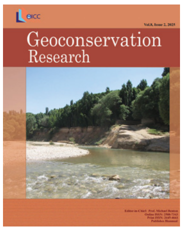


Volume 8, Issue 2, 082516 (1-19)

Geoconservation Research (GCR)

https://doi.org/10.57647/j.gcr.2025.0802.17

Analytical Seismic Risk Assessment in the Aegean Region of Türkiye Using an Adapted Fine-Kinney Method

Betül İrem Tarakçı [1*]

[1] *Department of Interior Architecture, Faculty of Architecture, İskenderun Technical University, İskenderun, Hatay 31200, Türkiye.*

Corresponding Author's E-mail: betuliremtemiz@outlook.com

Original Article

Received:
20-Nov-2025
Revised:
31-Dec-2025
Accepted:
20-Jan-2026

Abstract

This study provides a quantitative seismic hazard and risk assessment for eight provinces in Türkiye's Aegean Region by adapting the Fine–Kinney method to geological conditions. The method, commonly used in industrial safety, was modified by redefining probability (P), frequency (F), and severity (S) to reflect tectonic setting, historical seismicity, and structural vulnerability. Probability was based on each province's shortest distance to active faults, frequency on the number of Mw ≥ 4.5 earthquakes over the past 35 years, and severity on total building stock. The model was applied to Izmir, Manisa, Aydin, Mugla, Denizli, Usak, Kutahya, and Afyonkarahisar. Izmir and Manisa were classified as "very high risk" (R = 2000), Denizli and Mugla as "high risk" (R = 300), Afyonkarahisar and Aydin as "significant risk," Kutahya as "definite risk," and Usak as "acceptable risk." Seismic hazard is generally high, with risk distribution shaped by fault proximity and building density. The adapted method offers a practical framework for comparing provincial seismic risk and supports evidence-based decisions in disaster management, geoconservation, land-use planning, and earthquake-sensitive architectural and interior design.

Keywords: Seismic Hazard, Geological Hazards, Risk Assessment, Fine–Kinney Method, Aegean Region, Structural Vulnerability, Disaster Risk Reduction, Türkiye.

Introduction

Earthquakes are among the most destructive nature-based hazards worldwide in terms of loss of life, economic damage, and long-term societal impacts, particularly in tectonically active regions. Beyond being a geophysical phenomenon, earthquakes constitute a multidimensional risk that intersects numerous disciplines, including urban planning, architecture, interior architecture, and civil engineering. In this context, earthquake risk assessment requires a holistic approach that extends beyond the physical characteristics of seismic hazards to encompass building design principles, interior spatial organization, material behavior, and spatial safety strategies. In regions with high seismic potential, there is a growing need for decision-making processes in both disaster management and the built environment to be grounded in risk-based, quantitative, and comparable assessment frameworks.

Located in western Türkiye, the Aegean Region is one of the country's most seismically active areas, characterized by complex tectonic structures and frequent seismic activity. Although numerous studies have addressed seismic hazard assessment in Türkiye, a significant portion of the existing research focuses primarily on geological or engineering-based parameters, while comprehensive and comparative risk prioritization models capable of supporting decision-makers at the provincial scale remain limited. This highlights the need for practical, transparent, and adaptable methodologies that can support both policy development and design-oriented applications.

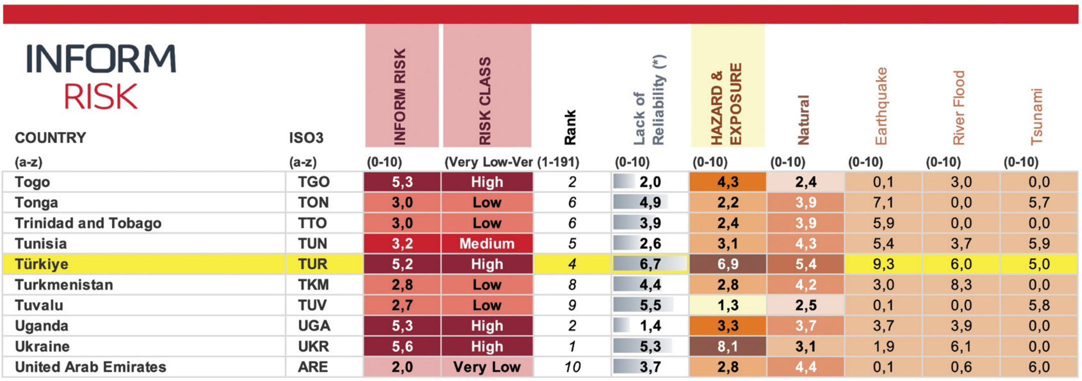
This study aims to conduct a quantitative earthquake risk assessment for selected provinces in the Aegean Region of Türkiye by adapting the Fine–Kinney risk analysis method to seismic hazard dynamics. Although the Fine–Kinney method has been widely applied in the field of industrial safety, its application to periodic and geologically driven hazards such as earthquakes remains limited. Addressing this methodological gap, the current study redefines the Fine–Kinney approach to incorporate components of seismic hazard, earthquake recurrence frequency, and structural vulnerability. The primary objective of the study is to determine the earthquake risk levels of eight provinces entirely located within the Aegean Region (Izmir, Manisa, Aydin, Mugla, Denizli, Usak, Kutahya, and Afyonkarahisar) within a comparable framework and to generate numerical risk scores for each province.

Risk assessment was carried out based on three core parameters: probability (P), frequency (F), and severity (S). The probability parameter was defined based on proximity to active fault lines, the frequency parameter was determined according to the number of earthquakes with Mw ≥ 4.5 recorded over the past 35 years, and the severity parameter was defined based on structural vulnerability indicators derived from building stock characteristics. Through this approach, earthquake risk was transformed into a quantitative model that holistically evaluates region-specific spatial and physical determinants.

Theoretical Framework

Disasters have historically been among the primary threats to human societies, emerging as multidimensional phenomena that directly affect physical structures and societal resilience (Tarakçı 2025a). Türkiye, due to its geological position, has a high exposure potential to various nature-based hazards. Within the national borders, there are three major fault systems: the North Anatolian Fault, the West Anatolian Fault, and the East Anatolian Fault, all of which significantly increase Türkiye's seismic hazard through their high seismic activity and the extensive geographical areas they affect. The impacts of earthquakes are closely related to local ground conditions, the characteristics of the building stock, and how seismic energy is released. Therefore, studies conducted before and after earthquakes play a crucial role in seismic risk assessment and building safety planning (Büyüksaraç *et al.* 2025; Tarakçı 2025b). Such studies enable more accurate identification of high-risk areas, analysis of damage levels, evaluation of structural safety, and improvement of disaster management strategies.

The Anatolian Peninsula is moving westward and southwestward under the compressional regime between the Eurasian and African Arabian plates. Within this tectonic framework, the release of accumulated stress along the North Anatolian and East Anatolian fault zones results in large and destructive earthquakes (Sborshchikov *et al.* 1981). The study conducted by Tarakçı and Kavut (2025) in August, based on Risk Management Index data, revealed that Türkiye's disaster risk level decreased from 5.0 in 2021 to 4.9 in 2025, transitioning into the "medium risk" category. However, according to recent data, this risk level has risen again to 5.2, placing the country back in the


INFORM
RISK

COUNTRY (a-z)	ISO3 (a-z)	INFORM RISK (0-10)	RISK CLASS (Very Low-Ver	Rank (1-191)	Lack of Reliability (*) (0-10)	HAZARD & EXPOSURE (0-10)	Natural (0-10)	Earthquake (0-10)	River Flood (0-10)	Tsunami (0-10)
Togo	TGO	5,3	High	2	2,0	4,3	2,4	0,1	3,0	0,0
Tonga	TON	3,0	Low	6	4,9	2,2	3,9	7,1	0,0	5,7
Trinidad and Tobago	TTO	3,0	Low	6	3,9	2,4	3,9	5,9	0,0	0,0
Tunisia	TUN	3,2	Medium	5	2,6	3,1	4,3	5,4	3,7	5,9
Türkiye	TUR	5,2	High	4	6,7	6,9	5,4	9,3	6,0	5,0
Turkmenistan	TKM	2,8	Low	8	4,4	2,8	4,2	3,0	8,3	0,0
Tuvalu	TUV	2,7	Low	9	5,5	1,3	2,5	0,1	0,0	5,8
Uganda	UGA	5,3	High	2	1,4	3,3	3,7	3,7	3,9	0,0
Ukraine	UKR	5,6	High	1	5,3	8,1	3,1	1,9	6,1	0,0
United Arab Emirates	ARE	2,0	Very Low	10	3,7	2,8	4,4	0,1	0,6	6,0

Figure 1. Some of the results from the INFORM Risk Management Index (Inform Risk 2025).

"high-risk" category (Fig. 1).

The destructive impacts of earthquakes in Türkiye have manifested repeatedly throughout history. Indeed, the 1939 Erzincan, 1999 Gölcük, 2011 Van, 2020 Izmir earthquakes, as well as the February 6 2023 Kahramanmaras-centered earthquakes that affected 11 provinces, have demonstrated the country's seismic fragility and the magnitude of its disaster risk in the most striking manner. The Emergency Event Database (EM-DAT), also known as the Emergency Disaster Database, is a comprehensive system that compiles disaster data obtained from various international organizations such as the International Federation of the Red Cross, United Nations agencies, Red Crescent societies, and national governments (Usta 2023).

Several earthquakes with a magnitude of Mw ≥ 7 have occurred in Türkiye (Table 1). A total of

Table 1. Major earthquakes with Mw ≥ 7.0 in Türkiye (EM-DAT 2025)

Year	Mw	Detailed Location	Province(s)	Total Deaths	Total Affected
1939	7.8	Erzincan city and surrounding districts	Erzincan	32,962	585,000
1942	7.0	Niksar and Erbaa districts	Tokat	3,000	—
1943	7.5	Ladik and Havza districts	Samsun	4,020	5,000
1944	7.6	Gerede district (Western Anatolia)	Bolu	3,959	—
1953	7.3	Yenice, Gonen and Balya districts	Canakkale, Balikesir	1,200	50,000
1957	7.1	Abant region	Bolu	53	119
1967	7.4	Mudurnu Valley and Adapazari area	Bolu, Sakarya	183	326,073
1970	7.2	Gediz district	Kutahya	1,086	83,448
1976	7.3	Muradiye district	Van	3,840	216,000
1999	7.6	Izmit, Golcuk, Adapazari and Yalova	Kocaeli, Sakarya, Yalova	17,127	1,358,953
1999	7.2	Duzce and Kaynasli districts	Duzce, Bolu	845	224,948
2011	7.1	Van city and Ercis district	Van	604	32,938
2020	7.0	Bornova, Bayrakli and Karsiyaka districts	Izmir	115	6,034
2023	7.8	Pazarcik and Elbistan districts and surrounding areas	Kahramanmaras, Hatay	53,000	16,107,000

26,949 disasters occurred worldwide between 1900 and 2024, the majority of which were natural disasters, followed by technological events. In Türkiye, 211 natural and 175 technological disasters were recorded during the same period (EM-DAT 2025; https://public.emdat.be/)). Furthermore, based on data retrieved on 01 November 2025, 994 disasters occurred globally between January 2024 and 1 November 2025, while Türkiye experienced 7 natural and 1 technological disaster during this period (EM-DAT 2025). Between 1900 and 2024, EM-DAT recorded 17,606 natural disaster events, with the most affected countries being the United States, China, India, the Philippines, Indonesia, Japan, Bangladesh, Mexico, Brazil, Iran, Pakistan, Colombia, Afghanistan, Australia, Peru, France, Italy, and Russia, respectively (Fig. 2). Türkiye ranks 16th among these countries. According to the same database, 116 of the 211 natural disasters that occurred in Türkiye, 54.97% were earthquake-related.

The Aegean Region has experienced intense seismic activity as a result of the westward movement of the Anatolian Plate and has historically been affected by destructive earthquakes. The region is situated within the Aegean Graben System, which is bounded by east–west–trending normal faults, and is characterized by the temporal and spatial clustering of low- to moderate-magnitude earthquakes (Büyüksaraç *et al.* 2025). The Aegean Region and its surrounding areas have been affected by destructive earthquakes with magnitudes of Mw ≥ 7.0. In this context, the 1919 Ayvalık earthquake (Mw = 7.0), the 1953 Yenice–Gönen earthquake (Mw = 7.2), and the 1970 Gediz (Kutahya) earthquake (Mw = 7.2) stand out as the major large-magnitude events that impacted the region. In addition, numerous moderate-magnitude earth-

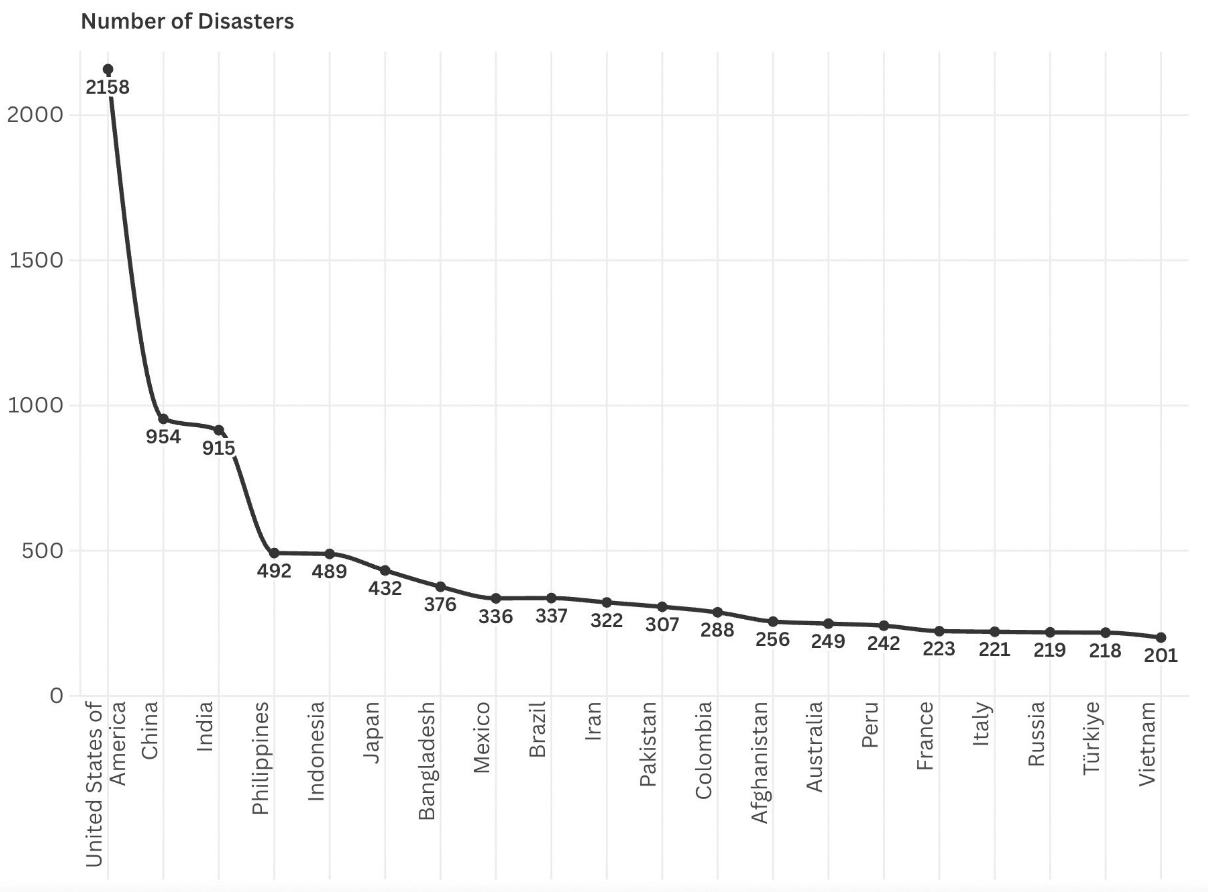


Figure 2. Disasters in the EM-DAT Database (EM-DAT 2025; Created by the Author).

quakes in the Mw 6.0–6.9 range are concentrated along the Simav, Gelenbe, Düvertepe, and Soma–Kırkağaç fault zones, as well as the Gediz Graben System (Gündoğdu *et al.* 2020). Recent seismic activity includes the Mw = 6.1 Balıkesir–Sındırgı earthquake that occurred on 10 August 2025, followed by an intense aftershock sequence. The seismotectonic characteristics and regional seismic hazard of the Aegean Region have been examined in numerous studies using different methodological approaches (Korkmaz *et al.* 2010; Isik *et al.* 2023; Makra *et al.* 2021; Sözbilir *et al.* 2016).

The assessment of earthquake hazards is a critical component of disaster risk reduction and preparedness efforts worldwide (Xu *et al.* 2015; Ismail *et al.* 2024). In order to mitigate the inherent unpredictability not only of earthquakes but of all natural disasters, various methods have been developed to determine risk levels. The literature presents multiple approaches for this purpose: Huang *et al.* (1998) used fuzzy mathematical methods; Peduzzi *et al.* (2009) employed modeling techniques; Gong and Forrest (2014) applied a grey system method suitable for meteorological disaster risk analysis; Deng *et al.* (2001) utilized probability- and statistics-based uncertainty analysis; and Ranger *et al.* (2010) proposed scenario analysis. Additionally, numerous risk assessment studies using the AHP method exist (Ganguly & Guin 2013; Dagsuyu *et al.* 2021). Moreover, Chen *et al.* (2019) employed the TOPSIS and VIKOR methods for determining natural disaster risk, while Hong & Jeong (2019) proposed a multi-objective programming model for network design related to natural disasters. Among these approaches, the Fine–Kinney method is also a significant tool used in risk assessment.

The Fine–Kinney method is widely used in occupational health and safety risk assessment (Oturakçı & Dağsuyu 2017; Aker & Özçelik 2020; Cündübeyoğlu & Kayabaşı 2022). Aminbakhsh *et al.* (2013) conducted an important study evaluating safety risks at the planning and budgeting stages of construction projects using the Analytic Hierarchy Process (AHP). Gürcanlı *et al.* (2015) developed a comprehensive method for estimating safety costs in the early stages of tendering processes by applying various risk assessment techniques—including project planning data, the L-matrix, the Fine–Kinney method, and the ABC method—to construction projects. Tappura *et al.* (2015) examined safety-oriented decision-making processes in cost–benefit analyses and the role of management accounting in valuing human life. Sousa *et al.* (2014) developed a Potential Risk Model to estimate the statistical costs of occupational safety and health risks.

In the area of natural disaster risk assessment, Luchuan (1999) and Xu *et al.* (2015) focused on regional disaster risk analysis; Emblemsvåg (2008) conducted an extensive risk analysis for rockfalls induced by nature-based hazards in Norway; and Osipov *et al.* (2019) evaluated risks associated with multiple disaster types such as earthquakes, floods, and landslides. Derse (2021) assessed the annual natural disaster risks of the provinces in the Aegean Region using a revised Fine–Kinney method, and due to the similarity of risk scores, an AHP-weighted ELECTRE I method was applied to determine the most vulnerable province. Following the identification of the most at-risk area, an optimal settlement location was selected using a goal programming approach that considered population and scope criteria. Kartal and Soyluk (2023) adapted the Fine–Kinney method to natural disasters and enhanced it through fuzzy logic, concluding that the fuzzy logic Fine–Kinney method captured uncertainties in natural disasters more effectively and produced more realistic results than the classical method. Daneshvar Rouyendegh and Gür (2020) also applied the fuzzy logic Fine–Kinney method to dam-related risks.

This study develops and applies an adapted version of the Fine–Kinney risk analysis method tailored to the dynamics of natural disasters to quantitatively assess earthquake risk in the provinces of the Aegean Region. The adapted Fine–Kinney method seeks to provide decision-makers with a rapid and applicable risk screening tool by incorporating components of seismic hazard, earthquake recurrence frequency, and structural vulnerability.

Method

The Fine–Kinney method was preferred in this study because it provides a transparent, algebraically simple, and numerically explicit framework that can be directly interpreted by decision-makers in both disaster risk management and design-related disciplines. Unlike probabilistic seismic hazard analyses (PSHA) or purely GIS-based multi-criteria models, the Fine–Kinney approach allows the three core components of risk probability, frequency, and severity to be expressed as separate yet combinable indices. This structure is particularly suitable for translating technical seismic information into prioritization schemes that can be readily used in urban planning, architecture, and interior architecture.

The theoretical basis of the method was established by Fine in the 1970s and later refined by Kinney, and it has been widely adopted in industrial safety applications. In this model, the level of risk is calculated as the product of three main components: probability (P), frequency of exposure (F), and severity of consequences (S) (Fine 1971; Kinney and Wiruth 1976). Thus, the method provides a decision-making framework by identifying risks through comparable numerical scores. The fundamental mathematical expression of the Fine–Kinney model is defined by the formula $R = P \times F \times S$.

$$\text{Risk Scoring (R)} = \text{probability (P)} \times \text{frequency (F)} \times \text{Severity (S)} \quad (1)$$

Kinney and Wiruth (1976) evaluated risk levels not by using direct mathematical ratios, but by relying on scores derived from these ratios. This approach enables the analysis of classified risk scores rather than the absolute numerical values themselves.

Probability expresses the likelihood that a given hazard may cause damage or harm during a process. In risk assessment models, this concept is used to quantitatively define the degree to which an event may occur (Table 2). *Frequency* (exposure frequency) refers to how often a particular hazard is encountered by measuring the intensity and periodicity with which the hazard is experienced (Table 3). *Severity* represents the magnitude of potential outcomes such as injury, loss of life, or property damage that may occur if the hazard materializes (Table 4). This parameter is used to characterize the seriousness of an event's impact and the potential level of harm it poses to the system.

The total risk value is obtained by multiplying the parameters defined in Tables 1, 2, and 3. Based on this approach, Kinney and Wiruth (1976) established five distinct risk classes (Table 5). The calculated risk score ranges between 0.01 and 10,000 and is evaluated in five categories. $R < 20$ is defined as “acceptable,” 20–70 as “definite,” 70–200 as “significant,” 200–400 as “high,” and $R > 400$ as “very high risk.” This classification provides a systematic decision-making framework that determines the intervention priority for each risk level.

It would be inappropriate to transfer the risk parameters from fields of industrial safety; for example, classifying an annual event as “very rare” is not realistic for periodic natural phenomena such as earthquakes (Ekinci *et al.* 2020). We adapted the core components of the method to reflect the physical and structural determinants of seismic risk (Ersöz and Bayrak 2023). The

Table 2. Probability Scale developed according to the method of Kinney and Wiruth (1976).

Probability (P)	Description (Qualitative Definition)
0.1	Impossible
0.2	Practically impossible
0.5	Weak probability
1	Fairly low probability
3	Rare, but possible
6	Strong probability
10	Very strong probability

Table 3. Frequency scale developed according to the method of Kinney and Wiruth (1976).

Frequency (F)	Explanation / Category
0.5	Very rare / Less than once per year
1	Rare / Once or several times per year
2	Occasional / Once or several times per month
3	Intermittent / Once or several times per week
6	Frequent / Once or several times per day
10	Continuous / Continuous or more than once per hour

Table 4. Severity scale developed according to the Kinney and Wiruth (1976) method.

Severity (S)	Description / Type of Outcome
1	Should be considered, low / Minor, harmless or negligible
3	Significant / Minor work loss, small damage, first aid required
7	Serious / Major damage, external medical treatment, inability to work
15	Very serious / Disability, limb loss, environmental impact
40	Very severe / Permanent disability, death, severe environmental impact
100	Catastrophic / Multiple fatalities, major environmental disaster

Table 5. Risk value classification according to the method of Kinney and Wiruth (1976).

Risk Level	Risk Class	Required Action
R> 400	Very high risk	The probability of occurrence is extremely high and almost certain. Necessary measures must be taken immediately with zero tolerance.
200 <R≤ 400	High risk	The probability of occurrence is high and possible. It is considered a fundamental risk and must be improved in the short term within a few months. Immediate action is required.
70 <R≤ 200	Significant risk	This is a serious risk with a measurable probability of occurrence. It should be reduced through long-term measures within approximately one year. Action must be taken, and an annual action plan should be prepared.
20 <R≤ 70	Definite risk	There is a possibility of occurrence; therefore, it must be kept under monitoring. It should be included in the action plan.
R≤ 20	Acceptable risk	The probability of occurrence is low and the impact is negligible. However, precautions to be taken are not of high priority.

threshold values defined in the adapted probability, frequency and severity scales (Tables 5–7) are based on a combination of existing literature, national guidelines and expert judgement.

The probability (P) was determined based on each province's shortest distance (d, km) to active fault lines. Fault-specific parameters such as maximum magnitude, slip rate, or PGA were not included due to data consistency limitations at the provincial scale (Table 6). Probability values were derived using data from the General Directorate of Mineral Research and Exploration (MTA) and the Disaster and Emergency Management Authority (AFAD) Earthquake Hazard Map (MTA 2025; AFAD 2025). Provinces located closer to fault zones, especially < 15 km, were considered to have a higher probability of earthquake occurrence.

The frequency (F) was determined from the total number (n) of medium- and large-scale earthquakes ($Mw \geq 4.5$) recorded within the administrative boundaries of each province over the past 35 years. Thus, the "exposure frequency" parameter in the Fine–Kinney method was adapted to represent the seismic activity level of each province in the context of nature-based hazards. The relevant data were obtained from the Emergency Events Database (EM-DAT 2025; Usta 2023). For the frequency scale (Table 7), the ranges of the number of events (1 2–4, 5–9, ≥10) were selected to distinguish between very rare, rare, moderate and clearly recurrent seismic activity over a 35-year window in a way that remains meaningful for decision-makers.

The 35-year analysis window (1990–2025) and the magnitude threshold of $Mw \geq 4.5$ were chosen for both methodological and practical reasons. Global earthquake catalogues, including EM-DAT, show improved completeness and consistency after 1990 in event reporting and parametrization. Second, focusing on $Mw \geq 4.5$ events ensures that the frequency index reflects earthquakes with at least moderate damage potential. While smaller earthquakes are important for detailed seismotectonic analyses, they may inflate frequency values without necessarily corresponding to significant risk for the built environment. EM-DAT was selected as the primary data source because it provides a harmonized, internationally comparable database of disaster events. However, national catalogues such as AFAD's earthquake database are acknowledged as valuable complementary sources, and future work will seek to cross-validate the present frequency indices using higher-resolution national records.

The severity parameter (S) was determined from the total number of buildings (b_{top}) in each province. A low proportion of newly constructed buildings indicates increased structural vulnerability and consequently a higher severity value. Data on the building stock were obtained from the 2021 Building and Housing Characteristics Survey conducted by TÜİK (TÜİK 2025). The building-stock intervals (Table 8) were determined by examining the national distribution of total buildings and identifying breakpoints that separate provinces with very large, large, medium and relatively small exposure levels.

These thresholds should therefore be understood as semi-empirical, region-specific classes that translate continuous variables into discrete Fine–Kinney scores, rather than as strict physical limits. To illustrate the application of the adapted P–F–S thresholds, a representative example scenario is considered. A hypothetical province located within 10 km of an active fault is classified as $P = 10$ due to near-fault strong-motion potential. If the province recorded 2–4 $Mw \geq 4.5$ earthquakes between 1990 and 2025, $F = 2$ is assigned, and if its total building stock is approximately 350,000, the severity parameter is set to $S = 15$. The resulting risk score is $R = 300$, corresponding to the 'high risk' category.

Table 6. Probability scale adapted using the data defined by Kinney and Wiruth (1976).

Shortest distance to the fault line (km)	Adapted Probability (P)	Fine–Kinney equivalent	Description
0 – 15 km	10	Very strong probability	Located directly on or very close to an active fault
15 – 20 km	6	Strong probability	Settlement area close to the fault
20 – 25 km	3	Rare, but possible	Moderately distant settlement
25 – 30 km	1	Fairly low probability	Relatively low hazard
> 30 km	0,5	Weak probability	Area distant from the active fault

Table 7. Frequency scale adapted using the data defined by Kinney and Wiruth (1976).

Number of Mw ≥ 4.5 earthquakes in the last 35 years	Adapted Frequency (F)	Fine–Kinney Equivalent	Description
≥ 10	6	Frequent	Active seismicity; regularly recurring earthquakes
5 – 9	3	Occasional	Moderate level of seismic activity
2 – 4	2	Rare	Infrequent but periodic earthquakes
1	1	Very rare	Earthquakes occurring at long intervals
0	0,5	Extremely rare	Region with no recorded earthquakes

Table 8. Severity scale adapted using the parameters defined by Kinney and Wiruth (1976).

Total number of buildings	Adapted Severity (S)	Fine–Kinney Equivalent	Description
>700.000	100	Catastrophic	Very high density of old buildings; high destruction potential
400.000-700.000	40	Very Severe	High proportion of old buildings; substantial damage expected
300.000-400.000	15	Severe	Partially renewed building stock
200.000-300.000	7	Serious	Increased proportion of new buildings; decreasing damage risk
150.000-200.000	3	Significant	Mostly new buildings; low structural vulnerability
<150.000	1	Acceptable risk	Modern building stock; low likelihood of structural damage

The provincial boundaries of the Aegean Region, located in western Türkiye, were included within the scope of the analysis. Only the provinces entirely located within the Aegean Region were considered, limiting the study to the provinces of Izmir, Manisa, Aydin, Mugla, Denizli, Usak, Kutahya, and Afyonkarahisar (Fig. 3). Since Canakkale, Balikesir, Bursa, and Bilecik are only partially included in the Aegean geography and most of their administrative areas belong to the Marmara

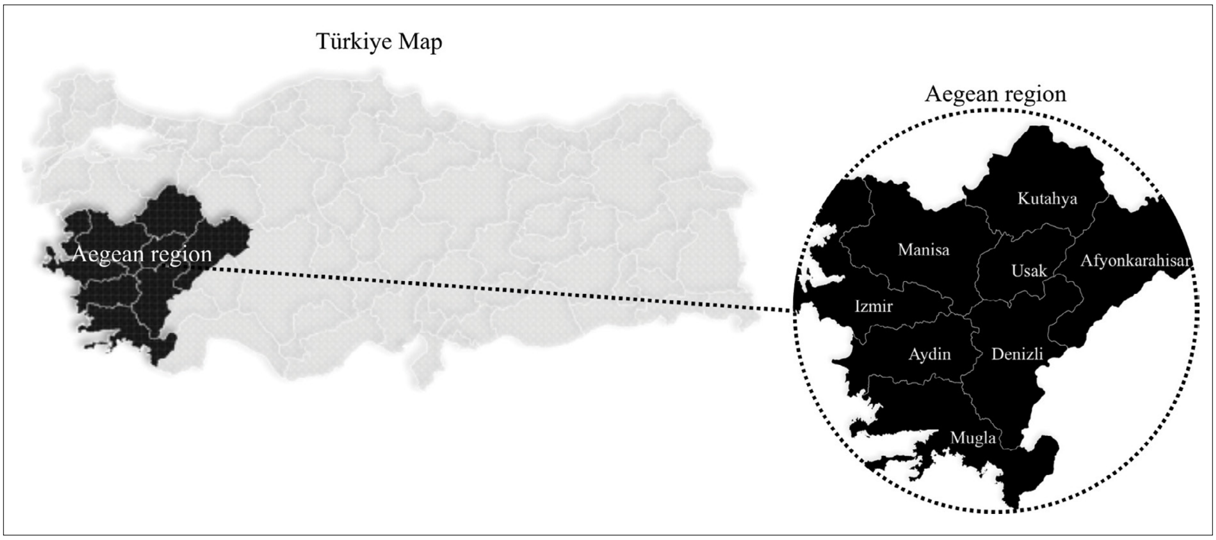


Figure 3. Selected study area (created by the author).

Region, these provinces were excluded. The active fault zones associated with them constitute the fundamental factors that determine the seismic hazard of the region (Fig. 4).

Results

The shortest distances of the provinces to active fault lines in terms of *d* (km/m) and in terms of probability in the Fine–Kinney method for seismic hazard range between P = 10 and P = 6 (Table 9). For seven of the eight provinces, *d* < 7 km, and these were classified with the maximum probability score of P = 10 in the adapted scale. For the calculated distance vector (di) = (6.68, 0.10, 0.10, 0.10 1.21, 0.669, 0.279 21), the corresponding probability vector was obtained as (Pi) = (10 10 10 10 10 10 10, 6). Accordingly, P_i = 10 for Afyonkarahisar, Aydin, Denizli, Kutahya, and Manisa, and P_i = 6 for Usak. These results indicate that the region exhibits a highly homogeneous pattern in terms of seismic hazard, with 87.5% of the provinces located within the critical threshold of 7 km from active fault zones, thereby falling into the high-probability category. The average probability value for all provinces is 9.25, which confirms that the likelihood of earthquake occurrence is high at the regional scale.

There are 116 records of earthquakes with Mw ≥ 4.5 in Türkiye over the last 35 years (1990–2025; Table 10). A total of 16 earthquakes occurred within the boundaries of the Aegean Region (Table 11). Earthquake frequency for each province is presented in Table 12. The number of earthquakes with a

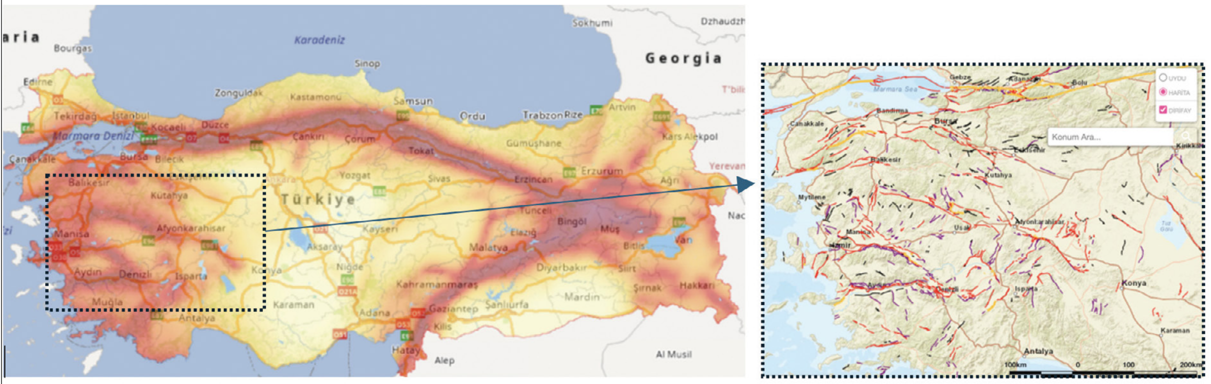


Figure 4. Türkiye Earthquake Hazard and Active Fault Maps (AFAD; MTA 2025).

Table 9. Probability scale by fault-line distance.

	Afyonkarahisar	Aydin	Denizli	Izmir
Shortest Fault Distance	6,68 km	0 10 km	0 10 km	5.30 km
Adapted Probability (P)	10	10	10	10
	Kutahya	Manisa	Mugla	Usak
Shortest Fault Distance	1.21 km	0,669 km	0,279 km	21 km
Adapted Probability (P)	10	10	10	6

Table 10. Earthquake frequency and impacts in Türkiye (Mw ≥ 4.5 1990–2025).

Mw Range	Number of Earthquakes	Main Affected Provinces	Number of Provinces	Total Deaths	Average Deaths per Event	Total Affected	Total Damage
4.5 – 5.4	10	Istanbul, Izmir, Erzurum	7	23	2.3	4,180	0
5.5 – 6.4	23	Bingol, Manisa, Denizli	25	549	23.9	2,133,146	2,106,123
6.5 – 7.4	9	Erzincan, Kocaeli, Izmir	11	2,303	255.9	936,588	6,774,861
≥ 7.5	2	Kahramanmaras, Hatay	20	70,127	35,063.5	17,465,953	72,666,218
TOTAL	44	All provinces	37	73,002	1,659.1	20,539,867	81,547,202

Table 11. Compiled earthquake dataset for the Aegean Region (EM-DAT 2025).

DisNo	Country	Location	Magnitude	Latitude	Longitude	End Year	Total Deaths
1928-0005-TUR	Türkiye	Torbah-Izmir		38,25	27,1	1928	50
1939-0023-TUR	Türkiye	Dikili	6,3	39,209	27,164	1939	60
1944-0046-TUR	Türkiye	Usak	6	38,9	29,3	1944	21
1969-0059-TUR	Türkiye	West Alasehir, Sarigol, Kirz	6,7	38,515	28,546	1969	53
1970-0019-TUR	Türkiye	Gediz	7,2	39,098	29,57	1970	1086
1970-0134-TUR	Türkiye	Demirci, Manisa	5,7	39,1	28,7	1970	
1976-0056-TUR	Türkiye	Denizli	4,9	37,7	28,89	1976	4
1986-0183-TUR	Türkiye	Aydin area	5,5	37,931	28,574	1986	
1995-0233-TUR	Türkiye	Dinar, Evciler	6,1	38	30,1	1995	94
1999-0376-TUR	Türkiye	Marmaris	5,2			1999	
2002-0065-TUR	Türkiye	Bolvadin district (Afyon province)	6,5	38,573	31,271	2002	42
2003-0648-TUR	Türkiye	Buldan district (Denizli province)	4,5	38,111	28,887	2003	
2003-0783-TUR	Türkiye	Seferihisar, Konak (Izmir province)	5,8	38,221	26,958	2003	
2011-0170-TUR	Türkiye	Simav district (Kutahya province)	5,8	39,149	29,103	2011	3
2017-0280-TUR	Türkiye	Bodrum	6,7			2017	
2020-0466-TUR	Türkiye	Izmir Bornova, Bayrakli and Karsiyaka	7	37,913	26,779	2020	115

magnitude of Mw ≥ 4.5 in each province over the last 35 years gave a resulting earthquake count vector of (n_i) = (2 1 2, 4 2 2 2 1), and the corresponding adapted frequency coefficients are (F_i) = (2 1 2 2 2 2 2 1). Afyonkarahisar, Denizli, Kutahya, Manisa, Mugla, and Izmir which recorded four events, fall into the $F_i = 2$ category. Since Aydin and Usak each recorded $n_i = 1$, these provinces were evaluated with $F_i = 1$. The distribution of frequency coefficients indicates that 75% of the provinces are clustered in the $F_i = 2$ class, while the remaining 25% fall into the $F_i = 1$ category. This confirms that the frequency parameter exhibits low variance and that earthquake recurrence rates across the region are concentrated within a narrow interval.

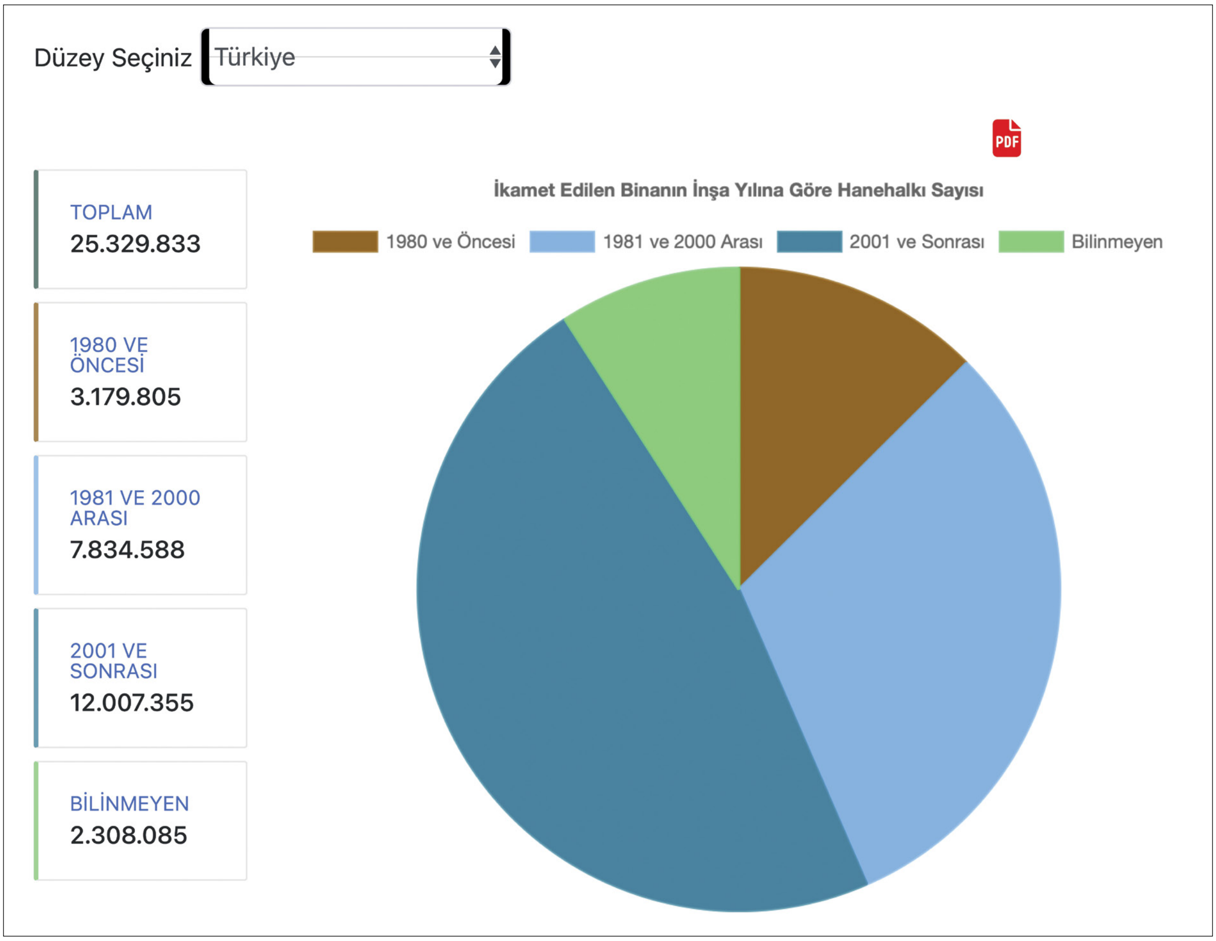
The severity parameter (S_i), representing the potential structural damage in the event of an earthquake, was determined using the total number of buildings, of which there are 25,329,833 dwellings inhabited by households in Türkiye (Fig. 5; Table 13). The adapted severity scale, defined as S ∈ (1, 3, 7, 15, 40, 100), matches the distribution of the provincial building stock, given as $(b_{top})_i$ = (124,856; 192,678; 218,348; 353,281; 362,287; 391,460; 475,046; 1,503,086). According to these results, Usak, having the lowest building stock, falls into the lowest severity category with S = 1; Kutahya, with S = 3, is in the low-severity class; and Afyonkarahisar, with S = 7, represents a medium severity level. Denizli, Mugla, and Aydin cluster within the same category with S = 15 due to their similar building stock levels. Manisa, with S = 40, is classified as a high-severity province, whereas Izmir, which has the largest building stock in the region, is represented by the maximum severity level of S = 100.

Table 12. Frequency scale (F) for Mw ≥ 4.5 earthquakes in the Aegean Region.

Provinces	Number of Mw ≥ 4.5 Earthquakes (Last 35 Years)	Adapted Frequency (F)
Afyonkarahisar	2	2
Aydin	1	1
Denizli	2	2
Izmir	4	2
Kutahya	2	2
Manisa	2	2
Mugla	2	2
Usak	1	1

Table 13. Severity scale (S) by total buildings.

Provinces	Post-2000 Buildings	Total Buildings	Adapted Severity (S)
Afyonkarahisar	85.170	218.348	7
Aydin	155.356	391.460	15
Denizli	159.055	353.281	15
Izmir	609.038	1.503.086	100
Kutahya	79.367	192.678	3
Manisa	197.130	475.046	40
Mugla	146.849	362.287	15
Usak	52.629	124.856	1


Düzey Seçiniz Türkiye

TOPLAM 25.329.833

1980 VE ÖNCESİ 3.179.805

1981 VE 2000 ARASI 7.834.588

2001 VE SONRASI 12.007.355

BİLİNMEYEN 2.308.085

Figure 5. Türkiye Statistical Institute Population Statistics Portal (TÜİK 2025).

The calculated total risk coefficients (R_i) indicate a wide distribution of seismic risk, ranging between $6 \leq R_i \leq 2000$ (Table 14). The spatial distribution of provincial-level risk scores across the Aegean Region (Fig. 2) are derived from the adapted Fine–Kinney method for earthquake hazard assessment (Fig. 6). The highest risk coefficients ($R_i = 2000$) are for Izmir and Manisa, both falling in the “very high risk” category, indicating that the likelihood of occurrence is almost certain and that immediate intervention is required. Among the provinces with high-risk potential are Denizli and Mugla ($R = 300$), areas where long-term mitigation measures should be planned within approximately one year. In Afyonkarahisar and Aydin, the risk coefficients ($R_i = 140–150$) place them in the “significant risk” category; this level reflects a serious risk with a realistic probability of occurrence. Long-term mitigation actions should be implemented within about one year, and an annual action plan should be established. Kutahya, with $R_i = 60$, is classified as “definite risk,” where the probability of an earthquake exists, but monitoring-based interventions are considered sufficient. Usak, located in the central part of the region, has $R_i < 20$, placing it in the “acceptable risk” category. For this province, earthquake risk is at a low level, and periodic monitoring along with measures aimed at strengthening the building stock are deemed adequate.

Conclusion and Recommendations

In this study, the Fine–Kinney risk assessment method was adapted to incorporate the geological, seismic, and socio-structural determinants of earthquake hazards, and the seismic risk for

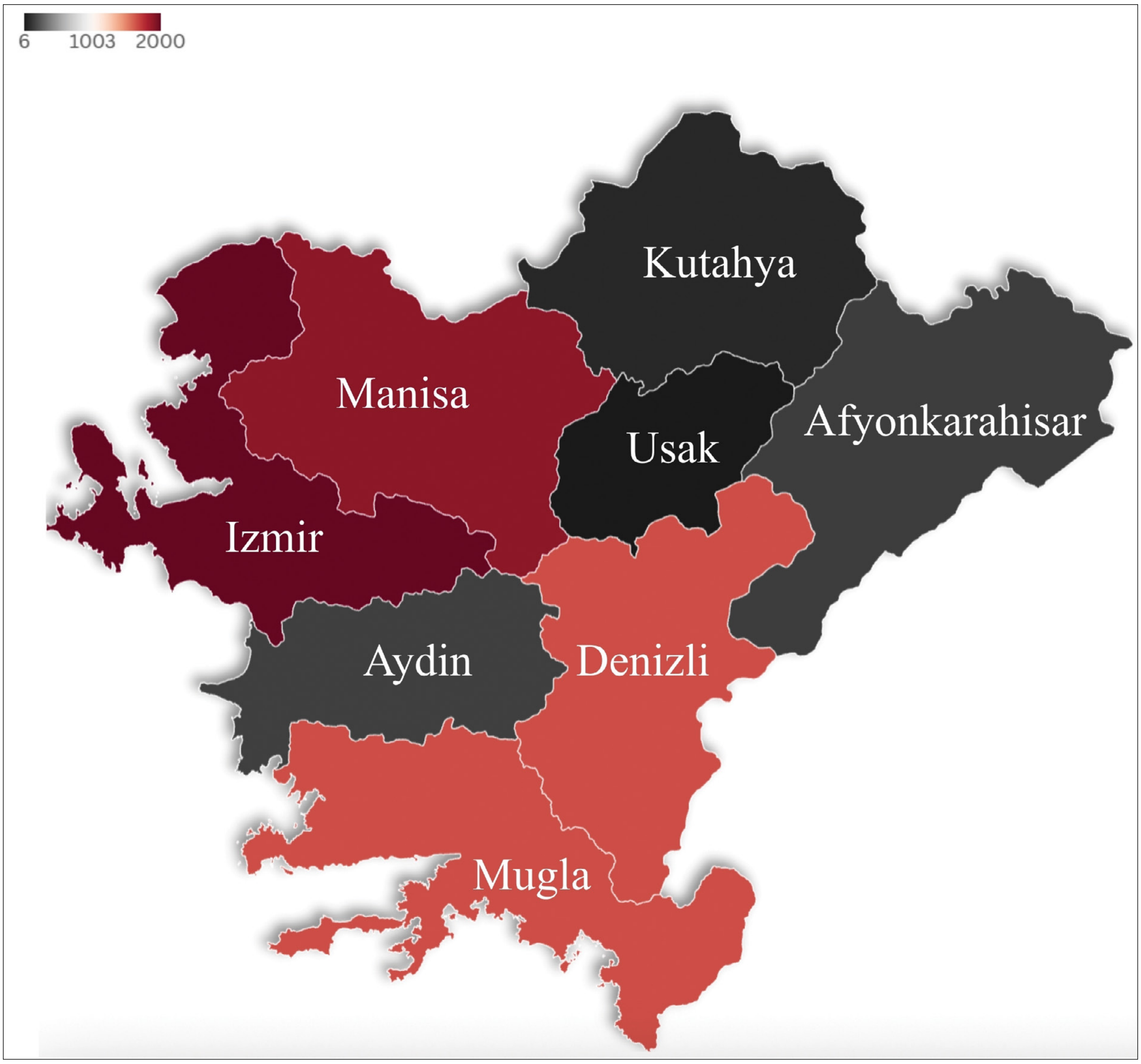


Figure 6. Fine–Kinney–based risk analysis of Aegean provinces (created by the author).

eight provinces in the Aegean Region was analyzed quantitatively. The probability (P) parameter was defined based on the shortest distance to active fault lines, the frequency (F) parameter on the number of Mw ≥ 4.5 earthquakes recorded over the past 35 years, and the severity (S) parameter on the total building stock of each province. Through these adaptations, the Fine–Kinney method traditionally used in industrial safety was transformed into a region-specific model suitable for evaluating natural hazard risks. The analysis results indicate that the Aegean Region exhibits a generally high level of seismic risk. Izmir and Manisa, driven by the combined effect of their extensive building stock and proximity to active fault zones, were classified as "very high risk" with a score of R = 2000; for these provinces, the likelihood of occurrence is considered nearly certain, necessitating urgent intervention. Denizli and Mugla were identified as "high risk" with R = 300, whereas Afyonkarahisar and Aydin exhibited "significant risk" levels with R ≈ 140–150. Kutahya, with a score of R = 60, falls in the "definite risk" category, requiring monitoring-based measures. Usak, located in the interior part of the region, was evaluated as having an "acceptable risk" level

Table 14. Adapted Fine–Kinney Risk assessments for the Aegean region.

PROVINCES	P	F	S	R	Conclusion	Required Action
Izmir	10	2	100	2000	**Very High Risk**	The probability of occurrence is extremely high and almost certain. Necessary precautions must be implemented immediately with zero tolerance.
Manisa	10	2	40	800	**Very High Risk**	
Denizli	10	2	15	300	**High Risk**	The event is highly likely and plausible. It is considered a primary risk and must be mitigated in the short term, ideally within a few months. Immediate action is required.
Mugla	10	2	15	300	**High Risk**	
Afyonkarahisar	10	2	7	140	**Significant Risk**	The probability of occurrence is considerable. Long-term measures should be taken to reduce the risk within approximately one year. Action is required, and an annual action plan should be developed.
Aydin	10	1	15	150	**Significant Risk**	
Kutahya	10	2	3	60	**Definite Risk**	There is a clear likelihood of occurrence; therefore, the situation should be monitored. It must be included in the action plan.
Usak	6	1	1	6	**Acceptable Risk**	The probability of occurrence is low and its impact is minor. Mitigation measures are not prioritized, although they may be implemented if necessary.

with R = 6, indicating relatively low seismic risk. This distribution reveals that even within the same regional system, risk levels vary substantially depending on geological positioning and structural exposure characteristics.

The findings of this study are significant for three reasons. First, the adapted Fine–Kinney model explains seismic risk not through a single hazard indicator, but through the integrated assessment of probability, frequency, and severity components, thereby providing decision-makers with a multidimensional analytical framework. Second, the quantitative risk scores generated for each province enable prioritization in intervention and resource allocation, contributing to the development of disaster management policies grounded in rational and evidence based principles. Third, the study offers a regionally applicable model that complements the limited number of existing studies on adapting the Fine–Kinney method to nature-based hazards. The results of this research provide valuable insights not only for disaster management and geological sciences, but also for the fields of architecture and interior architecture. The province-based numerical risk scores support the design of safety strategies, material selections, fixed furniture details, and spatial organization decisions in a risk-sensitive manner. In particular, the severity coefficient derived from the building stock presents a scientific basis for evaluating interior-space vulnerability at the level of non-structural elements. Accordingly, the adapted Fine–Kinney model serves as a guiding tool for earthquake-responsive design and interior spatial planning, offering practical applicability within the architectural literature.

Based on the findings of this research, several policy and implementation recommendations can be developed. In provinces classified as "very high" and "high risk" notably Izmir, Manisa, Denizli, and Mugla the strengthening of building stock and the implementation of urban transformation programs are of critical importance. In these areas, unsafe and old structures lacking proper engineering services should be identified and gradually reinforced. Additionally, comprehensive urban transformation strategies supported by microzonation data should be developed for districts and neighborhoods with high-risk scores. In regions located near active fault zones or characterized by weak soil conditions, new construction should be restricted, and residential or critical infrastructure investments should be planned only when necessary. In these processes, the risk scores and maps produced in this study should be treated as essential inputs. Within the scope of non-structural risk reduction, it is also important to update disaster logistics centers, assembly areas, and evacuation routes in high-risk provinces; expand regular earthquake drills in public institutions, schools, and hospitals; and prepare continuity plans to ensure the functioning of critical services. At the interior-space scale, non-structural elements should be re-evaluated according to seismic performance, units with falling or overturning potential should be tested through analytical methods, design standards should be developed for securely anchoring fixed furniture to walls and floors, lightweight and impact-absorbing materials should be preferred over heavy interior finishes, and spatial layouts should be arranged to facilitate emergency circulation. Furthermore, urban transformation programs should aim not only to improve structural elements but also to enhance interior safety simultaneously. Increasing community-based awareness efforts in high-risk provinces, particularly in densely built-up urban areas, will raise public knowledge regarding building safety, strengthening methods, emergency kits, and proper behavioral responses during earthquakes. The implementation of sustainable education and awareness programs through collaboration among local authorities, universities, and non-governmental organizations is therefore essential.

Regular updates of earthquake, fault-line, and building-stock datasets, along with re-running the model with newly available information, are necessary for dynamic risk monitoring. As a limitation, the adapted Fine–Kinney framework is a deterministic decision-support index and does not explicitly model aleatory/epistemic uncertainties in seismic hazard (e.g., ground-motion uncertainty, site effects, and attenuation). The parameters used in this study were selected in line with data availability and the objective of regional comparison. Variables such as soil classifications, maximum magnitude of fault segments, slip rates, building age, and structural system types were not included in the model due to considerations of data consistency and applicability at the provincial scale. Therefore, the proposed approach should be regarded as a decision-support tool intended for prioritization and screening purposes rather than for detailed engineering analyses. In addition to the EM-DAT database, other databases are also available. Therefore, the results should be interpreted as relative prioritization indicators rather than absolute loss estimates. Future research would benefit from integrating additional variables such as population density, income level, critical infrastructure distribution, and soil classes into the model. Moreover, applying the adapted Fine–Kinney method to other seismic zones of Türkiye and to different types of nature-based hazards would help test and validate the robustness of the framework.

In conclusion, this study provides a comparative and prioritization-oriented assessment framework for quantifying earthquake risk across the provinces of the Aegean Region. The adapted Fine–Kinney model constitutes a tool capable of contributing both to the systematic monitoring of disaster risk at the national scale and to the design of concrete intervention programs at the local scale. Enhancing the model with updated datasets and additional parameters will provide a strong foundation for developing evidence-based earthquake safety policies in Turkey.

Conflict of Interest

The author declares that there is no conflict of interest regarding this work.

Acknowledgments

AI tools were used exclusively for grammar checking and language editing of the manuscript.

Funding

No funding was received for this study.

References

AFAD (2025). Türkiye Deprem Tehlike Haritası Portalı. Retrieved from: https://tdth.afad.gov.tr/TDTH/main.xhtml (accessed on 10 November 2025).

Aker A, Özçelik ÖT (2020). Metal sektöründe 5x5 Matris ve Fine-Kinney yöntemi ile risk değerlendirmesi. Karaelmas Journal of Occupational Health and Safety. 4:65–75. https://doi.org/10.33720/kisgd.630799

Aminbakhsh S, Gunduz M, Sonmez R (2013). Safety risk assessment using analytic hierarchy process (AHP) during planning and budgeting of construction projects. Journal of Safety Research. 46:99–105. https://doi.org/10.1016/j.jsr.2013.05.003

Büyüksaraç A, Avcil F, Alkan H, Işık E, Harirchian E, Özçelik A (2025). Seismic hazard implications of the 2025 Balıkesir earthquake of Mw 6.1 for Western Türkiye. GeoHazards. 6:64. https://doi.org/10.3390/geohazards6040064

Chen N, Chen L, Tang C, Wu Z, Chen A (2019). Disaster risk evaluation using factor analysis: a case study of Chinese regions. Natural Hazards. 99:321–335. https://doi.org/10.1007/s11069-019-03742-w

Cündübeyoğlu İ, Kayabaşı R (2022). Seramik fabrikasında Fine-Kinney yöntemi ile risk değerlendirmesi. Avrupa Bilim ve Teknoloji Dergisi, 35:633–642. https://doi.org/10.31590/ejosat.1061103

Dagsuyu C, Derse O, Oturakci M (2021). Integrated risk prioritization and action selection for cold chain. Environmental Science and Pollution Research. 28:15646–15658. https://doi.org/10.1007/s11356-021-12733-z

Daneshvar Rouyendegh B, Gür L (2020). Bulanık Fine–Kinney Yöntemiyle risk değerlendirmesi uygulaması. Journal of Industrial Engineering (Turkish Chamber of Mechanical Engineers). 31(1):75–86.

Deng G, Wang AS, Li SK, Zhou YS (2001). Risk theory and method and its initial application in grain yield. Journal of Natural Resources. 16:221–226. https://doi.org/10.11849/zrzyxb.2001.03.005

Derse O (2021). A new approach to the Fine Kinney method with AHP-based ELECTRE I and math model on risk assessment for natural disasters. Journal of Geography. 42:155–164. https://doi.org/10.26650/JGEOG2021-875427

Ekinci R., Büyüksaraç A, Ekinci YL, Işık, E (2020). Bitlis ilinin doğal afet çeşitliliğinin değerlendirilmesi. Doğal Afetler ve Çevre Dergisi. 6(1): 1-11. https://doi.org/10.21324/dacd.535189

EM-DAT (2025). Emergency Events Database. Retrieved from: https://public.emdat.be/data (accessed on 20 November 2025).

Emblemsvåg J (2008). On probability in risk analysis of natural disasters. Disaster Prevention and Management: An International Journal. 17(4): 508-518. https://doi.org/10.1108/09653560810901755

Ersöz T, Bayrak G (2023). Investigation of possible earthquake risk in districts of Istanbul using the Fine-Kinney Method. Uluslararası Sürdürülebilir Mühendislik ve Teknoloji Dergisi. 7(2): 139-151.

Fine WT (1971). Mathematical evaluation for controlling hazards. Journal of Safety Research. 3:157–166. https://doi.org/10.21236/AD0722011

Ganguly KK, Guin KK (2013). A fuzzy AHP approach for inbound supply risk assessment. Benchmarking: International Journal 20:129–146. https://doi.org/10.1108/14635771311299524

Gong Z, Forrest JYL (2014). Special issue on meteorological disaster risk analysis and assessment: on basis of grey systems theory. Natural Hazards. 71:995–1000. https://doi.org/10.1007/s11069-013-0864-y

Gündoğdu E, Özden S, Bekler T (2020). Sındırgı Fayı ve Düvertepe Fay Zonu Yakın Civarının Kinematik ve Sismotektonik Özellikleri: Batı Anadolu (Türkiye). Çanakkale Onsekiz Mart Üniversitesi Fen Bilimleri Enstitüsü Dergisi. 6(2): 378-395. https://izlik.org/JA24FU64FW

Gürcanlı GE, Bilir S, Sevim M (2015). Activity based risk assessment and safety cost estimation for residential building construction projects. Safety Science. 80:1–12. https://doi.org/10.1016/j.ssci.2015.07.002

Hong JD, Jeong KY (2019). Humanitarian supply chain network design using data envelopment analysis and multi-objective programming models. European Journal of Industrial Engineering. 13:651–680. https://doi.org/10.1504/EJIE.2019.102158

Huang CF, Liu XL, Zhou GX, Li XJ (1998). Agricultural natural disaster risk assessment method according to the historic disaster data. Journal of Natural Disasters. 7(2):1–9.

INFORM Risk (2025). INFORM Risk Index. Retrieved from: https://drmkc.jrc.ec.europa.eu/inform-index (accessed on 10 November 2025).

Isik E, Ulutaş H, Büyüksaraç A (2023). The comparison of sectional damages in reinforced-concrete structures and seismic parameters on regional Basis; a case study from western Türkiye (Aegean Region). Earthquakes and Structures 24(1):37–51. https://doi.org/10.12989/eas.2023.24.1.037

Ismail A, Rashid ASA, Amhadi T, Nazir R, Irsyam M, Faizal L (2024). Exploring the evolution of seismic hazard and risk assessment research: a bibliometric analysis. Sustainability. 16(7):2687. https://doi.org/10.3390/su16072687

Kartal D, Soyluk A (2023). Revision of fuzzified Fine-Kinney method, an adaptive method for natural disaster risk management. Geoconservation Research. 6(2):409–426. https://doi.org/10.57647/j.gcr.2023.0602.25

Kinney GF, Wiruth AD (1976). Practical Risk Analysis for Safety Management. NWC Technical Publication 5865, Naval Weapons Center, China Lake, CA, USA. https://hdl.handle.net/10945/31846

Korkmaz KA, Irfanoglu A, Kayhan AH(2010). Seismic risk assessment of buildings in Izmir, Turkey. Natural Hazards. 54:97–119. https://doi.org/10.1007/s11069-009-9455-3

Luchuan REN (1999). Advance in risk analysis for regional natural disasters. Advances in Earth Sciences. 3:242–246. https://doi.org/10.11867/j.issn.1001-8166.1999.03.0242

Maden Tetkik ve Arama (MTA) (2025). MTA Yerbilimleri Portalı. Retrieved from: https://yerbilimleri.mta.gov.tr/anasayfa.aspx (accessed on 1 November 2025).

Makra K, Rovithis E, Riga E, Raptakis D, Pitilakis K (2021). Amplification features and observed damages in İzmir (Turkey) due to 2020 Samos

(Aegean Sea) earthquake: identifying basin effects and design requirements. Bulletin of Earthquake Engineering. 19:4773–4804. https://doi.org/10.1007/s10518-021-01148-3

Oturakçı M, Dağsuyu C (2017). Risk değerlendirmesinde bulanık Fine-Kinney yöntemi ve uygulaması. Karaelmas İş Sağlığı ve Güvenliği Dergisi. 1(1):17–25.

Osipov VI, Rumyantseva NA, Eremina ON (2019). Living with risk of natural disasters. Russian Journal of Earth Sciences. 19(6): 4. https://doi.org/10.2205/2019ES000673

Peduzzi P, Dao H, Herold C, Mouton F (2009). Assessing global exposure and vulnerability towards natural hazards: the Disaster Risk Index. Natural Hazards and Earth System Sciences. 9(4):1149–1159. https://doi.org/10.5194/nhess-9-1149-2009

Ranger N, Hallegatte S, Bhattacharya S, Bachu M, Priya S, Dhore K et al. (2010). An assessment of the potential impact of climate change on flood risk in Mumbai. Climatic Change. 104:139–167. https://doi.org/10.1007/s10584-010-9979-2

Sborshchikov IM, Savostin LA, Zonenshain LP (1981). Present plate tectonics between Turkey and Tibet. Tectonophysics. 79(1-2):45–73. https://doi.org/10.1016/0040-1951(81)90232-8

Sousa V, Almeida NM, Dias LA (2014). Risk-based management of occupational safety and health in the construction industry. Part 1: Background knowledge. Safety Science. 66:75–86. https://doi.org/10.1016/j.ssci.2014.02.008

Sözbilir H, Özkaymak Ç, Uzel B, Sümer Ö, Eski S, Tepe Ç (2016). Palaeoseismology 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. 28(4):254–272. https://doi.org/10.1080/09853111.2016.1171111

Tappura S, Sievänen M, Heikkilä J, Jussila A, Nenonen N (2015). A management accounting perspective on safety. Safety Science. 71(B):151–159.https://doi.org/10.1016/j.ssci.2014.01.011

Tarakçı Bİ (2025a). Afet Sonrası Barınma Alanlarına Yönelik Uluslararası Yayınların Bibliyometrik Analizi (2000–2025). Afet ve Risk Dergisi. 8(3):1323-1340. https://doi.org/10.35341/afet.1761204

Tarakçı Bİ (2025b). From local disasters to global design discourse: Interior architecture theses in Türkiye. Trends in Higher Education 4(4):72. https://doi.org/10.3390/higheredu4040072

Tarakçı BI, Kavut IE (2025). Problems experienced in post-disaster temporary shelter units: The case of Hatay/Iskenderun. Türk Deprem Araştırma Dergisi. 7:321–334. https://doi.org/10.46464/tdad.1648044

TÜİK (2025). 2021 Bina ve Konut Nitelikleri Araştırması. Retrieved from: https://nip.tuik.gov.tr/?value=BinaIstatistikleri (accessed on 10 November 2025).

Usta G (2023). Dünya'da Meydana Gelen Afetlerin İstatistiksel Olarak Analizi (1900-2022). Gümüşhane University Journal of Social Sciences. 14(1): 172-186. https://doi.org/10.36362/gumus.1138791

Xu X, Liang D, Chen X, Zhou Y (2015). A risk elimination coordination method for large group decision-making in natural disaster emergencies. Human and Ecological Risk Assessment: An International Journal. 21:1314–1325. https://doi.org/10.1080/10807039.2014.955394