Research Article
Academic Platform Journal of Natural Hazards and Disaster Management
4(1), 22-33, 2023 DOI: 10.52114/apjhad.1218427

Seismicity of the Southern Marmara Region of Turkey Before and After the August 17, 1999 İzmit Earthquake

Murat Utkucu[1,2*], Fatih Uzunca[3], Hatice Durmuş[4], Serap Kırım[3], Süleyman Sami Nalbant[5]

[1] Department of Geophysics, Engineering Faculty, Sakarya University, Sakarya, Türkiye
[2]Disaster Management Application and Research Center, Sakarya University, Sakarya, Türkiye
[3]Institute of Natural Sciences, Sakarya University, Sakarya, Türkiye
[4] Geological Engineering Department, Engineering Faculty, Kütahya Dumlupınar University Kütahya, Türkiye
[5] Geography Department, Faculty of Science and Literature, Iğdır University, Iğdır, Türkiye

Received: / Accepted: 19-December-2022 / 23-May-2023

Abstract

In the present study seismicity of the Southern Marmara Region before and after the 1999 İzmit earthquake is analyzed and compared. A homogeneous seismicity catalogue that has completeness above M_C=2.9 and covers the time period between 1978 and 2020 is used. Comparisons of the spatial mapping of the frequency-magnitude distribution before and after the 1999 İzmit earthquake revealed that *b*-values demonstrate a general increase after the earthquake indicating a general stress decrease in the region. The shortest computed T_L value of about 450 years in the east of the city of Bursa vanished after the 1999 earthquake. The computed time variations of the *b*-value have shown an increase from 0.8 to 1.6 between 1978 and 1997 and an anomalous increase from 1.1 to 2.1 between 2000 and 2006. After 2006, the *b*-values have decreased from 2.1 to 0.8, implying that decreased stress after the 1999 İzmit earthquake began to increase after that year. Since the historical seismicity indicates no large earthquake on the fault segments of the North Anatolian Fault Zone extending along the towns of Geyve, İznik, Gemlik and Bandırma, these fault segments are considered to be the most likely hosts of the next destructive earthquake in the region.

Keywords: The Northern Anatolian fault zone, The Southern Marmara region, 1999 İzmit earthquake, Seismicity parameters

1. Introduction

The main active tectonic property of the Marmara Region is the North Anatolian Fault Zone (NAFZ) [1-4] (Figure 1a). The NAFZ enters the Marmara region at its east section and bifurcates into three fault strands, the Northern, Middle, and Southern strands [1,5] (Figure 1b). The northern strand passes under the Sea of Marmara, while the other strands extend all over the Southern Marmara Region [6]. The fault segments in the Southern Marmara Region undertake much smaller deformation compared to the segments along the Northern Strand, as indicated by GPS and kinematics reconstruction studies [5,7]. Nevertheless, the middle and southern strands produced a number of large destructive earthquakes over the past twenty centuries, as revealed from the historical sources [8,9], indicating high seismic activity in the region.

* Corresponding author e-mail: mutkucu@sakarya.edu.tr

In the present study, the seismicity of the Southern Marmara region, both in historical and instrumental periods, is investigated. Large earthquakes in the last two millennia are used to define fault segments that have not produced a large earthquake for a long period. The instrumental seismicity is analyzed to calculate *b*-values of the frequency-magnitude distribution (FMD) [10,11] and FMD based earthquake recurrence times [11]. The results will then be utilized to interpret earthquake hazards in the study area. Similar investigations have also been performed by several studies using similar and different methodologies [12-17].

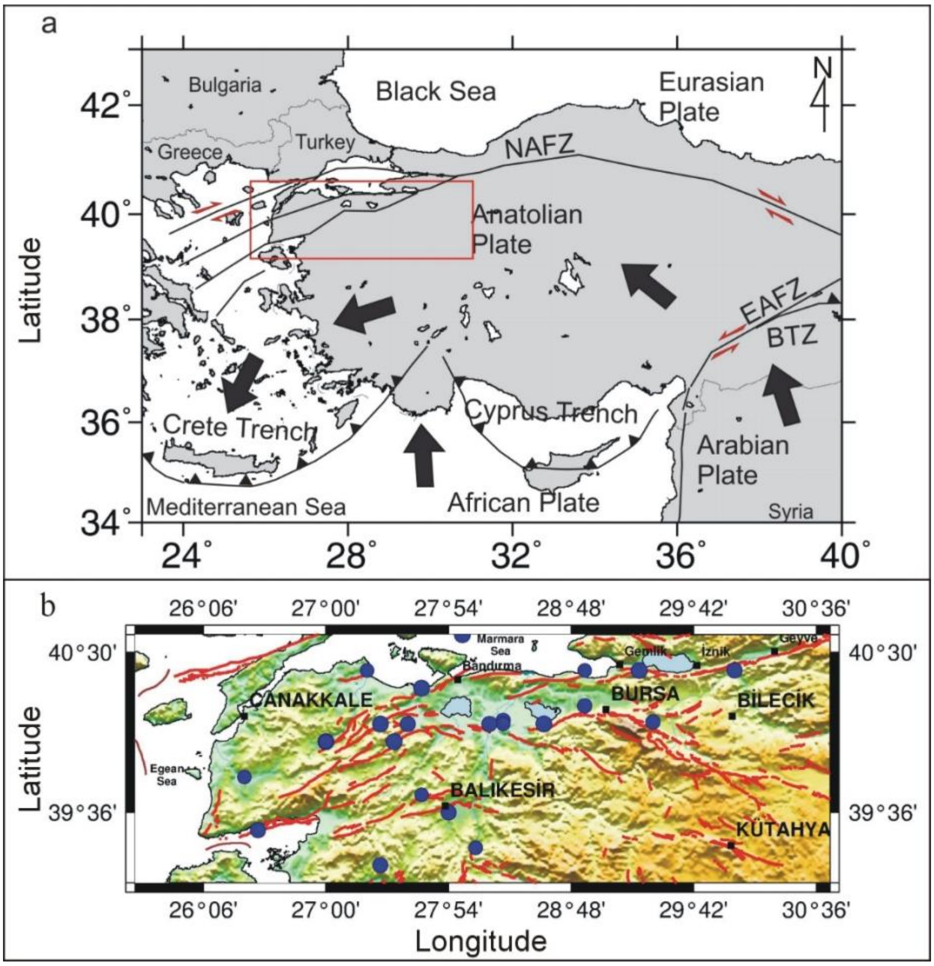

Figure 1. (a) The map demonstrating the main tectonic elements of Türkiye. The red rectangle encloses the study area. (b) The epicentral distribution of the $M_S \geq 6.8$ earthquakes occurred in the Southern Marmara Region, NW Türkiye, after 1 AD and $M_S \geq 6.0$ earthquakes after 1800 (compiled from [8,9,19-21]). See Table 1 for further detail.

2. Method

The relationship between the size of an earthquake and its frequency of occurrence is named FMD [10] and is defined as:

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

where N is the cumulative number of earthquakes with a magnitude exceeding a given magnitude, M, and a and b are constants. The constant a is positively related to the level of seismic activity. The b-value has been shown to be inversely related to the shear stress in the crust [11] and shows strong heterogeneity in finer scales in the range of 0.5 to 1.5. After determining the FMD relation from the seismicity catalogue of a certain region or fault zone, the probabilistic recurrence time (T_r) of an earthquake of targeted magnitude (M_{targ}) can be practically estimated by

$$T_r = \frac{\Delta T}{10^{(a-bM_{targ})}} \tag{2}$$

where ΔT is the recording period covered by the seismicity catalogue. When T_r is based on the finer scale distribution of FMD, its calculation in this way is called local recurrence time (T_L) [11,23]. To calculate *b*-value, we have used the maximum likelihood method [24]:

$$b = \frac{\log_{10} e}{(M_{mean} - M_{\min})} \tag{3}$$

where M_{mean} is the average value of magnitude and M_{min} is the minimum magnitude of completeness in the seismicity catalogue to be analysed. A software package called *ZMAP* is used for mapping the *b*-value of FMD and T_L value as a function of space [11,18].

Table 1. The earthquakes with magnitude $M_S \geq 6.8$ occurred in the Southern Marmara Region, NW Türkiye, after 1 AD and $M_S \geq 6.0$ earthquakes after 1800 (compiled from [8,9,19-22]). See [21] for the empirical relation used for calculation of M_S magnitude from the intensity data and Figure 1b for the epicentre map.

No.	Date	Latitude (°)	Longitude (°)	M_S	Intensity	Region
1	10.11.123	40.3	27.7	7.0		Erdek
2	??.??.160	40.0	27.5	7.1		Çanakkale
3	??.??.460	40.1	27.6	6.9		Erdek
4	25.09.478	40.7	29.8	7.3		Karamürsel
5	06.09.543	40.4	27.8		IX	Erdek
6	715	40.4	28.9		IX	İznik
7	??.09.1065	40.4	30.0	6.8		İznik
8	26.11.1143	40.11	29.4	6.4		Bursa
9	12.05.1327	40.12	28.3	6.4		Bursa
10	15.03.1419	40.4	29.3	7.2		Bursa
11	10.05.1556	40.6	28.0	7.1		Erdek
12	21.09.1577	39.7	27.7		VIII	Balıkesir
13	06.02.1737	40.0	27.0	7.0		Biga
14	07.02.1809	40.0	27.0	6.1		Bayramiç
15	08.02.1826	39.8	26.4	6.2		Ezine
16	19.04.1850	40.1	28.3	6.1		M.Kemalpaşa
17	28.02.1855	40.1	28.6	7.1		Bursa
18	11.04.1855	40.2	28.9	6.3		Bursa
19	28.02.1898	39.6	27.9	6.9		Balıkesir
20	18.11.1919	39.3	27.4	6.9		Soma
21	06.10.1944	39.5	26.5	6.8		Edremit
22	15.11.1942	39.4	28.1	6.2		Bigadiç
23	18.03.1953	40.1	27.4	7.1		Gönen
24	07.02.1809	40.0	27.0	6.1		Bayramiç
25	06.10.1964	40.1	28.2	6.8		Manyas
26	05.07.1983	40.4	27.3	6.1		Karabiga

3. Seismicity

The Southern Marmara region is a seismically active area with a number of large destructive earthquakes over the past two millennia as compiled from the historical seismicity [8,9,19,21,22] and paleo-seismological studies [25-30] (Table 1) (Figure 1). Table 1 reflects the results of the compilation of large earthquakes from a careful examination of the existing seismicity studies. The epicentre distribution of the historical seismicity in Table 1 is shown in Figure 1.

The data used in the study is taken from a homogenized catalogue published by Tan [22], which is based on the earthquake parameters obtained from ISC seismicity bulletins. The catalogue of Tan [22] covers the time period from 1900 to October 2018 and is based on moment magnitude, which is determined, if not available, from regression analysis. The catalogue is extended till July 2020 using Kandilli Observatory and Earthquake Research Institute (KOERI) catalogue [31]. After a preliminary examination of the catalogue, it was decided to use the seismicity after 1978 in the analyses herein (Figure 2).

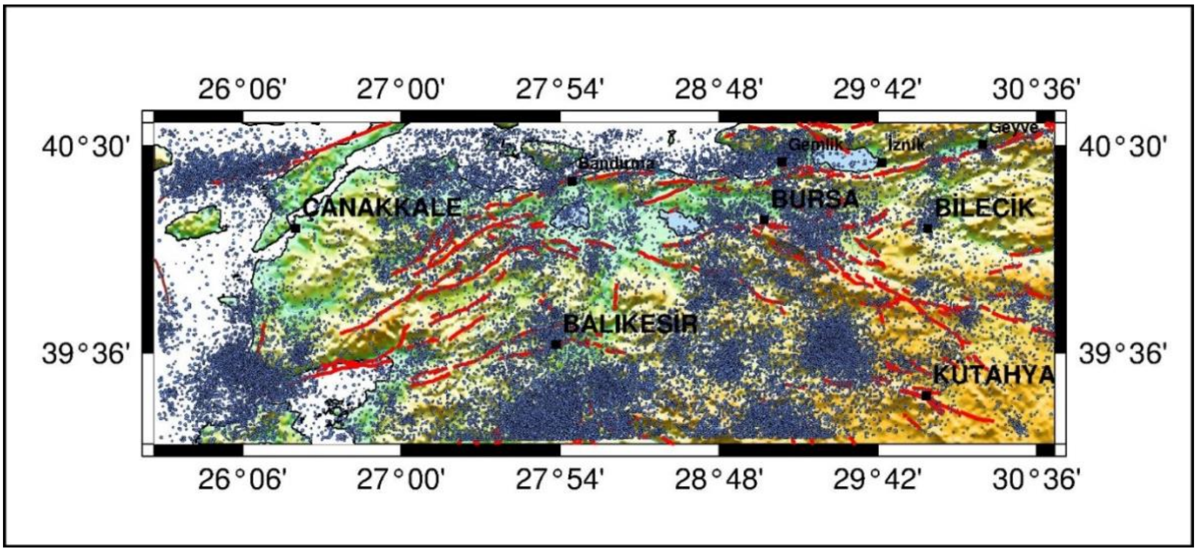

Figure 2. Map showing seismicity of the study area for the period of 1978-2020. The seismicity data comprise all magnitude range (0.4≤Mw≤6.1) available in the catalogue.

The cumulative number of earthquakes and FMD for the raw seismicity data are shown in Figure 3. The same plots for the declustered seismicity data are shown in Figure 4. Both Figures 3 and 4 indicates that magnitude of completeness (M_C) is 2.5. Nevertheless, the cumulative number of earthquake curves indicate that the use of nonhomogeneous seismicity data through declustering resulted in some improvements. M_C for the raw seismicity data through time is calculated and shown in Figure 5, which indicates that M_C is higher than M=2.5. From Figure 5, it is interpreted that M_C is 2.9. The cumulative number of earthquakes and FMD of the declustered seismicity data for M≥2.9 are shown in Figure 6, which indicates relatively homogeneous seismicity.

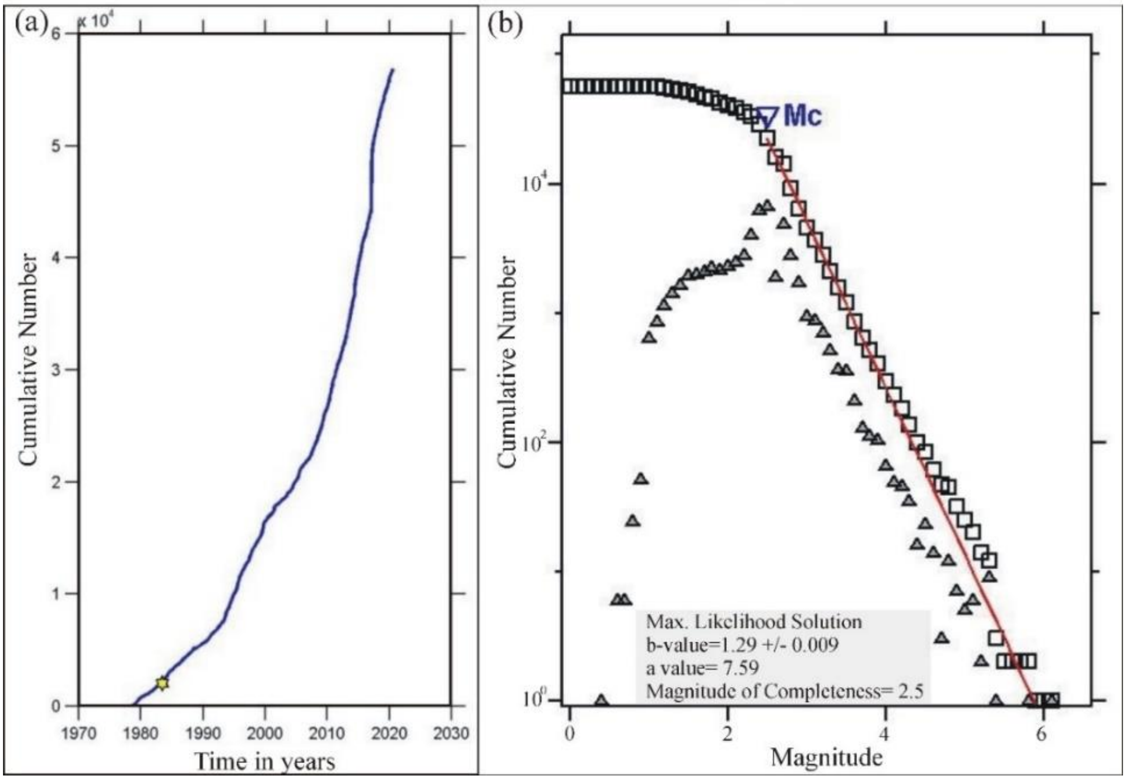

Figure 3. (a) Cumulative number and (b) frequency magnitude distribution of earthquakes for the raw seismicity of the Southern Marmara Region between 1978 and 2020. The triangles and squares in (b) denote the discrete (non-cumulative) and the cumulative distributions of earthquakes, respectively.

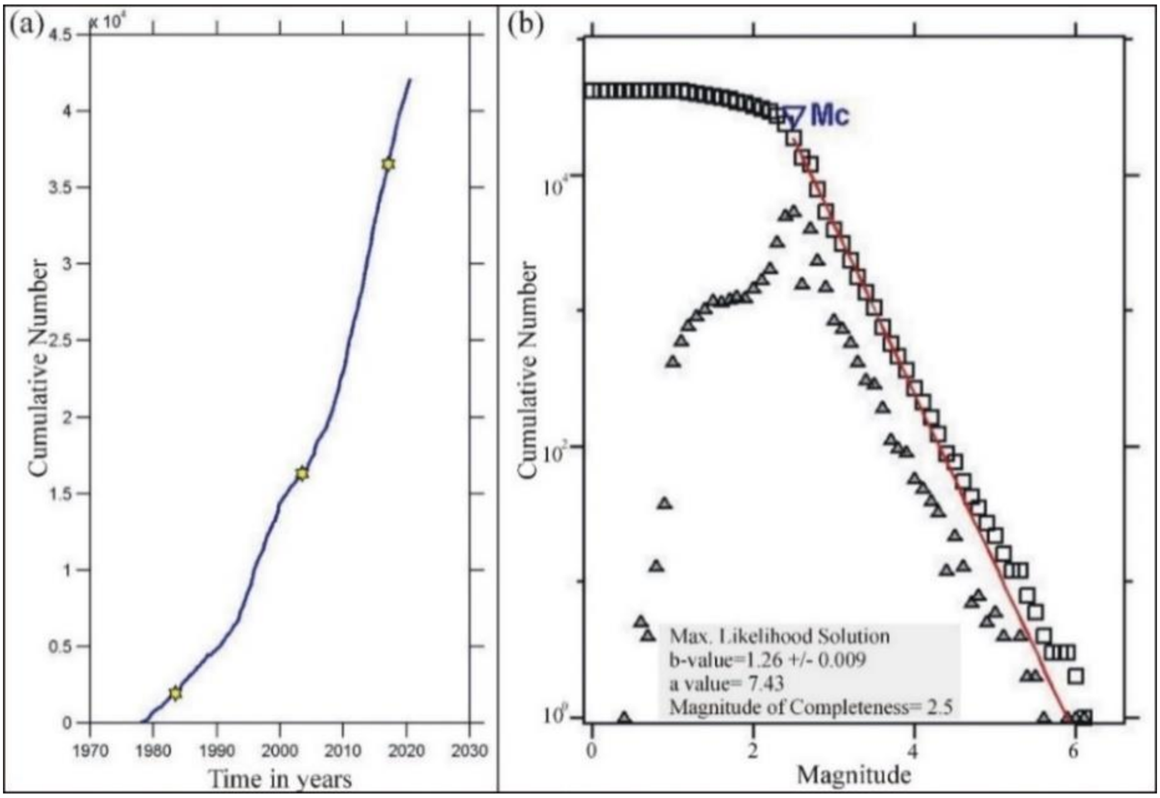

Figure 4. (a) Cumulative number and (b) frequency magnitude distribution of earthquakes for the declustered seismicity of the Southern Marmara Region between 1978 and 2020. The triangles and squares in (b) denote the discrete (non-cumulative) and the cumulative distributions of earthquakes, respectively.

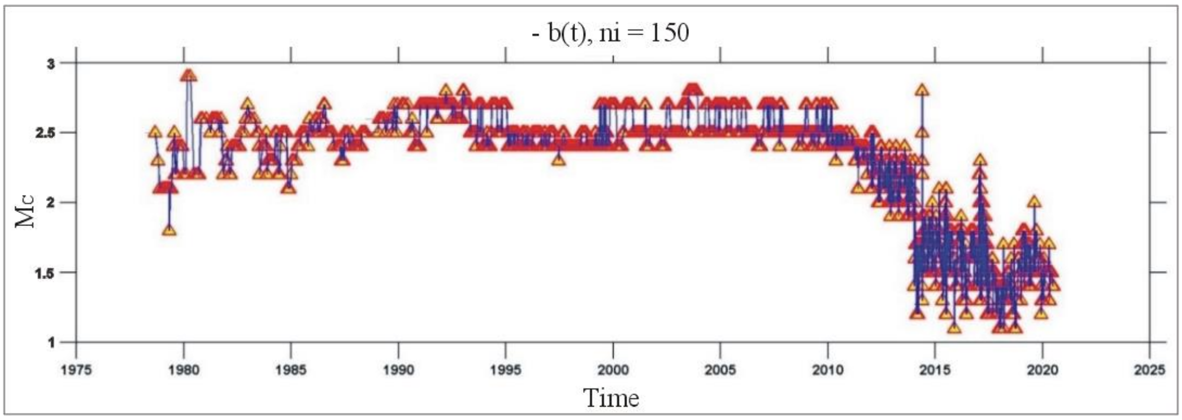

Figure 5. Variation of the magnitude of completeness (M_C) with time calculated for the raw seismicity of Southern Marmara Region between 1978 and 2020.

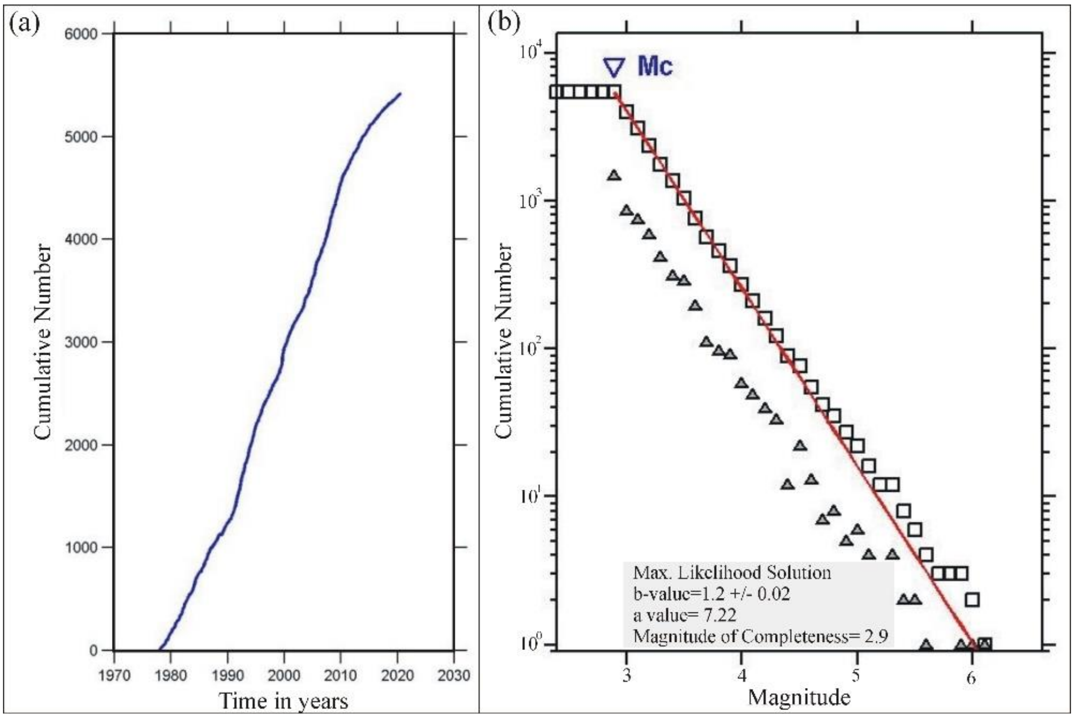

Figure 6. (a) Cumulative number and (b) frequency magnitude distribution of earthquakes for the declustered M≥2.9 seismicity of the Southern Marmara Region between 1978 and 2020. The triangles and squares in (b) denote the discrete (non-cumulative) and the cumulative distributions of earthquakes, respectively.

4. Results

In order to compare seismicity of the Southern Marmara Region before and after the 1999 İzmit earthquake, spatial mapping of the FMD distributions is carried out [11]. The cylindrical data volumes with a radius of 15 km that are centered at grid nodes separated by 0.015 are utilized for spatial mapping. The minimum number of events within the cylindrical data volumes is set to 50. The results of the calculations are demonstrated as the spatial distributions of b, M_C and T_L values. Spatial mapping is first implemented for seismicity before the 1999 İzmit earthquake or for the time period between 1978 and 1999. The results of the seismicity analysis before the 1999 İzmit earthquake are demonstrated in Figure 7. Figure 7 indicates that b, M_C, and T_L values are changing in the range of 0.78-2.3, 2.9-3.2, and 130-660 years, respectively. Several anomalously low b-value areas, such as east of Bursa and Gemlik Bay and Balıkesir areas, are mapped (Figure 7a). Over these anomalously low *b*-value areas, M_C values are 2.9 (Figure 7b), indicating that *b*-value calculations have no connection with variations of M_C values. As apparent from Figure 7c, one of the shortest T_L values of about 450 years is computed in the east of Bursa.

Results of the seismicity analysis for the seismicity after the 1999 İzmit earthquake are shown in Figure 8. An anomalously low *b*-value is notable in the Gemlik Bay and Karabiga areas and the SW tip of Biga Peninsula (Figure 8a). Despite the fact that M_C varies between 2.9 and 3.0, it does not change over the mentioned anomalously low *b*-value areas (Figure 8b), implying that *b*-value variations are not affected by *M*c variations. Figure 8c indicates longer T_L values of as much as 1500 years. The shortest T_L value for the Southern Marmara Region is computed for offshore SW of Biga Peninsula.

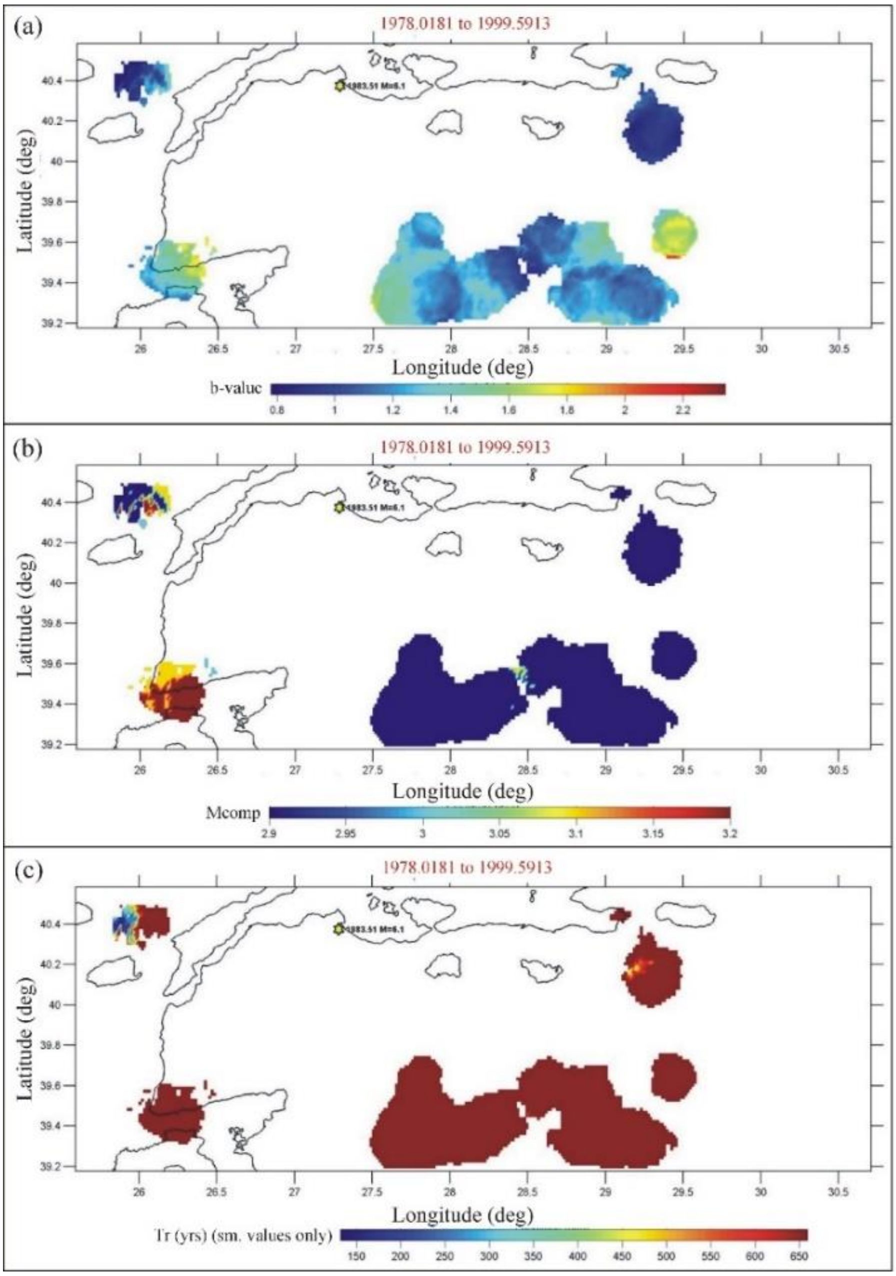

Figure 7. Spatial distributions of (a) *b*-value, (b) magnitude of completeness- M_C and (c) local earthquake recurrence times-T_L (targeted event has Mw=7.0) obtained for the declustered M≥2.9 seismicity of the Southern Marmara Region between 1978 and 1999.

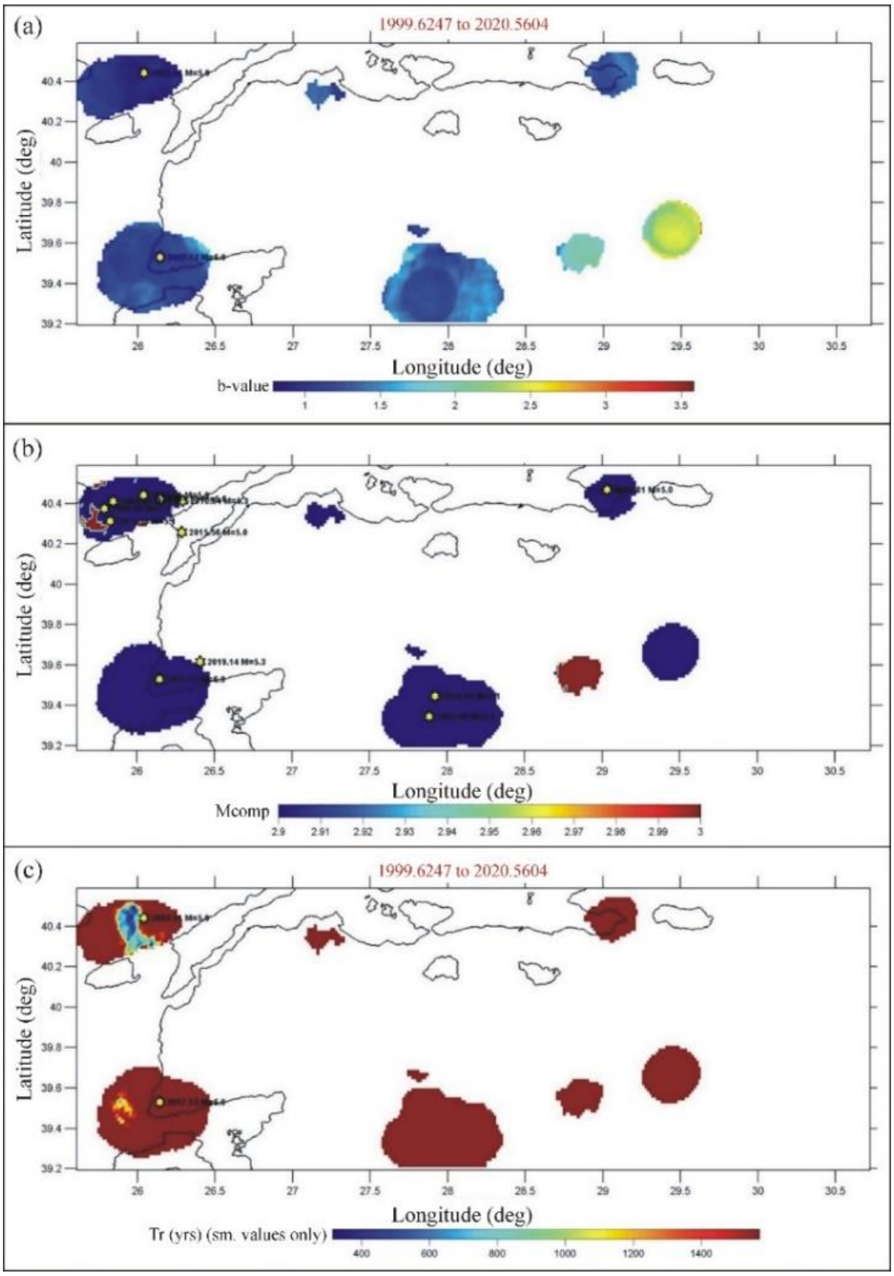

Figure 8. Spatial distributions of (a) *b*-value, (b) magnitude of completeness- M_C and (c) local earthquake recurrence times-T_L (targeted event has Mw=7.0) obtained for the declustered M≥2.9 seismicity of the Southern Marmara Region between 1999 and 2020.

5. Discussion

A comparison of Figures 7 and 8 indicates significant changes of seismicity within the Southern Marmara Region. The computed *b*-values demonstrate a general increase. For example, the anomalously low *b*-value area in the east of Bursa (Figure 7a) vanished after the 1999 İzmit earthquake while a new one appeared in the Karabiga Area. Gemlik, Balıkesir and SW of Biga Peninsula areas show a decrease in the *b*-values. T_L values show an approximately two-fold increase after the 1999 İzmit earthquake in coincidence with general increase of the *b*-value. Since *b*-values are inversely related to stress in the crust, it could be said that the occurrence of the 1999 İzmit earthquake caused a general stress decrease in the Southern Marmara Region during the observation period.

However, *b*-value spatial mappings shown in Figure 7a for the time period 1978-1999 and in Figure 8a for the time period 1999-2020 represent average values for the interested time periods. Therefore *b*-value variations with time are computed. The result is shown in Figure 9a. Figure 9a indicates that the *b*-value increased from 0.8 to 1.6 between 1978 and 1997 and exhibited short-time variations both decreasing and increasing before the 1999 İzmit earthquake. After the occurrence of the 1999 İzmit earthquake, *b*-values demonstrated an anomalous increase from 1.1 to 2.1 between 2000 and 2006. This implies that the 1999 İzmit earthquake decreased the stress in the crust. After 2006 *b*-values have decreased from 2.1 to 0.8, indicating that the stress began to increase after 2006. An increase in the stress is supported by increasing number of relatively larger magnitude events as seen from the time-magnitude plot of the seismicity (Figure 9b).

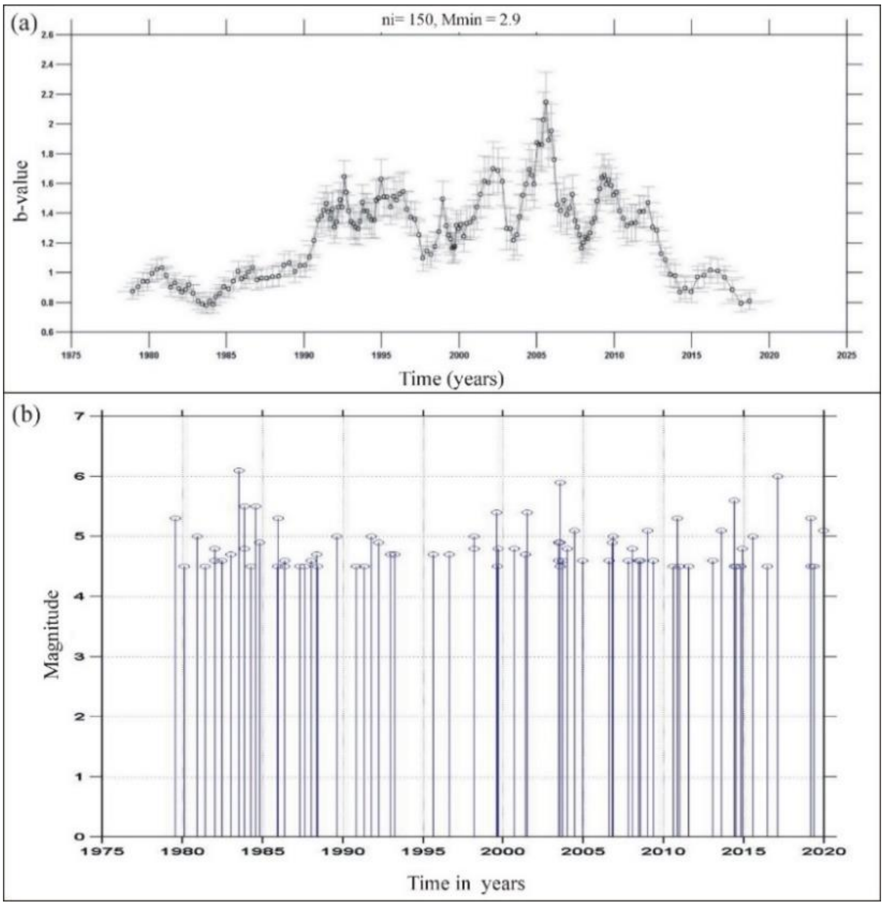

Figure 9. (a) *b*-value variations with time and (b) time-magnitude plot for the declustered M≥2.9 seismicity of the Southern Marmara Region between 1999 and 2020.

Utkucu [32] pointed out that the fault segments of the Northern Strand have a mean recurrence interval of 250-300 years and the other strands have at least twice larger intervals (600-700 years) compared with the Northern strand for a target event of M_W=7.4 using the seismicity between 1981 and 1999. T_L value of 450 years calculated for the east of Bursa in the present study agrees on larger earthquake intervals for the middle and southern strands. Historical earthquake activity (Figure 1) indicates no large earthquakes in the last 400 years for the fault segments of the NAFZ extending along the Geyve, İznik, Gemlik and Bandırma geographic line. These fault segments are considered as the most possible candidates to host next destructive earthquake ruptures in the region.

6. Conclusions

Seismicity of Southern Marmara region both in historical and instrumental periods has been studied. A homogeneous seismicity catalogue that have completeness above the M_C=2.9 and covers the time period between 1978 and 2020 has been analyzed. The seismicity before and after 1999 İzmit earthquake is compared. Comparison of the spatial mapping of the frequency-magnitude distribution before and after the 1999 İzmit earthquake has shown that *b*-values increase after the earthquake indicating stress decrease in the region. The shortest computed T_L value of about 450 years in the east of Bursa vanished following the 1999 earthquake. The computed time variations of *b*-value have demonstrated an increase from 0.8 to 1.6 between 1978 and 1997 and an anomalous increase from 1.1 to 2.1 between 2000 and 2006. After 2006 *b*-values have decreased from 2.1 to 0.8, implying that decreased stress after the 1999 İzmit earthquake begun to increase after 2006. As the historical seismicity indicates no large earthquakes on the fault segments of the North Anatolian Fault Zone extending along the Geyve, İznik, Gemlik and Bandırma geographic line in the last 400 years these fault segments are deemed as the most likely candidates to host the next destructive earthquake ruptures in the region.

Conflict of Interest

The authors declare no competing financial or personal interests that may appear and influence the work reported in this paper.

Author Contributions

Murat Utkucu: Funding acquisition, Conceptualization, Investigation, Writing- Original draft preparation, Project administration, Data curation, Writing-review and editing, Fatih Uzunca: Investigation, Writing-review and editing, Software, Visualization, Data curation, Hatice Durmuş: Funding acquisition, Project administration, Software, Investigation, Writing-review and editing, Serap Kırım: Writing-review and editing, Visualization, Süleyman Nalbant: Conceptualization, Investigation, Supervision, Writing- Original draft preparation.

Acknowledgements

This study was both funded by The Scientific and Technical Research Council of Türkiye (TÜBİTAK) (project number: 121Y271).

References

[1] A. Barka and K. Kadinsky-Cade, “Strike-slip fault geometry in Turkey and its influence on earthquake activity,” *Tectonics*, vol. 7, pp. 663-684, 1988.

[2] S. McClusky, S. Balassanian, A. Barka, C. Demir, S. Ergintav, I. Georgiev, O. Gürkan, M. Hamburger, k Hurst, H. Kahle, K. Kastens, M. Nadariya, A. Ouzounis, D. Paradissis, Y. Peter, M. Prilepin, R. Reilinger, I. Sanli, H. Seeger, A. Tealeb, M. N. Toksöz and G. Veis, “GPS constraints on plate kinematics and dynamics in the Eastern Mediterranean and Caucasus,” *J. Geophys. Res.*, vol. 105, pp. 5695-5719, 2000.

[3] A. M. C. Şengör, O. Tüysüz, C. Imren, M. Sakınç, H. Eyidoğan, N. Görür, X. Le Pichon and C. Rangin, “The North Anatolian Fault: A new look,” *Annu. Rev. Earth Planet,* vol. 33, pp. 37-112, 2005.

[4] Ö. Emre, T. Y. Duman, S. Özalp, H. Elmacı, Ş. Olgun, and F. Şaroğlu, “Active fault map of Turkey with explanatory text,” *General Directorate of Mineral Research and Exploration Special Publication Series*, 30. Ankara, Turkey, 2013.

[5] T. Armijo, B. Meyer, S. Navarro, G. King and A. Barka, “Asymmetric slip partitioning in the Sea of Marmara pull-apart: a clue to propagation processes of the North Anatolian Fault?” *Terra Novai,* vol. 14, pp. 80-86, 2002.

[6] H. Yalçın, A. Kürçer, M. Utkucu and L. Gülen, “Seismotectonics of the Southern Marmara Region, Nw Turkey,” *Bulletin of the Geological Society of Greece*, vol. 50, pp. 173-181, 2016. http://dx.doi.org/10.12681/bgsg.11717

[7] F. Flerit, R. Armijo, G. C. P. King, B. Meyer and A. Barka, “Slip partitioning in the Sea of Marmara pull-apart determined from GPS velocity vectors,” *Geophys. J. Int.*, vol. 154, pp. 1-7, 2003.

[8] N. Ambraseys, “The seismic activity of the Marmara Sea Region over the last 2000 years,” *Bull. Seism. Soc. Am.*, vol. 92, pp. 1-18, 2002.

[9] N. Ambraseys, “Earthquakes in the Mediterranean and Middle East: a multidisciplinary study of seismicity up to 1900” Cambridge University Press., ISBN: 978-0-521-87292-8, 2009.

[10] R. Gutenberg, and C. F. Richter, “Frequency of earthquakes in California,” *Bull. Seismol. Soc. Am.*, vol. 34, pp. 185-188, 1944.

[11] S. Wiemer, and M. Wyss, “Mapping the frequency-magnitude distribution in asperities: an improved technique to calculate recurrence times?” *J. Geophys. Res.*, vol. 102, pp. 15115-15128, 1997.

[12] B.C. Papazachos, G.F. Karakaisis and E.M. Scordilis, “Time dependent seismicity in the continental fracture system” *Bollettino di Geofisica Teorica ed Applicata.*, vol. 55, 3, 617-639. DOI 10.4430/bgta0117, 2014.

[13] S. Öztürk, “Characteristics of seismic activity in the Western, Central and Eastern parts of the North Anatolian Fault Zone, Turkey: Temporal and spatial analysis” *Acta Geophysica*, 59(2), 209–238, 2011.

[14] K.H. Çoban and N. Sayıl, “Different probabilistic models for earthquake occurrences along the North and East Anatolian fault zones”, *Arabian Journal of Geosciences*, 13, 971, 2020.

[15] P. Chingtham, R.B.S. Yadav, S. Chopra, Arabind Kumar Yadav, A.K. Gupta, P.N.S. Roy, “Time-dependent seismicity analysis in the Northwest Himalaya and its adjoining regions” *Nat Hazards*, 80:1783–1800, DOI 10.1007/s11069-015-2031-0, 2016.

[16] S. Pasari, “Nowcasting Earthquakes in the Bay of Bengal Region” *Pure and Applied Geophysics*, 176, pages1417–1432, 2019.

[17] N. Sayıl, “Evaluation of the seismicity for the Marmara region with statistical approaches”, *Acta Geodaetica et Geophysica*, 49, 265–281, 2014.

[18] S. Wiemer, “A software package to analyse seismicity: ZMAP”. *Seis Res Let* 72(3): 373–382, 2001.

[19] N. N. Ambraseys and C. F. Finkel, “The Saros-Marmara earthquake of 9 August 1912,” *Earthquake Eng. and Struct. Dyn.*, vol. 15, pp. 189-211, 1987.

[20] R. A. Ganse and J. B. Nelson, “1982 Catalog of Significant Earthquakes 2000 B.C. To 1979, Including Quantitative Casualties and Damage,” *Bull. Seism. Soc. Am.*, vol. 72, No. 3, pp. 873-877, 1982

[21] B.C. Papazachos and C.B. Papazachou, “The earthquakes of Greece” Ziti Publication, Thessaloniki, 304, 1997.

[22] O. Tan, “A homogeneous earthquake catalogue for Turkey,” *Nat. Hazards Earth Syst. Sci.*, vol. 21, pp. 2059–2073, 2021. https://doi.org/10.5194/nhess-21-2059-2021.

[23] A.O. Öncel and M. Wyss, “The major asperities of the 1999 MW=7.4 İzmit earthquake defined by the microseismicity of the two decades before it,” *Geophys. J. Int.*, vol. 143, pp. 501-506, 2000.

[24] K. Aki, “Maximum likelihood estimate of b in the formula log N= a-bM and its confidence limits,” Bull. Earthquake Res. Inst. Univ. Tokyo, vol 43, pp. 237-239, 1965.

[25] A. Kürçer, A. Chatzipetros, S. Z. Tutkun, S. Pavlides, Ö. Ateş and S., Valkaniotis, “The Yenice-Gönen active fault (NW Turkey): Active tectonics and paleoseismology,” *Tectonophysics*, vol. 453, pp. 263-175, 2008.

[26] A. Kürçer, V. Özaksoy, S. Özalp, Ç. Uygun Güldoğan, E. Özdemir and T. Y. Duman, “The Manyas fault zone (southern Marmara region, NW Turkey): active tectonics and paleoseismology,” *Geodinamica Acta*, vol. 29, no. 1, pp. 42-61, 2017. https://doi.org/10.1080/09853111.2017.1294013.

[27] A. Kop, S. Özalp, H. Elmacı, M. Kara and T. Y. Duman, “Active tectonic and paleoseismological features of the western section of Mustafakemalpaşa Fault; Bursa, NW Anatolia,” *Geodinamica Acta*, vol. 28, no. 4, pp. 363-378, 2016. https://doi.org/10.1080/09853111.2016.1208525.

[28] H. Sözbilir, Ç. Özkaymak, B. Uzel, Ö. Sümer, S. Eski and Ç. Tepe, “Paleoseismology of the Havran-Balıkesir Fault Zone: evidence for past earthquakes in the strike-slip-dominated contractional deformation along the southern branches of the North Anatolian fault in northwest Turkey,” *Geodinamica Acta*, vol.28, no.4, pp. 254-272, 2016. https://doi.org/10.1080/09853111.2016.1171111.

[29] V. Özaksoy, H. Elmacı, S. Özalp, M. Kara and T. Y. Duman, “Holocene activity of the Orhaneli Fault based on paleoseismological data, Bursa, NW Anatolia,” *Bull. Min. Res. Exp.*, vol. 156, pp. 1-16, 2018.

[30] V. Karabacak, T. Sancar, A. Saglam Selcuk and Y. Buyukdeniz, “Paleoseismicity of the Ulubat Fault: Inferences on Seismic Behaviour of the Southern Branch of the North Anatolian Fault Zone, South Marmara,” *Turkish Journal of Earthquake Research*, vol. 3, no. 1, pp.1-19, 2021.

[31] KOERI, “26 Eylül 2019 Silivri açıkları-İstanbul (Marmara Denizi) Depremi, Basın Bülteni, Kandilli Rasathanesi Deprem Araştırma Enstitüsü, İstanbul, 2019.

[32] M. Utkucu, E. Budakoğlu and H. Durmuş, “A Discussion on the Seismicity and Seismic Hazard of the Marmara Region (NW Turkey),” *Bulletin of the Earth Sciences Application and Research Centre of Hacettepe University*, vol. 32, no.3, pp. 187-212, 2011.

© 2023 by the authors. Submitted for possible open access publication under the terms and conditions of the Creative Commons Attribution (CC BY) License (http://creativecommons.org/licenses/by/4.0/).