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Probabilistic Seismic Hazard Analysis of Burdur City

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Abstract

This study's objective is to evaluate the seismic risk for Burdur City (SW Turkey) using a probabilistic methodology. Within the framework of the study, a new earthquake catalog for Burdur City and the surrounding area was created with a unified moment magnitude scale. The region's seismicity was assessed using the Gutenberg-Richter recurrence relationship. Software called R-CRISIS (v18) was used to calculate risks. Analyses were conducted using New Generation Attenuation models. With hazard levels of 2% and 10% probability of exceedance in 50 years, seismic hazard maps for the peak ground acceleration and bedrock were created. The study's findings indicate that peak ground acceleration values on bedrock vary between 0.70-0.75 g and 0.44-0.48 g, respectively, for hazards levels of 2% and 10% probability of exceedance in 50 years.

Keywords: Burdur, Seismic hazard analysis, PGA, R-CRISIS

1. Introduction

The danger posed to civilization by devastating earthquakes in many regions of the globe is sufficient justification for evaluating the seismic hazards of earthquakes while constructing buildings and infrastructures [1,2,3]. As a result of the region's high seismic activity, a number of researchers have evaluated the seismic hazard of several areas in southwest Turkey [4,5,6,7,8].

The Burdur Basin and its environs are situated in a region that has seen high seismic activity over both the historical and instrumental periods [9]. On October 3, 1914, and May 12, 1971, there were two large earthquakes. Both events created extensive damage. The earthquake that occurred on October 3, 1914 (Ms:7.0) was the largest of the two, killing about 4000 people and demolishing 90 percent of Burdur's residences. The May 12, 1971, incident (Ms:6.2) produced more localized devastation and resulted in the deaths of 57 persons. These events caused surface fault ruptures [10].

Western Turkey, situated at the eastern extremity of the Aegean Extensional Province, represents one of the biggest instances of active continental expansion [11]. Numerous academics have examined the Western Anatolia tectonic area to determine the relationship between relative plate motions and complicated tectonic features. The horst-graben system in this region, which comprises the Edremit, Bakırçay, Kütahya, Simav, Gediz, Küçük Menderes, Büyük Menderes, and Gokova grabens, is considered to be one of the most active extensional tectonic structures in the world, with an average GPS velocity of 20 mm/yr [12].

Burdur city center is located on the Burdur fault, one of the most important active faults in Western Anatolia, located in the Fethiye-Burdur fault zone. An important part of Burdur city center is located on Quaternary lacustrine sediments and young creek alluvium. When the tectonic environment of the city is considered together with its geotechnically unfavorable situation, the seismic vulnerability increases. In the present research, seismic hazard study was conducted for Burdur City using a probabilistic approach. Western Anatolia (WA), between 34° and 40° N latitudes and 26° and 33° E longitudes, was considered as seismic study region for the evaluation of seismic hazards.

2. Method

2.1 Seismicity model

The Modified Gutenberg-Richter seismicity model [13], that is related to Poissonian occurrences, was applied in the Probabilistic Seismic Hazard Analysis (PSHA) computations using the R-CRISIS v18 [14] program. The phase of intensity exceedance maintains the Poissonian procedure, together with the Poissonian occurrences. According to the Poissonian procedure, the possibility that an intensity would above a certain level during the next t years becomes as follows:

$$\Pr\,(A > a|t) = 1 - \exp[-\upsilon(a)t] \tag{1}$$

where $\upsilon(a)$ is the exceedance frequency of intensity a. If an event of magnitude M occurs at a hypocenter distance r from the chosen site, the Modified Gutenberg-Richter seismicity model predicts that the chance of hazard intensity above a threshold in the next t years will be estimated by the following formula:

$$P_E(a, t|M, r) = 1 - \exp[-\Delta\lambda(M)t.\,p_1(a|M, r)] \tag{2}$$

where, $p_1(a|M, r)$ is the exceedance probability of the hazard intensity a, assuming that an earthquake of magnitude M occurred at a hypocenter distance r from the point of interest. The Poissonian magnitude exceedance frequency, $\Delta\lambda(M)$, is determined by the magnitude range that magnitude M defines as in Eq. 3:

$$\Delta\lambda(M) = \lambda\left(\frac{M-\Delta M}{2}\right) - \lambda\left(\frac{M+\Delta M}{2}\right) \tag{3}$$

The modified Gutenberg-Richter model [15] gives the Eq. 4 for the exceedance frequency of the earthquake magnitude M:

$$\lambda(M) = \lambda_0 \frac{\exp(-\beta M) - \exp\,(-\beta M_{max})}{\exp(-\beta M_{min}) - \exp\,(-\beta M_{max})}, M_{min} \le M \le M_{max} \tag{4}$$

where M_{min} is the threshold earthquake magnitude and λ_0 is the exceedance frequency of the M_{min}. β represents a seismicity parameter equal to the natural logarithm of "b" value, and M_{max} denotes the predicted maximum earthquake magnitude for the seismic source.

2.2 Earthquake data and seismic source zones

The first step in this PSHA is creating an earthquake catalog for the region, that is homogenized and declustered, and identifying of the seismic sources that may produce ground motions at the region. The seismicity of WA was studied by different researchers. They suggested different zonation models related to WA. In this study, the zonation model containing 15 seismic regions suggested by Bayrak and Bayrak [16] is used. Earthquake epicenter distribution and seismic sources are shown in Figure 1.

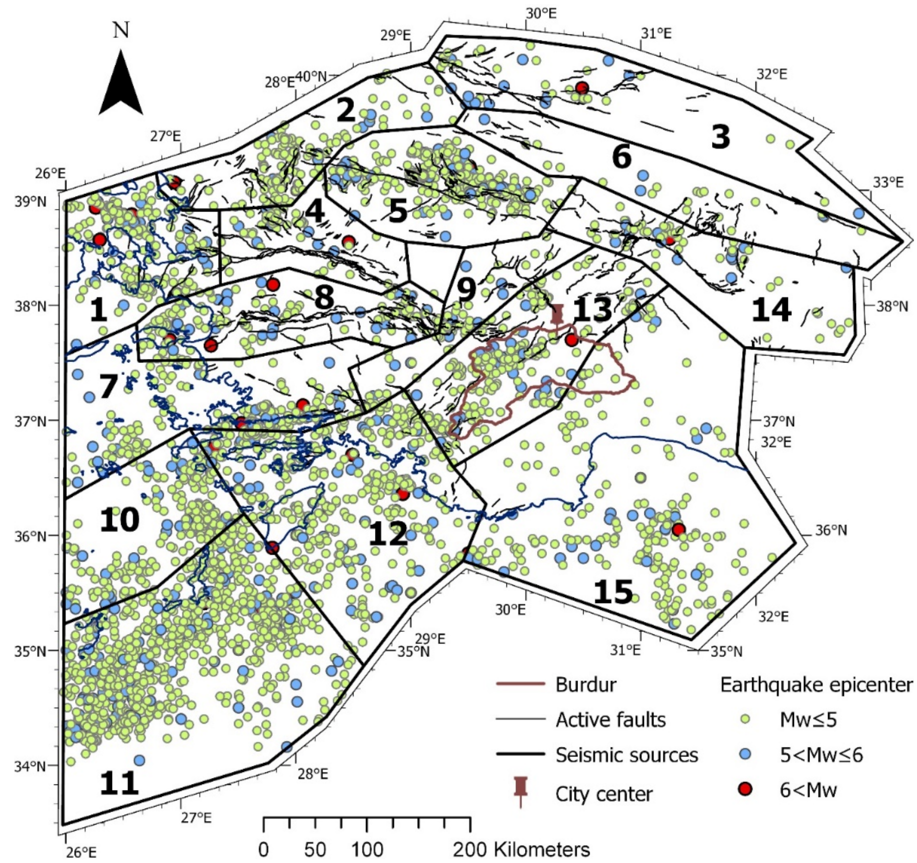

Fig.1. Location of earthquake epicenters and 15 main seismic sources in SW Turkey.

In this study only instrumental shallow earthquake (h < 70 km) data was used. The earthquake data from 1900 to 2005 was obtained from Kalafat et al. [17] and the data from 2005 to 2020 was obtained from the earthquake catalog of the Disaster and Emergency Management Presidency of Turkey. Data homogeneity is essential to the analysis. For this reason, the following magnitude conversion equations provided by Akkar et al. [18] were utilized to convert different magnitude scales, including body wave magnitude (Mb), surface wave magnitude (Ms), local magnitude (Ml), and duration magnitude (Md), to moment magnitude (Mw) in order to achieve magnitude scale homogeneity.

$$Mw = 0.5716(\pm 0.024927)Ms + 2.4980(\pm 0.117197),\ 3.4 \leq Ms \leq 5.4 \tag{5}$$

$$Mw = 0.8126(\pm 0.034602)Ms + 1.1723(\pm 0.208173),\ 5.5 \leq Ms \tag{6}$$

$$Mw = 1.0319(\pm 0.025)Mb + 0.0223(\pm 0.130) \tag{7}$$

$$Mw = 0.7947(\pm 0.033)Md + 1.3420(\pm 0.163) \tag{8}$$

$$Mw = 0.8095(\pm 0.031)Ml + 1.3003(\pm 0.154) \tag{9}$$

The completeness of the earthquake data is another important criterion for the analysis. In other words, the catalog must contain all of the events with magnitudes greater a specific minimum (cut-off) magnitude (Mc) that occurred in a particular seismic source over a particular time period. The selection of the main shocks from the earthquake catalog is another basic consideration. For usage in the Gutenberg-Richter equation, the catalog must be free of all after- and for-shocks. For this reason, these dependent events, after- and for-shocks, were exluded from the catalog using Reasenberg's [19] declustering approach. In this study, Mc, a and b parameters were determined using the ZMAP (v7) software developed by Wiemer [20], where the maximum likelihood method suggested by Aki [21] is applied. The Gutenberg-Richter recurrence relationship was utilized to assess the seismicity of the seismic sources. This well-known equation has the following general form:

$$LogN(M) = a - bM \tag{10}$$

where N(M) (cumulative frequency), is the number of earthquakes equal or larger than M magnitude. The magnitude-frequency relation's variables (a) and (b) denote constants. The average yearly seismic activity index is defined by value (a), which is dependent on the observation period and the seismic activity. The slope of the linear function is provided by parameter (b), which relates to the physics of earthquakes.

It is essential to understand how ground motions attenuate with distance in order to assess the seismic risk at a given location. This statement, often known as the law of attenuation, connects magnitude, distance, and seismic intensity. The impact of the earthquake's size will be lessened by the larger the distance between the rupture area and the location where the risk is assessed [22]. Usually, empirical attenuation relationships, in other words Ground Motion Prediction Equations (GMPE), constrain how PGA values reduce with distance. The Turkish earthquake database is largely dominated by 1999 Kocaeli and Düzce earthquakes with lower intensities; there are no seismological indications that this pattern will be endorsed by potential large magnitude occurrences [23]. Hence GMPEs derived from global database were preferred in this study. Attenuation models developed by Abrahamson et al. - ASK14 [24], Campbell and Bozorgnia - CB14 [25], Chiou and Youngs - CY14 [26], Boore et al. - BSSA14 [27], Idriss - I14 [28], Akkar et al. - ASB14 [29] and Derras et al. - D16 [30] are examined with different earthquake scenarios, and ASK14, CB14, and CY14 models were selected according to the results shown in Figure 2.

For hazard computation, R-CRISIS v18 software was used. This program complies to the Cornell [31] approach. This technique integrates the effect of all probable seismic sources, assigns their average activity rate, and then analyzes the seismic hazard at the location of interest.

The creation of hybrid GMPE models with selected GMPEs and assigned branch weights constitutes the final stage of the analysis. After examining 7 GMPEs chosen for active shallow crustal earthquakes, 3 of them (ASK14, CB14, and CY14) were selected for hybrid model (HM) applications, and 6 different hybrid GMPE models were created as shown in Table 1.

Table 1. Hybrid models and weights of selected GMPEs.

	HM1	HM2	HM3	HM4	HM5	HM6
ASK14	0.4	0.3	0.3	0.5	0.25	0.25
CB14	0.3	0.4	0.3	0.25	0.5	0.25
CY14	0.3	0.3	0.4	0.25	0.25	0.5

Earthquake recurrence parameters were determined by carrying out calculations using a maximum-likelihood approach within the ZMAP (v7) software. Earthquake hazard parameters for 15 different seismic sources are given in Table 2.

The M_{max} value represents the highest predicted magnitude of an earthquake for each source zone. It is expected that no source will generate an earthquake with a magnitude larger than the predicted M_{max}. In the present study, $\mathrm{M_{max}}$ value was estimated by adding a constant value to maximum observed magnitude (M_{max}^{obs}). Different maximum probable magnitudes of each source were predicted as M_{max}^{obs}, M_{max}^{obs}+0.3, and M_{max}^{obs}+ 0.5. Seismic hazard calculations for Burdur city were conducted for each hybrid GMPE models and M_{max} combinations.

Table 2. Calculated earthquake hazard parameters for 15 different seismic regions by ZMAP.

Source no	Tectonics	M_{max}^{obs}	a	b	Mc
1	Aliağa Fault	6.4	5.54	0.81	4.2
2	Akhisar Fault	6.0	5.99	0.91	4.2
3	Eskişehir, İnönü Dodurga Fault Zones	6.3	4.28	0.83	4.0
4	Gediz Graben	6.3	4.69	0.81	4.1
5	Simav, Gediz-Dumlupınar Faults	6.2	6.23	0.91	4.3
6	Kütahya Fault Zone	6.5	5.40	0.82	4.4
7	Karova-Milas, Muğla-Yatağan Faults	6.4	5.82	0.85	4.2
8	Büyük Menderes Graben	6.5	5.29	0.83	4.2
9	Dozkırı-Çardak, Sandıklı Faults	6.0	5.19	0.85	4.2
10	Aegean Islands	6.0	6.22	0.93	4.1
11	Aegean Arc	7.0	6.32	0.84	4.2
12	Aegean Arc, Marmaris, Köyceğiz, Fethiye Faults	6.5	5.89	0.81	4.2
13	Gölhisar-Çameli, Acıgöl, Tatarlı Kumdanlı Faults, Dinar Graben	6.6	5.98	0.87	4.0
14	Sultandağı Fault	6.5	5.27	0.80	4.1
15	Beyşehirgölü, Kaş Faults	6.1	5.87	0.88	4.1

3. Results

The findings of the seismic hazard assessments for the Burdur City center, including PGA (peak ground acceleration), T=0.2s and T=1s spectral acceleration values, are depicted in Table 3.

Table 3. Values of PGA and spectral accelerations for bedrock level, in units of g, for periods of 0.2 and 1s, with 10% and 2% probability of exceedance (PoE) in 50 years.

		$\mathbf{M_{max}^{obs}}$			$\mathbf{M_{max}^{obs}+0.3}$			$\mathbf{M_{max}^{obs}+0.5}$		
		PGA	0.2s	1s	PGA	0.2s	1s	PGA	0.2s	1s
10% PoE in 50 yr (475-yr return period)	HM1	0.409	0.985	0.270	0.479	1.200	0.350	0.537	1.380	0.411
	HM2	0.404	0.959	0.264	0.466	1.150	0.339	0.514	1.300	0.395
	HM3	0.396	0.950	0.260	0.458	1.140	0.335	0.510	1.300	0.391
	HM4	0.417	1.010	0.277	0.497	1.260	0.363	0.562	1.460	0.428
	HM5	0.405	0.950	0.262	0.459	1.130	0.335	0.504	1.260	0.388
	HM6	0.385	0.927	0.253	0.444	1.110	0.325	0.494	1.260	0.379
2% PoE in 50 yr (2475-yr return period)	HM1	0.649	1.610	0.430	0.748	1.920	0.601	0.820	2.130	0.697
	HM2	0.639	1.570	0.419	0.724	1.840	0.576	0.789	2.040	0.672
	HM3	0.630	1.560	0.413	0.719	1.840	0.568	0.786	2.040	0.667
	HM4	0.663	1.650	0.444	0.772	1.990	0.624	0.849	2.220	0.722
	HM5	0.638	1.550	0.415	0.714	1.810	0.566	0.773	1.990	0.661
	HM6	0.615	1.520	0.400	0.701	1.790	0.546	0.766	1.990	0.648

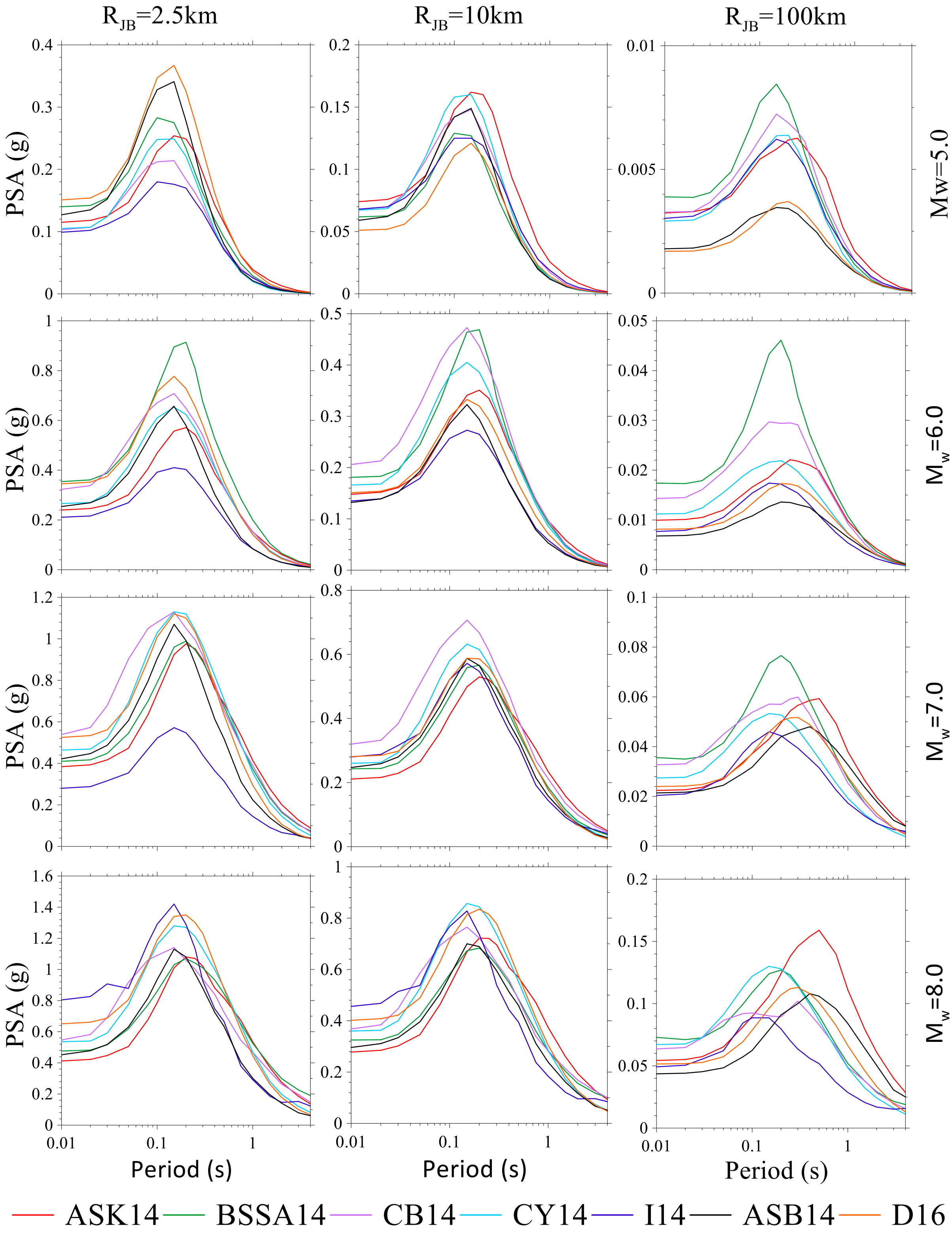

Fig. 2. Response spectrum of examined GMPEs (V_{s30}=760 m/s, H=10km, Z_{TOR}=0, Dip=90, Strike=180, K_1=0.0038, K_2=1.15).

Results of the probabilistic seismic hazard analyses show that in the city center of Burdur, PGA values for $M_{max}^{obs} + 0.3$ and for hazard levels of 2% and 10% probability of exceedance in 50 years change with HMs between 0.70-0.75 g and 0.44-0.48 g, respectively. Seismic hazard maps of Burdur City in terms of PGA values for HM3 and M_{max}^{obs}+0.3 are shown in Figure 3.

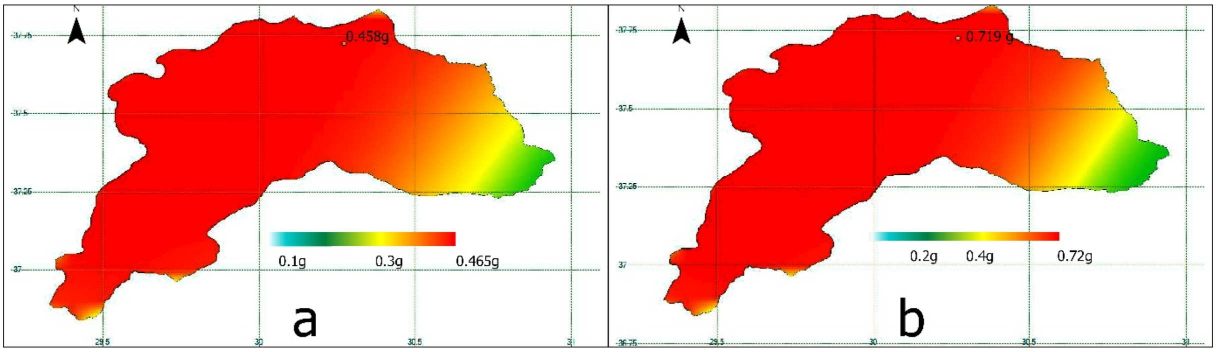

Fig. 3. PGA values of PSHA with HM3 and M_{max}^{obs}+0.3; a) 475 and b) 2475-year return periods

4. Conclusions

The city center of Burdur is mostly built on loosely constructed new alluviums and accumulation cones. The Burdur city center is largely established on the Fethiye-Burdur Fault Zone (FBFZ), one of the most important active faults in Western Anatolia. When these two situations are evaluated together, it is concluded that the seismic risk for the Burdur settlement area is high. Burdur and comparable areas are thus in serious need of any and all scientific research that can aid in the evaluation of seismic risks. In this study, the seismic risk of Burdur Province was investigated by PSHA and the results that may occur for different earthquake scenarios were evaluated.

References

[1] Gupta, I.D., The state of the art in seismic hazard analysis. *ISET Journal of Earthquake Technology*, 39, 311–346, 2002.

[2] Alpyürür, M. and Lav, M.A., An assessment of probabilistic seismic hazard for the cities in Southwest Turkey using historical and instrumental earthquake catalogs. *Natural Hazards*, 114, 1-31, 2022.

[3] Alpyürür, M. and Lav, M.A., Burdur Kent Merkezinin Deterministik Sismik Tehlike Analizi, *9.Türkiye Deprem Mühendisliği Konferansı*, İTÜ, İstanbul, 2021.

[4] Dipova, N. and Cangir, B., Probabilistic seismic hazard assessment for the two layer fault system of Antalya (SW Turkey) area. *Journal of Seismology,* 21, 1067–1077, 2017.

[5] Deniz, A, Korkmaz, K.A., Irfanoglu, A., Probabilistic seismic hazard assessment for Izmir, Turkey. *Pure and Applied Geophysics,* 167, 1475–1484, 2010.

[6] İnce, G.Ç, Yılmazoğlu M.U., Probabilistic seismic hazard assessment of Muğla, Turkey. *Natural Hazards,* 1–30, 2021.

[7] Kırım, S., Budakoğlu, E., Horasan, G., Probabilistic seismic hazard assessment for Isparta province (Turkey) and mapping based on GIS. *Arabian Journal of Geosciences,* 14, 1–15, 2021.

[8] Kutanis, M., Ulutaş, H., Işik, E., PSHA of Van province for performance assessment using spectrally matched strong ground motion records. *Journal of Earth System Science,* 127(7), 1-14, 2018.

[9] Över, S., Yilmaz, H., Pinar, A., Özden, S., Ünlügenç, U. C., Kamaci, Z., Plio-Quaternary Stress State in the Burdur Basin, SW-Turkey. *Tectonophysics,* 588, 56–68, 2013.

[10] Taymaz, T. and Price, S., The 1971 May 12 Burdur earthquake sequence, SW Turkey: a synthesis of seismological and geological observations. *Geophysical Journal International,* 108(2), 589–603, 1992.

[11] Asti, R, Faccenna, C., Rossetti, F., et al., The Gediz supradetachment system (SW Turkey): magmatism, tectonics, and sedimentation during crustal extension. *Tectonics,* 38, 1414–1440, 2019.

[12] Aktug, B., Nocquet, J.M., Cingöz, A., et al., Deformation of western Turkey from a combination of permanent and campaign GPS data: Limits to block-like behavior. *Journal of Geophysical Research: Solid Earth,* 114, 2009.

[13] Gutenberg, B. and Richter, C.F., Frequency of earthquakes in California. *Bulletin of the Seismological Society of America,* 34, 185–188, 1944.

[14] Ordaz, M., and Salgado-Gálvez, M.A., R-CRISIS validation and verification document. Technical Report. Mexico City, Mexico, 2017.

[15] Cornell, C.A. and Vanmarcke, E.H., The Major Influences on Seismic Risk. *Proceedings of the fourth world conference on earthquake engineering,* 69–83, 1969.

[16] Bayrak, Y., and Bayrak, E., An Evaluation of Earthquake Hazard Potential for Different Regions in Western Anatolia Using the Historical and Instrumental Earthquake Data. *Pure and Applied Geophysics,* 169(10), 1859–1873, 2012.

[17] Kalafat, D., Güneş, Y., Kara, M., Deniz, P., Kekovalı, K., Kuleli, H. S., Gülen, L., Yılmazer, M., Özel, N., A revised and extended earthquake catalogue for Turkey since 1900 ($M \geq 4.0$). Boğaziçi University, Kandilli Rasathanesi ve Deprem Araştırma Enstitüsü, Bebek-İstanbul, 553, 2007.

[18] Akkar, S., Azak, T., Çan, T., Çeken, U., Demircioğlu, M. B., Duman, T., Erdik, M., Ergintav, S., Kadirioğlu, F. T., Kalafat, D., Türkiye sismik tehlike haritasının güncellenmesi projesi.UDAP-Ç-13-06, AFAD, 2014.

[19] Reasenberg, P., Second-order moment of central California seismicity, 1969–1982. *Journal of Geophysical Research: Solid Earth,* 90(B7), 5479–5495, 1985.

[20] Wiemer, S., A software package to analyze seismicity: ZMAP. *Seismological Research Letters,* 72(3), 373–382, 2001.

[21] Aki, K., Maximum likelihood estimate of b in the formula log N= a-bM and its confidence limits. *Bull. Earthq. Res. Inst., Tokyo Univ.,* 43, 237–239, 1965.

[22] Gregori, S. D., and Christiansen, R., Seismic hazard analysis for central-western Argentina. *Geodesy and Geodynamics,* 9(1), 25–33, 2018.
[23] Yunatcı, A.A., GIS Based seismic hazard mapping of Turkey, Ph.D. thesis, Middle East Technical University, Ankara, Turkey, 2010.

[24] Abrahamson, N.A., Silva, W.J., Kamai, R., Summary of the ASK14 ground motion relation for active crustal regions. *Earthquake Spectra,* 30(3), 1025–1055, 2014.

[25] Campbell, K.W. and Bozorgnia, Y., NGA-West2 ground motion model for the average horizontal components of PGA, PGV, and 5% damped linear acceleration response spectra. *Earthquake Spectra,* 30(3), 1087–1115, 2014.

[26] Chiou, B.S.J. and Youngs, R.R., Update of the Chiou and Youngs NGA model for the average horizontal component of peak ground motion and response spectra. *Earthquake Spectra,* 30(3), 1117–1153, 2014.

[27] Boore, D.M., Stewart, J.P., Seyhan, E., Atkinson, G.M., NGA-West2 equations for predicting PGA, PGV, and 5% damped PSA for shallow crustal earthquakes. *Earthquake Spectra,* 30(3), 1057–1085, 2014.

[28] Idriss, I.M., An NGA-West2 Empirical model for estimating the horizontal spectral values generated by shallow crustal earthquakes. *Earthquake Spectra,* 30(3), 1155–1177, 2014.

[29] Akkar, S., Sandıkkaya, M.A., Bommer, J.J., Empirical ground-motion models for point- and extended-source crustal earthquake scenarios in Europe and the Middle East. *Bulletin of Earthquake Engineering,* 12(1), 359–387, 2014.

[30] Derras, B., Bard, P.Y., Cotton, F., Site-condition proxies, ground motion variability, and data-driven GMPEs: Insights from the NGA-West2 and RESORCE data sets. *Earthquake Spectra,* 32(4), 2027–2056, 2016.

[31] Cornell, C.A., Engineering seismic risk analysis. *Bulletin of the Seismological Society of America,* 58(5), 1583–1606, 1968.