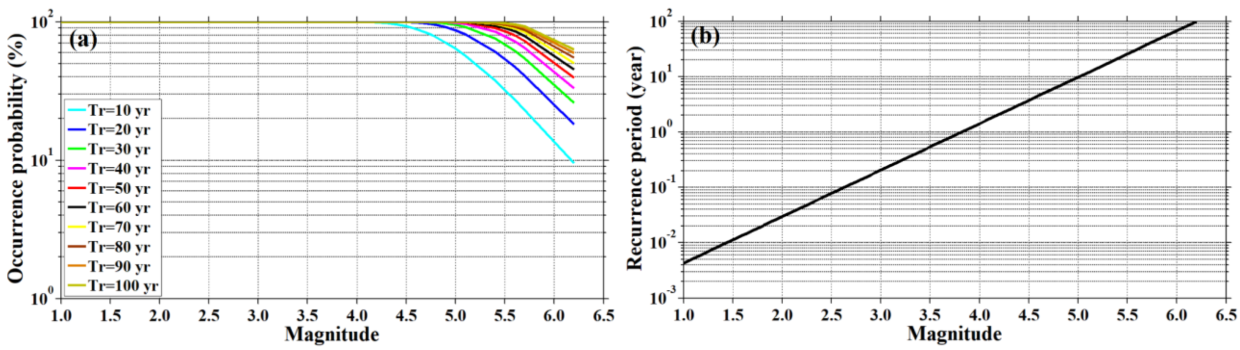


Figure 7. (a) Occurrence probabilities of different magnitude levels in the catalog for the certain values of *Tr* (years) such as 10, 20, 30, …, etc., given in the text. (b) Recurrence periods of different earthquake magnitudes in the catalog.

As mentioned before, definition of the precursory quiescence in the seismicity reveals the earthquake activity rate in a zone and may supply significant results in earthquake prediction. To this end, as in the estimation process of *b*-value, the study region was divided into 0.05°×0.05° grid intervals and *Z*-value map was created by considering the length of time window Tw=3.5 years (Figure 8). For this analysis, a declustered catalog with containing 3135 earthquakes with *Mw*≥2.3 was utilized. For the temporal variation of *Z*-value regional distribution, we mapped the quiescence areas by using Tw=2.5, 3.5, 4.5 and 5.5 years, but the quiescence anomalies are the best imaged at the epicentral regions for Tw=3.5 years. We concluded that quiescence areas are better visible for a window of 3.5 years. As indicated in Figure 8, there exist 5 anomaly areas showing seismic quiescence in the study region at the beginning of 2025. These quiescence regions are centered in the north of Haçlı Gölü fault (region A) and its south direction (region B), on the MFZ and its surroundings (region C), in the southwest of Ilıcaköy segment (region D), on the south and southwest parts of Kulp segment, in the northwest of Beğendik segment covering Hizan (region F), in the southeast Cizre fault covering Şırnak (region G) and in the south and southwest parts of Siirt (southern parts of SEATZ, region H). As imaged in Figures 6b and 8, an appraisal of small *b*-value and high *Z*-value areas together may supply primary and reliable information to appraisal the earthquake hazard in Bitlis and its nearby regions. Also, some regions have large *b*-value and high *Z*-value or small *b*-value and small *Z*-value. If one considers each parameter individually, the regions with low *b*-value or the regions with high *Z*-value are important, and each anomaly area may be suggested as the possible earthquake regions in the future by itself. However, as mentioned above, if one uses both parameters together, the regions with small *b*-values and large *Z*-values should be taken into consideration for a more accurate interpretation. As a result, anomaly regions with seismic quiescence may be significant, and these detailed analyses of *b*- and *Z*-values may increase the reliability of seismic precursors (indicators) in earthquake prediction.

Based on the Earth's parameters and the average depth interval (20 km) for calculating changes, Figure 9 illustrates the Coulomb stress change map for 25 earthquakes listed in Table 1, each with a moment magnitude $Mw \geq 4.0$, that occurred in Bitlis province and nearby areas such as Siirt, Şırnak, and Muş between 2012 and 2024. According to Figure 9, positive values of Coulomb stress marked by red were calculated in the NW-SE direction, particularly throughout the MFZ and KFZ covering Kaleköy, Kayalısu, and Ilıcaköy segments, as well as the Beğendik Segment to the southeast. It is important to acknowledge that there exists positive stress transfer along the southeast of the KFZ, even though no faults were present in this area. The September 25, 2024, Yumrukaya-Tatvan earthquake ($Mw=4.5$), also occurred in this area. Moreover, the stress values were noted to be scattered but primarily positive in relation to the SEATZ around the Kulp and Şirvan segments.

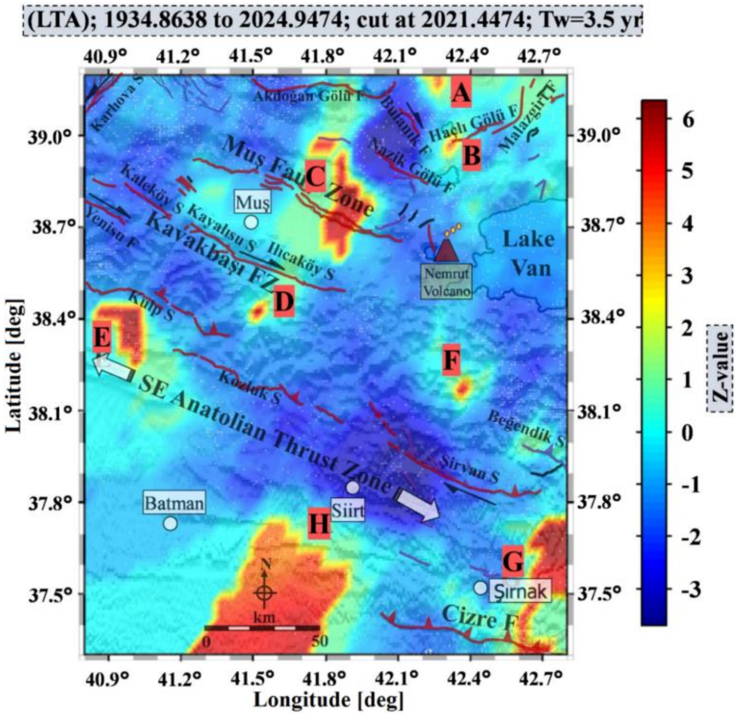


Figure 8. Regional variation map of *Z*-value. Areas (A, B, C, D, E, F, G and H) showing seismic quiescence at the beginning of 2025 were mapped with a time window of Tw=3.5 years.

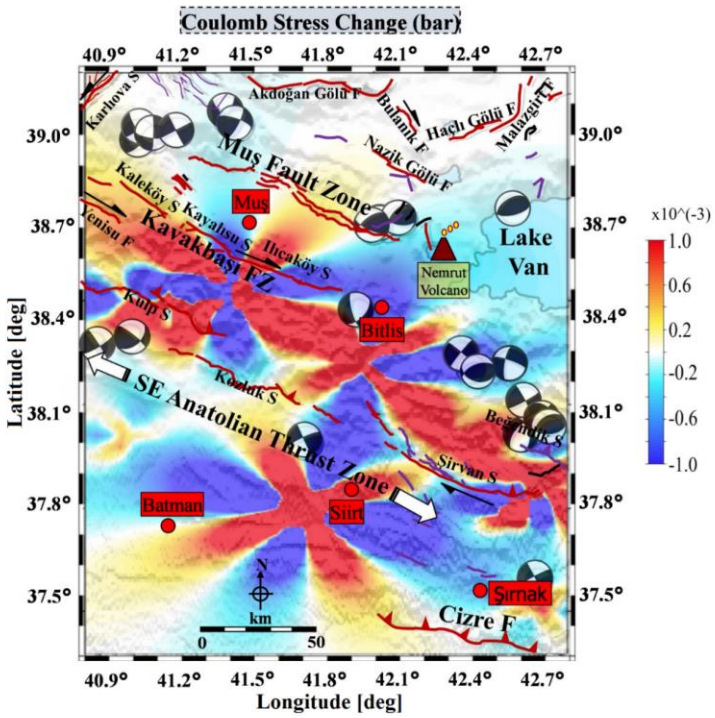


Figure 9. Coulomb stress change map prepared from 25 earthquakes with $Mw \geq 4.0$ listed in Table 1.

Additionally, a region with intermediate stress values emerged around the MFZ. Positive stress lobes can be seen in the northwest-southeast and northeast-southwest directions around the SEATZ, which corresponds to the southern part of the study region. Negative stress lobes can also be released in the northeast-southwest and northwest-southeast directions within the same region. These scattered positive and negative stress lobes were associated with an earthquake that occurred in the south and exhibited a strike-slip mechanism (see Table 1, event no 9). This event had a significant impact, with energy surpassing that of the other selected earthquakes. Conversely, low stress values marked by blue color were calculated in the region covering the north and west of the Lake Van.

5. Discussion

There exist many significant faults and fault zones in and around Bitlis as shown in Figure 1b. In the last 13 years, although large/destructive earthquakes have not occurred according to records of AFAD and KOERI, there are several strong/shaking earthquakes in the study area in recent years (see Figure 2 and Table 1). Therefore, statistical analyses of earthquake behaviors and evaluations for possible relation between seismo-tectonic variables are quite rare for this area. Hence, a comprehensive seismo-tectonic evaluation of earthquake distributions would be contributive for the current earthquake hazard and prediction of the great earthquakes in the intermediate-term. However, there are very few assessments using different techniques/parameters to perform the time-region-magnitude properties of earthquakes in Bitlis and its surroundings (e.g., Işık at al., 2012; Aktug et al., 2013; Işık, 2013; Öztürk, 2015; 2017; 2018; Işık and Harirchian, 2022) and they can provide some useful contributions with this updated detailed study.

Işık et al., (2012) aimed to reveal the faults and their properties in and around Bitlis located in the Lake Van, seismotectonically active region of Türkiye. They stated that faults in Bitlis and its vicinity may have earthquake hazard and hence, they considered a region of 150 km radius to Bitlis for describing the faults and their behaviors. According to their analyses, the earthquakes occurred in historical and instrumental periods indicate that Bitlis and its vicinity are seismically active, but stated that tectonic structures of this region is not well known with its all segments. In this scope, they suggested that seismo-tectonic studies in this region is of vital for the earthquake hazard and for the structural design of earthquake resistant. Thus, evaluation of recent changes in seismo-tectonic parameters as in our present study may be encouraging on a large scale for supplying supportive results of earthquake hazard in and around Bitlis as stated by Işık et al., (2012).

A study on the earthquake activity and strain distribution in and around KTJ, Türkiye was made by Aktug et al., (2013). They stated that although KTJ lies at the intersection of the EAFZ and NAFZ. However, they stated that there exist relatively very few researches for seismically less-active EAFZ although EAFZ has great earthquake hazard for strong/large earthquake occurrences. For this purpose, they made a comparison between geodetic slip rates measured along the block patterning of GPS velocities and *b*-values to evaluate earthquake activity in the area. Their results show that relatively small *b*-values throughout Yedisu segment confirm the seismic energy gathering of this segment, and geodetic slip rates with GPS-derived propose that there exists a potential to cause an earthquake of *Mw*7.5 across this zone. Also, they stated that mapping of small *b*-value regions is useful to evaluate the stress distribution and hence, advanced comparison of *b*-values with geodetic slip rates may indicate the regions subject to brittle deformation. As suggested by these researchers, combination of these two parameters may supply an insight into the earthquake hazard of the region and hence, a special attention must be given to the zones with small *b*-value and positive stress changes in our present study. Thus, the result show that evaluation of all seismo-tectonic parameters considered in our study is more accurate approach for the earthquake hazard and forecasting in this part of Türkiye.

Işık (2013) made a detailed earthquake hazard analyzing of Bitlis province and its vicinity considering by seismo-tectınic *b*-value, occurrence probabilities and return periods of earthquakes. *b*-value was estimated to be 0.78 for surface magnitudes $Ms \geq 4.0$. According to results of Işık (2013), occurrence probabilities of earthquakes for *Mw*=5.0, 5.5 and 6.0 in *Tr*=10 years were computed as 94%, 68% and 37%, respectively. Also, occurrence probabilities for *Mw*=6.0, 6.5, 7.0 and 7.5 in *Tr*=50 years 90%, 61%, 32% and 15%, respectively. Recurrence periods of events with *Mw*=5.0, 5.5 and 6.0 were computed as 3.6, 8.7 and 21.4 years, respectively. Also, recurrence periods of events with *Mw*=6.5, 7.0 and 7.5 were found as 52.6, 129.9 and 312.5 years, respectively. These results of Işık (2013) show that occurrence probabilities and recurrence periods for *Mw*=5.0-6.0 in the intermediate-term (~10 year) are more likely than those of other earthquake magnitudes. Thus, the results given by Işık (2013) are in corroboration with those obtained in our up-to-date study.

Öztürk (2015; 2017; 2018) made detailed spatio-temporal analyses for the earthquake potential and hazard in the Eastern Anatolia region of Türkiye by considering different seismo-tectonic parameters and applying a model on the estimation of the locations for future earthquakes occurrence. The results in these three studies show that analysis with multiple parameter may supply supportive assessment for intermediate-term earthquake prediction. A significant result can be drawn from these studies that *b*-value decreases may indicate to stress increases and *Z*-value increases may show quiescence regions before the future earthquakes. Considering the seismo-tectonic variables used in our study such *b*-value, *Z*-value, occurrence probability, recurrence period and Coulomb stress, our findings specify that comparison of these parameters contributes to a better comprehension of seismo-tectonic and structural characteristics of the study area. Thus, we suggest that a specific attention must be paid to the anomaly regions of seismo-tectonic variables since these anomaly zones may be commented as one of the most probably locations for the expected earthquakes in the next.

Işık and Harirchian (2022) made a probabilistic seismic hazard assessment for Bitlis (Eastern Türkiye) by using different attenuation relationships. They stated that Bitlis and its surroundings has a large seismic risk according to earthquake hazard maps of Türkiye in 2018 and 2019. They stated that this study is important for Türkiye Building Earthquake Code and Türkiye Hazard Maps given with this code. According to their calculations of design spectrum on a point basis, the behavior of structures in an earthquake can be estimated more realistically. For this reason, these areas may be subjected to seismological, geodetical, geological or geotechnical observations. As a result, a combination of different statistical earthquake parameters must be made for a reliable assessment of earthquake potential and current hazard of Bitlis and its surroundings.

Literature studies performed in this section and results of our present study show that multiple parameter analyses of seismo-tectonic variables such as *b*- and *Z*-values and Coulomb stress supply more reliable evidence for a comprehensive appraisal and determination of earthquake hazard, as well as for intermediate-term earthquake prediction. Also, it is important to carefully monitor the seismo-tectonic indicators to define the anomalies in the intermediate-term before a great mainshock expected in the future. This region was struck by a large (1934, *Mw6*.2) earthquake in the past and some strong/shaking events occurred in Bitlis and its surroundings in recent years. The most recent mainshock that occurred in the study region on September 25, 2024 (*Mw4*.5) corresponds to small *b*-value regions on *b*-value map (Figure 6b), to high Z-value regions on seismic quiescence map (Figure 8) and to positive stress regions on streets map (Figure 9). As for the earthquake data and variables considered in this research, the anomaly areas given above, and estimated findings such as small *b*-value, large *Z*-value and positive stress changes are confirmed by other different seismo-tectonic variables. Therefore, the relationships between different seismo-tectonic variables can contribute to the determination of the current earthquake hazard and particular attention should be paid to these regions where anomalies are observed. Consequently, these types of preliminary information may provide more reliable interpretations for assessing earthquake hazards and predicting of earthquakes in the intermediate-term and will enable the prevention of structural failures and taking of emergency preparedness measures.

6. Conclusions

In this study, the future earthquake potential and recent hazard assessment of seismo-tectonic structures with strike-slip and normal fault mechanisms such as SEATZ, MFZ, KFZ, Akdoğan, Bulanık and Nazik Gölü faults in and around Bitlis province were achieved by analyzing *b*-value in G-R relation, *Z*-value of standard normal deviate (seismic quiescence), Coulomb stress change, occurrence probability and recurrence period of earthquakes. Taking into account the instrumental period of earthquake activity, it is shown that strong events generally occurred in the region. Although no large/destructive earthquakes occurred in recent years, the last earthquake with a magnitude *Mw*=4.6 occurred in Yumrukaya-Tatvan (Bitlis) in the north of Şirvan and Beğendik segments in September 25, 2024. In this purpose, the events were considerd for the study region between 37.3°N-39.2°N in latitudes and 40.8°E-42.8°E in longitudes. For the calculation of seismo-tectonic parameters, a homogeneous earthquake catalog was prepared for *Mw* and 7056 earthquakes with magnitudes ranging between 1.0≤*Mw*≤6.2 from 1934 to 2025 were used. In order to map Coulomb stress changes, focal mechanism solutions of 25 earthquakes with magnitudes *Mw*≥4.0 between 2012 and 2024 were considered.

b-value was calculated as 0.84±0.06 by using *Mc*=2.3 and its regional variation is between 0.61 and 1.57. Small *b*-values and positive stress lobs generally covers the same areas and are observed in in and around MFZ, KFZ, Akdoğan and Nazik Gölü faults, Yenisu fault, Kulp, Şirvan and Beğendik segments, in and around

Nemrut Volcano, in the eastern section of the study region covering west of the Lake Van. In addition to these two valuable parameters, seismic quiescence *Z*-value that is related to the decrease in the number of earthquakes before the mainshock, was observed and large *Z*-values were centered in the north of Haçlı Gölü fault and its south direction, on the MFZ and its surroundings, in the southwest of Ilıcaköy segment, on the south and southwest parts of Kulp segment, in the northwest of Beğendik segment covering Hizan, in the southeast Cizre fault cevering Şırnak and in the south and southwest parts of Siirt (southern parts of SEATZ). Considering the past seismic activity of the study area, estimated occurrence probabilities and recurrence periods of the certain magnitude levels, occurrence probability of an vent with $Mw \geq 5.0$ in the intermediate-term (~10 years) after 2025 is quite high (≥~65%). The zones (in and round MFZ, KFZ, Ilıcaköy, Kulp and Beğendik segments) exhibiting small *b*-values, large *Z*-values and positive stress accumulation may be commented to be the most possible locations for the next expected earthquakes. As a remarkable fact, the statistical relations between these seismo-tectonic variables will offer supportive and significant strategies for the evaluation of earthquake hazard and future earthquake prediction in the intermediate-term in Bitlis and its surroundings.

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Author contribution

Serkan ÖZTÜRK: Contributed to every stage of the paper. Hamdi ALKAN: Contributed to every stage of the paper.

Declaration of ethical code

The authors declare that materials and methods used in this paper do not require ethics approval and/or permission.

Conflicts of interest

The authors declare no competing interests.

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