Uluslararası Sürdürülebilir Mühendislik ve Teknoloji Dergisi
International Journal of Sustainable Engineering and Technology
Sayı 2, Cilt 7, (2023), Sayfa: 139-151

INVESTIGATION OF POSSIBLE EARTHQUAKE RISK IN DISTRICTS OF ISTANBUL USING THE FINE-KINNEY METHOD

Taner ERSOZ*[1], Gurkan BAYRAK[2]

[1]Karabuk University, Faculty of Business, Department of Actuary and Risk Management, TURKEY
[2]Karabuk University, Faculty of Engineering, Department of Industrial Engineering, TURKEY

Article Info
Received: 27.11.2023
Accepted: 06.12.2023
Published: 29.12.2023

ABSTRACT

Earthquakes have negatively affected countries socially, economically, and demographically throughout history. The increase in population and the construction of buildings that do not comply with legal regulations will significantly increase the impact of the consequences of the earthquake. In this research, the possible earthquake risk that may occur in Istanbul was calculated. The data collected for this study are the distances of the districts to the fault line, the construction years of the buildings in Istanbul, and the earthquakes with Mw>4 in Istanbul and its surroundings for approximately 120 years. These data were taken from AFAD and Istanbul Metropolitan Municipality Earthquake and Soil Investigation Branch Directorate. Fine-Kinney method (FKM), one of the risk assessment methods, was used in risk calculation. Earthquake intensity, frequency and probability values were used in analysis calculations. In the study, while calculating the probability value in the Fine-Kinney method, the distances of the districts to the fault line were considered, and the frequency value of 268 earthquakes in the past and the construction years of the buildings in the districts were calculated. density value. As a result of the risk analysis, 39 districts in Istanbul were classified as very high risk, high risk, significant risk, possible risk and acceptable risk according to their risk scores. According to the results of the research, Adalar, Bahcelievler, Bakirkoy, Beylikduzu, Kartal, Zeytinburnu districts have the highest risk.

Keywords; Earthquake, Seismic Risk, Istanbul, Districts, Fine-Kinney Risk Method

İSTANBUL’UN İLÇELERİNDE OLASI DEPREM RİSKİNİN FINE-KINNEY YÖNTEMİYLE ARAŞTIRILMASI

Makale Bilgisi
Geliş tarihi: 27.11.2023
Kabul Tarihi: 06.12.2023
Yayın tarihi: 29.12.2023

ÖZET

Depremler geçmişten günümüze kadar insan hayatını olumsuz bir şekilde etkilemiştir. Gün geçtikçe artan nüfus ve inşa edilen yapıların artması deprem riskini giderek arttırmaktadır. Bu çalışmada İstanbul’da yaşanacak olası bir depremin risk analizi yapılmıştır. Bu çalışmada ilçelerin fay hattına olan uzaklıkları, İstanbul’daki binaların yapım yılları ve yaklaşık 120 yıldır İstanbul ve çevresinde Mw>4 olan depremler veri olarak toplanmıştır. Veriler AFAD (Afet ve Acil Durum Yönetimi Başkanlığı) ve İstanbul Büyükşehir Belediyesi Deprem ve Zemin İnceleme Şube Müdürlüğü’nden alınmıştır. Risk analizi için Fine-Kinney metodu kullanılmıştır. Fine-Kinney metodu hesaplanırken olasılık, frekans ve şiddet değerlerinin çarpımı sonucunda risk sınıfı ortaya çıkmaktadır. Yapılan çalışmada Fine-Kinney metodundaki olasılık değerinin hesaplanması için ilçelerin fay hattına olan uzaklıkları, frekans değeri olarak geçmişte yaşanan 268 adet deprem ve şiddet değerinin hesaplanması için ilçelerde olan binaların yapım yılları ele alınmıştır. Yapılan risk analizi sonucunda İstanbul’daki 39 adet ilçe risk puanlarına göre çok yüksek risk, yüksek risk, önemli risk, olası risk ve kabul edilebilir risk olarak sınıflandırılmıştır. Araştırma sonuçlarına göre Bahçelievler, Bakırköy, Beylikdüzü, Kartal, Zeytinburnu ilçeleri çok yüksek riske sahip ilçeler olarak bulunmuştur.

Anahtar Kelimeler; Deprem, Sismik Risk, İstanbul, İlçeler, Fine-Kinney Risk Yöntemi

1. Introduction

An earthquake is an unexpected natural disaster because of the energy released through within the earth's crust. The stresses that arise on the outer layer of the earth push the edges of the fault together creating stress, and the rocks suddenly slide, releasing energy in the form of waves passing through the earth's crust. This situation causes the shaking that we feel during the earthquake (USGS Government). An earthquake is a phenomenon in which vibrations occur in the earth's crust and the seismic waves created by these vibrations reach the earth and shake the earth (Tang et al., 2020).

Due to this technical dimension, the magnitude of the earthquake is a numerical value, and the duration and intensity of the earthquake are also effective in whether the earthquake is destructive or not. Earthquakes are natural disasters related to geological processes. Earthquakes are one of the most devastating and unpredictable natural disasters that cause both the greatest number of casualties and serious economic damage and have a great impact on society. For this reason, instead of making earthquake predictions, it should be a priority to reveal the risks that are predicted to occur due to the earthquakes in the buildings and settlements to be established in the region and to take precautions accordingly.

Predicting earthquakes before they occur has been a challenge for many years due to many factors (Knopoff, 1996; Wyss et al., 1997).

Generally, the interactions between seismic events, active faults, tectonic plates, and other geological factors and these complexities make it very difficult to accurately predict the timing and magnitude of earthquakes (Sibson, 1994). In recent years, many researchers dealing with earthquake research have not been able to provide clear information about predicting earthquakes. In addition, the technology available today does not give the exact time of an earthquake in this area. That's why many models and formulas have been developed for prediction. Earthquake seismic movements, future earthquakes of the region; time, place, size, and other features cannot be predicted in advance. However, due to the confusion and various uncertainties that earthquakes create in the region in terms of their previous occurrence time, occurrence and magnitude, machine learning, artificial intelligence, statistical methods, data mining and deep learning approaches can be used.

Kulkarni (2012) presented a literature on the data mining approach used in earthquake prediction. It is also important to increase earthquake awareness (Kivrak et al., 2018a) and to constantly research and monitor this awareness with scaled surveys (Kivrak et al., 2018b).

Ersoz et al. (2016) the earthquakes that occurred in Karabuk province and its surroundings, located on the North Anatolian fault line, were examined using statistical methods and data mining. In the research, data from a 113-year observation interval were analyzed using earthquake records that occurred between 1900 and 2013 in Karabuk province and its surroundings between 1999 and 2019. In the research, it was determined that the return period of a 5-magnitude earthquake is three years, the probability of an earthquake occurring within 10 years is 97.1%, the return period of a 6.5 magnitude earthquake is 23 years, and the probability of an earthquake occurring within 10 years is 97.1%. The rate of earthquakes that will occur within 10 years were estimated to be 35.4%.

Thanks to technological revolutions (AI, IoT, Machine learning, cloud computing etc.), there are efforts to develop smart earthquake prediction models for early warning in possible earthquake areas. For example, by using IoT-edge cloud computing platforms, optimal features of uncertain and complex data can be revealed and IoT data and events from IoT sensors can be analyzed.

Since the 1990s, scientists have used the machine learning approach in seismology research (Tang et al., 2020; Yair and Nathan, 1998; Li et al., 2018; Rouet-Leduc et al., 2017). Many machine learning methods have been used in the fields of earthquake seismic classification, location, seismic event prediction and early warning system. In a study conducted in the Sichuan-Yunnan region (Li et al., 2022), the occurrence and maximum magnitudes of earthquakes were predicted with machine learning, using seismic parameters in earthquake formation.

The February six earthquake in Kahramanmaras, whose epicenter was Pazarcik, and the earthquakes in Syria, which occurred at the beginning of 2023, were a devastating earthquake in which more than 50,000 people died, and scientists have begun to create models based on artificial intelligence to predict earthquakes, save lives, and reduce their effects (CDP, 2023).

The application of the artificial intelligence algorithm developed by University of Texas researchers in China was tested for seven months and 70% of the earthquakes were predicted correctly a week before they occurred. In the research, earthquake predictions of artificial intelligence were compared with real-time data and statistical fluctuations were revealed (UTNEWS, 2023).

MTA General Directorate, it has been producing information about active faults since the 1970s. Turkey Active Fault Map was first published in 1992 and is the first study to use standards in documenting the basic features of active faults (MTA, 2020). This map is used by all researchers interested in earthquakes and tectonics (Earth scientists and various related disciplines, planners, and engineers).

It is still not possible to predict earthquakes with today's technological resources. Reducing the loss of life and property in earthquakes, hazard assessment management and risk analysis. It was prepared to reduce earthquake losses within the framework of the Turkey National Earthquake Strategy and Action Plan (UDSEP, 2023) and was prepared and entered into force in 2011. Until now, public, and private institutions have been involved in reducing and predicting the risk of earthquakes, creating earthquake-ready societies, and creating infrastructure for this purpose by local/national institutions. 80 different actions in cooperation with the sector and universities appears to have been carried out (AFAD, 2023).

Istanbul province is one of the provinces with the highest earthquake risk in Turkey. It is located on the North Anatolian Fault Line and is in the 2nd and 3rd groups in terms of risk. When the earthquake map of Istanbul is examined, the regions of the city are divided into three groups (Low, Medium and High). Districts of Istanbul with low earthquake risk are "Istinye", "Darica", "Pendik", "Erenkoy", "Kartal", "Kadikoy", "Sile", "Umraniye", "Uskudar", "Cengelkoy", "Suadiye", "Polonezkoy", "Nisantasi", "Besiktas", "Levent", "Altunizade", "Gultepe", "Sisli", "Taksim", "Eminonu", "Adalar", "Rumelihisari", "Icerenkoy", Sariyer", "Kagithane" and "Arnavutkoy" districts; medium risk districts; "Topkapi", "Tophane", "Tarabya cukuru", "Uskudar cukuru", "Cayirbasi cukuru", "Eastern parts of Ortakoy", "Alibeykoy", "Kadikoy Kurbagalidere and the sea-facing part of “Moda", "Fatih", "Silivri" and "Gumusyaka". The districts with high earthquake risk, taking advantage of Istanbul earthquake fault lines, are "Zeytinburnu", "Florya", "Kucukcekmece coasts", "Ispartakule", "Esenkent", "Avcilar", "Ambarli" and "Haramidere". It is seen that the "Avcilar" district of the European side of Istanbul is at high risk of earthquake due to its ground (Generali Sigorta, 2021).

In general, studies on the earthquake risk were carried out by evaluating the relationship of the geological structure of the region with the construction. In addition, different earthquake risk maps related to seismicity were also made. It has been observed that these studies are mostly based on the determination of the risk of the region before the earthquake. Figure 1 is a map by AFAD which shows the earthquakes over Mw ≥ 4.0 that occurred in and around Istanbul.

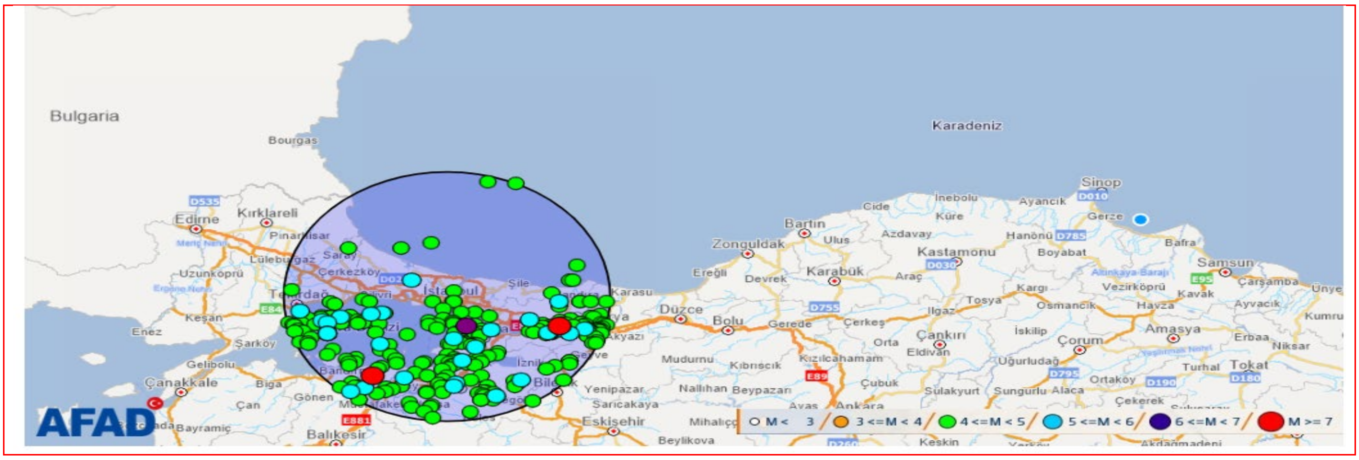

Figure 1. Earthquakes over Mw ≥ 4.0 that occurred in Istanbul and its surroundings after 1900 (AFAD, IRAP, 2022).

According to researchers, it is known that the extension of the North Anatolian Fault line, which broke off from the Marmara earthquake in Istanbul, passes through the Islands and its surroundings in the south. While TMMO Istanbul states that the regions in Istanbul are at risk of earthquake for various reasons, AFAD earthquake department stated in its statement in 2018 that, according to the earthquake scenario, a 7.5 magnitude earthquake will occur in Istanbul.

Burton et al. (2004), predicted that an earthquake with a magnitude of 5.5 to 7.5 would likely to occur in and around Greece with a probability of 90% by 2054.

Kundak and Turkoglu (2007), stated in their study that Istanbul, located on the Northern Anatolian fault line, is at risk of earthquake. In the study, they evaluated the earthquake risk of Istanbul by considering demographic, economic and environmental variables. They found that growth of Istanbul with an unplanned construction played the biggest role in increasing the risk and magnitude of the earthquake.

Turkey is a country where destructive earthquakes are frequently experienced due to its tectonic structure. The biggest and most severe earthquake ever experienced in Turkey is the 1939 earthquake in Erzincan with a magnitude of 7.9 (TMMO). The next earthquake with the highest intensity occurred on 17 August 1999 in Kocaeli and surrounding provinces. This 7.4 magnitude earthquake caused many casualties, and in November of the same year, a 7.2 magnitude earthquake occurred in Duzce and its surroundings. Many earthquakes have occurred in Turkey and the North Anatolian Fault line in the last century. These earthquakes reveal an earthquake risk that has accumulated for 250 years in the southern region of Istanbul and under the Sea of Marmara (Bohnhoff et al., 2013).

Sonmez (2014) conducted a study on earthquake damage risk in the “Zeytinburnu” district of Istanbul. The distance to the fault line, geological structure and other seismic features of the district were discussed. The researchers made use of the ArcGIS 9.3 program to analyze the risks that might come out with an earthquake, created a risk map of the district, and determined the areas that are suitable and unfavorable for settlement.

Guven and Gercek (2017) conducted a study where they developed a GIS-based system aiming to minimize the damages that might arise with an earthquake in the “Degirmendere” district of “Kocaeli”. The Golcuk Earthquake of 1999 was considered in the study, along with the damages and the outcomes. Risk ratios were determined based on the collected data. The values obtained at the end of the study were weighed with the AHP method and were uploaded to the GIS system. At the end of the research, the data about the structures and population of the “Degirmendere” district were evaluated together and recommendations were given accordingly.

Géli et al. (2018), focused on understanding the mechanical behavior and micro seismicity in the Marmara Sea, including the Istanbul seismic gap of the North Anatolian Fault. They stated that seismic research should not be interpreted only as tectonics in assessing earthquake risk. In the research, it was determined that the Marmara Fault hit more than one hydrocarbon gas source and that all gas-related factors and processes should be considered in the interpretation of this micro-seismicity (~M < 3) off the coast of Istanbul.

In a study conducted by scientists from ITU, Bogazici and Ankara University (BBC Istanbul News, 2019), the magnitude of the earthquake expected to occur in Istanbul and its surroundings was estimated using historical data and fault line measurements in Istanbul. According to the estimated results of the research, Earthquakes with magnitudes of 7.5, 7.4 and 7.2 are expected to occur on the North Anatolian Fault line, which follows the Cinarcik line in the east, Kumburgaz in the center and Tekirdag line in the west.

It is estimated that the rupture of this fault line passing through the Sea of Marmara will affect more settlements in the southern regions, especially in the province of Istanbul, and a major earthquake will occur with a probability of 62% in Istanbul and its vicinity within 30 years in the future. The probability of a strong shaking was found as 32% +/-12% for the next 10 years (Parsons et al., 2020).

Gourain (2022), pointed out the importance of city planning to define the earthquake risk in Istanbul. With its methodology based on ANT theory and interviews with geologists, geophysicists and interviews, it proposes the inclusion of earthquake planning in Istanbul's plan and laws designed as sociotechnical tools.

Pura et al. (2023), earthquakes with a magnitude of 3.0 and above that occurred in Duzce between 1990 and 2022 were investigated. In the study, some parameter values were calculated and classified with an artificial neural network model using seismic data. According to the research results, it was determined that 756 earthquakes with magnitudes between 1.0 and 6.1 occurred in the determined regions and years, and 16 of them were calculated to have earthquake magnitudes of 3.0 and above.

In this study, earthquake risk levels were investigated with the Fine-Kinney method, considering the earthquakes that occurred, and the way buildings constructed in the districts of Istanbul in the past.

2. Materials and Methods

2.1. Materials

The data in this research was obtained from the AFAD organization. The data used are approximately 268 earthquakes with a magnitude of Mw > 4.0 that occurred in Istanbul and surrounding provinces from 1900 to 2020. Another set of data that was received from the Department of Soil and Earthquake Research for being used in the study was the distribution of buildings within the districts of Istanbul by their construction year. AFAD's web application about the earthquake hazard maps of Turkey was used to find the distance of the districts to the North Anatolian fault line.

2.2. Methods

Risk prediction analysis can be calculated with many numerical prediction techniques such as statistical predictions, data mining, artificial intelligence, and machine learning techniques. In earthquake predictions, the size and intensity of the earthquake; can be revealed as a function of distance, size, time, latitude and longitude conditions (Ersoz et al., 2016) In this study, the Fine-Kinney risk assessment method (FKM) was used to calculate the earthquake risk of Istanbul districts. The first risk assessment study conducted with this method was published in 1976 under the title "Practical risk analysis for security management". The method is a risk assessment method and is formulated as follows;

Risk value = Severity * Probability * Frequency

The probability, frequency and severity values of the scales used in the Fine-Kinney risk analysis method are shown in Table 1 with necessary explanations. Also, Table 2 reveals the risk value and risk assessment chart by the FKM.

Table 1. Scales in the Fine–Kinney method (KinneyandWiruth, 1976).

Probability Value	Likelihood of a hazardous event	Frequency Value	Exposure factor	Severity Value	Possible consequences
0.2	Practically impossible, unexpected possibility	0.5	Occurring once a year/Rare	1	Noticeable/No environmental damage
0.5	Weak probability hard to expect, but very unlikely	1	Occurring several times, a year	3	Important - Minor damage/limited environmental damage on land
1	Possible, only remotely possible	2	Occurring once/several times a month	7	Major-serious damage/external environmental damage
3	Rare, but can happen	3	Occasional /several times a week	15	Very serious
6	High and possible probability	6	Occurring once/several times a day	40	Few fatalities
10	Very high probability of happening, might well be expected	10	Occurring several times in a few hours	100	Many fatalities

Table 2. Fine–Kinney risk value and risk assessment table (KinneyandWiruth, 1976).

Risk Value	Risk Assessment Result
400 < R	Very high risk. It is associated with a very high and certain probability of occurrence. Necessary precautions should be taken without showing tolerance.
200 < R < 400	High risk. It is defined as a high probability and possible probability. As the main risk, it needs to be improved in the short term within a few months. Immediate improvement.
70 < R < 200	Substantial risk. It is defined as a substantial risk that may occur. It needs to be improved in the long term like one year. Measure to be taken.
20 < R < 70	Possible risk. It is a possible risk and should be kept under surveillance.
R < 20	Negligible risk. There is a possibility that it will happen, albeit insignificant. However, the action to be taken is not a priority.

2.2.1. Calculation of Severity Value

According to the number of buildings built after 2000, 39 districts were divided into six groups and violence values were determined using the Fine-Kinney method. While dividing these districts into six groups, the number of buildings between “0-4000”, “4000-8000”, “”8000-12000, “12000-16000”, “16000-20000”, “20000-24000” were considered. Districts with the number of buildings between “0-4000” received the values of “100”, “40”, “15”, “3” respectively, according to the earthquake magnitude (“Mw >7.0”, “Mw >6.0 – Mw <7.0”, “Mw >5.0” – “Mw <6.0, Mw >4.0” – “Mw <5.0”). Districts with the number of buildings between “4000-8000” have the value “100”, “40”, “7.3”, districts with the number of buildings between “8000-12000” have the value “40”, “15”, “7.3”, districts with the number of buildings between “12000-16000” have the value “40”, “15”, “7.1”. Districts with the number of buildings between “16000-20000” and districts with the number of buildings between “20000-24000” received the values “40”, “15”, “3”, “1”. Table 3 gives data on the number of buildings built after 2000 in the districts of Istanbul.

Table 3. Number of buildings built after 2000.

District	Number of the building
Adalar	1068
Gungoren	1114
Sile	1417
Sisli	1601
Bakirkoy	1989
Beyoglu	2343
Bayrampasa	2417
Zeytinburnu	3303
Besiktas	3570
Fatih	3774
Bahcelievler	3901
Maltepe	4057
Kagithane	5413
Esenler	5446
Kartal	6279
Uskudar	6378
Beylikduzu	6491
Cekmekoy	6605
Kadikoy	6783
Bagcilar	7828
Gaziosmanpasa	8122
Atasehir	9551
Avcilar	9879
Sultanbeyli	10646
Sultangazi	11046
Basaksehir	11357
Kucukcekmece	11980
Eyup	12226
Arnavutkoy	12649
Sancaktepe	13962
Tuzla	14347
Esenyurt	14884
Catalca	16173
Sariyer	16323
Buyukcekmece	16418
Beykoz	16868
Pendik	16905
Umraniye	18885
Silivri	23466

2.2.2. Calculation of Probablity Value

In the Fine-Kinney method, the distances of the districts in Istanbul to the North Anatolian Fault line were considered to give probability values. 39 districts are divided into six groups. Districts with a distance between “10 km-15 km” from the North Anatolian Fault line received the highest value of 10 on the probability scale. Districts with a distance between “15 km - 20 km” have a value of 6, districts with a distance between “20 km - 25 km” have a value of 3, districts with a distance between “25 km - 30 km” have a value of 1, districts with a distance between “30 km - 35 km” have a value of 0.5, and districts with a distance between “25 km - 30 km” have a value of 35. Districts with a distance of km or more took the value of 0.2. Table 4 shows the distances of the districts in Istanbul to the North Anatolian Fault line.

Table 4. Distances of provinces to the North Anatolian Fault line (km).

District	Distances
Tuzla	10.1
Adalar	10.9
Bakirkoy	11.3
Avcilar	11.3
Beylikduzu	11.9
Zeytinburnu	12.9
Bahcelievler	13.7
Kucukcekmece	13.9
Kartal	14.7
Gungorenn	15.2
Pendik	15.8
Maltepe	16.1
Fatih	16.8
Buyukcekmece	17.1
Kadikoy	17.3
Bagcilar	17.3
Esenyurt	17.7
Esenler	18.1
Bayrampasa	18.3
Eyupsultan	19.8
Uskudar	20.3
Beyoglu	20.4
Gaziosmanpasa	20.7
Besiktas	21.5
Atasehir	22.5
Basaksehir	22.5
Sisli	22.6
Umraniye	23.9
Kagithane	24.3
Silivri	25.4
Sultanbeyli	25.6
Sultangazi	25.8
Sancaktepe	25.7
Cekmekoy	27.4
Catalca	29.3
Beykoz	33.8
Arnavutkoy	34.1
Sariyer	36.1
Sile	48.3

2.2.3. Calculation of Frequency Value

268 earthquakes taken from AFAD were used to determine the frequency scale for the Fine-Kinney method. The frequency values of 235 earthquakes with “Mw>4” and “Mw<5.0”, 29 earthquakes with “Mw>5.0 and Mw<6.0”, 2 earthquakes with Mw>6.0 and Mw<7.0” and two earthquakes with “Mw>7.0” were calculated. The frequencies found are “0.88”, “0.11”, “0.007”. These values are given as “6”, “2”, “0.5”, respectively, in the Fine-Kinney Method.

3. Results

In this study, FKM was used in the earthquake risk analysis of Istanbul districts and the values obtained in the analysis are given in the sub-titles.

The values taken in the calculation of the earthquake severity value are given below:

According to the number of buildings built after 2000, 39 districts were divided into six groups and their severity values were determined using the FKM. While dividing these districts into six groups, the number of buildings between “0-4000”, “4000-8000”, “8000-12000”, “12000-16000”, “16000-20000”, and “20000-24000” was considered. Districts with several buildings between “0-4000” received the intensity values of “100”, “40”, “15” and “3”, respectively, according to the earthquake magnitude (“Mw >7.0”, “6.0<Mw <7.0, “5.0<Mw <6.0”, “4.0< Mw <5.0”). Districts with a number of buildings between “4000-8000” had the values of “100”, “40”, “7” and “3”; districts with the number of buildings between “8000-12000” had the intensity values of “40”, “15”, “7”, and “3”; districts with the number of buildings between “12000-16000” had the severity values of “40”, “15”, “7”, and “1”; the districts with the number of buildings between “16000-20000” and the districts with the number of buildings between “20000-24000” received the intensity values of “40”, “15”, “3”, and “1”.

The values taken in the calculation of the earthquake probability value are given below:

In the FKM, the distances of the districts in Istanbul to the North Anatolian fault line are considered to give the probability values. 39 districts of Istanbul were divided into six probability levels. Districts with a distance of 10 km to 15 km received the highest value of "10" on the probability scale. Districts with a distance of 15 km to 20 km had the value of “6”, districts with a distance of 20 km to 25 km had the value of “3”, districts with a distance of 25 km to 30 km had the value of “1”, a distance of 30 km to 35 km. districts took the value of “0.5”, and districts with a distance of 35 km or more took the value of “0.2”.

The values taken in the calculation of the earthquake frequency value are given below:

In the FKM, the data of the 268 earthquakes received from AFAD were used to determine the frequency scale. 235 units of “4.0< Mw<5.0”; 29 units “5.0<Mw<6.0”; the probability values of two “6.0<Mw<7.0” and 2 units Mw>7.0” earthquakes were calculated. The probabilities found (0.88, 0.11, and 0.007) were given the frequency values of “6”, “2” and “0.5” respectively.

In a possible earthquake with a Mw >7.0, six districts are under a "very high risk", 10 districts under "high risk", eight districts under "substantial risk", 11 districts under "possible risk" and four districts under "insignificant risk".

Table 5 shows the earthquake risk assessment results of Istanbul districts found by using the FKM in a possible earthquake with “Mw >7.0”.

The districts of Istanbul at earthquake risk calculated by FKM were mapped according to risk classes with the Paintmaps tool and are given in Figure 2.

Table 5. Earthquake risk assessment results of Istanbul districts found using the FKM.

Districts	Risk Class	Risk Assessment Definitions
Adalar	Very High Risk	A very high-risk value is associated with a very high and certain probability of occurrence. Necessary precautions should be taken without showing tolerance.
Bahcelievler	Very High Risk	
Bakirkoy	Very High Risk	
Beylikduzu	Very High Risk	
Kartal	Very High Risk	
Zeytinburnu	Very High Risk	
Avcilar	High risk	A high-risk value is associated with a high and probable probability of occurrence. As the main risk, it needs to be improved in the short term within a few months.
Bagcilar	High risk	
Bayrampasa	High risk	
Esenler	High risk	
Fatih	High risk	
Gungoren	High risk	
Kadikoy	High risk	
Kucukcekmece	High risk	
Maltepe	High risk	
Tuzla	High risk	
Besiktas	Substantial risk	Substantial risk value is defined as a potential risk and should be monitored.
Beyoglu	Substantial risk	
Buyukcekmece	Substantial risk	
Esenyurt	Substantial risk	
Kagithane	Substantial risk	
Pendik	Substantial risk	
Sisli	Substantial risk	
Uskudar	Substantial risk	
Atasehir	Possible risk	Possible risk value is defined as a significant risk that is likely to occur. It needs to be improved in the long term like one year.
Basaksehir	Possible risk	
Catalca	Possible risk	
Cekmekoy	Possible risk	
Eyupsultan	Possible risk	
Gaziosmanpasa	Possible risk	
Sancaktepe	Possible risk	
Silivri	Possible risk	
Sultanbeyli	Possible risk	
Sultangazi	Possible risk	
Umraniye	Possible risk	
Arnavutkoy	Negligible Risk	Negligible Risk value is considered to be possible even if it is insignificant. However, the measures to be taken are not a priority.
Beykoz	Negligible Risk	
Sariyer	Negligible Risk	
Sile	Negligible Risk	

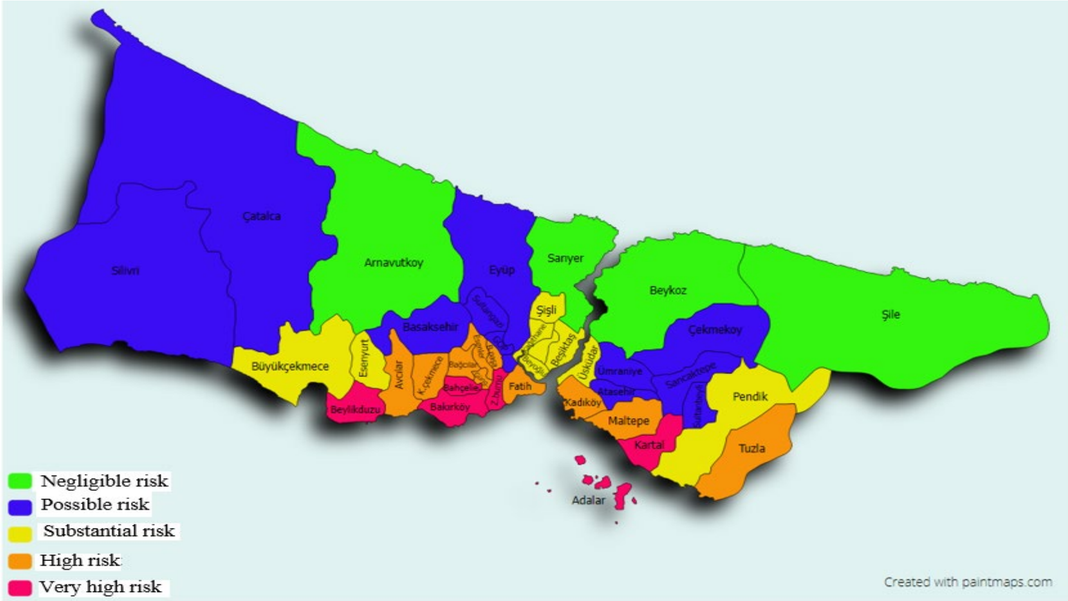

Figure 2. Earthquake risk map of Istanbul districts using Fine-Kinney risk assessment method (Paintmaps).

4. Conclusions

AFAD states that large and small scaled earthquakes occur almost every day in Turkey. Turkey's 1999 Golcuk and Duzce 1999 earthquakes, as well as the Kahramanmaras Pazarcık-centered earthquake on February 6, 2023, turned into a major disaster due to the damages caused. It was observed that studies based on disaster planning and risk analysis gained momentum after the losses experienced in our country.

Considering the dense population and urbanization in Istanbul, a possible major earthquake will cause a lot of loss of life and property. Research shows that in the province of Istanbul, where an earthquake is expected to occur with a high probability, it is worried that the damages of a possible earthquake will be great due to the population density and unplanned urban settlement.

In this study, the possible earthquake risk levels of 39 districts of Istanbul were investigated using the FKM. As a result of the research, the districts of Istanbul under a very high risk were determined as "Adalar", "Bahcelievler", "Bakirkoy", "Beylikduzu", "Kartal", and "Zeytinburnu", whereas the districts with the lowest risk levels were estimated as "Arnavutkoy", "Beykoz", "Sariyer" and "Sile". In this study, the possible earthquake risk levels of 39 districts of Istanbul were investigated using the FKM.

According to AFAD's predictions, it is known that the expected Marmara earthquake will affect all districts of Istanbul and poses an earthquake risk. In order to minimize the loss of life and damage in the city of Istanbul, it is necessary to carry out earthquake risk analysis, including examining the infrastructures in the districts of Istanbul with high earthquake risk in terms of earthquake resistance and carrying out feasibility studies for improvement. Due to its deep-rooted history of hosting the world's greatest civilizations and its strategic location, it is important for Istanbul to have a more resistant and sustainable urban structure against the Marmara earthquake risk.

It is known that one of the basic rules of earthquake preparation is the construction of earthquake-resistant buildings. In order to reduce the risk of earthquakes, changes need to be made to support this, such as strengthening buildings against earthquakes and tax exemptions. Scientific studies should be carried out in determining earthquake risk(s), the city's need for earthquake risk preparation should be considered and awareness should be increased. It is evaluated that increasing earthquake risk analysis studies, together with improvements to be made against earthquake risk by local governments, authorized institutions, and scientists, and sharing the results will reduce the earthquake risk and increase citizens' awareness.

Modern scientific methods are used to estimate the intensity, location and time of the earthquake and to investigate the relationships. Among these modern scientific methods, the role of artificial intelligence in reducing the effects of earthquakes and the role of earthquake prediction and early warning systems are increasingly accepted in the scientific community. Today, Japan is one of the most effective countries in reducing earthquake impacts and risks. Various research studies have been conducted on the use of artificial intelligence for seismic prediction and early warning systems in regions with high seismic wave activities, such as California and Mexico. Thanks to these systems, real-time data from seismic sensors is used to predict earthquakes and provide relatively early warning to those in the affected area. Such systems may be useful in areas where these catastrophic disasters occur in areas with high seismic activity.

The use of artificial intelligence in disaster studies will provide many benefits. It is considered to be very useful, especially in terms of predicting and monitoring seismic activity, supporting search and rescue efforts, managing evacuation routes, supporting rescue efforts and damage assessment.

References

AFAD (The Disaster and Emergency Management Presidency). 06 February 2023 Pazarcık-Elbistan Kahramanmaras (Mw: 7.7–Mw:7.6) Depremleri Raporu. Access Date:10.09.2023. https://deprem.afad.gov.tr/assets/pdf/Kahramanmara%C5%9F%20Depremi%20%20Raporu_02.06.2023.pdf

AFAD, IRAP (Istanbul Il Afet Risk Azaltma Planı), (2022). Access Date:13.08.2022. https://istanbul.afad.gov.tr/kurumlar/istanbul.afad/PDF-Dosyalar/irap_istanbul.pdf

AFAD, Ulusal Deprem Stratejisi ve Eylem Planı 2012-2023. (UDSEP, 2023). Access Date:17.10.2023. https://deprem.afad.gov.tr/assets/udsep/UDSEP2023.pdf

BBC Istanbul News, 2019. Istanbul beklenen 'buyuk depreme' hazir mi? Access Date: 12.04.2023 https://www.bbc.com/turkce/haberler-turkiye-49342666

Bohnhoff, M., Bulut, F., Dresen, G. Malin, P., Eken, T., Aktar, M., 2013. An earthquake gap south of Istanbul Nature Communications, Ar.Num 4. https://doi.org/10.1038/ncomms2999

Burton, P., Qin, C., Tselentis, A., Sokos, E., 2004. Extreme Earthquake and Earthquake Perceptibility Study in Greece and its Surrounding Area. Natural Hazards, 32, 277-312. https://doi.org/10.1023/B:NHAZ.0000035545.89097.0d

CDP, 2023, Turkey-Syria Earthquake. Access Date: 23.09.2023. https://disasterphilanthropy.org/disasters/2023-turkey-syria-earthquake/.

Ersoz, F., Ersoz.T., Kivrak, O., Kardes., S., 2016. Kuzey Anadolu fay hatti uzerinde yer alan Karabuk ili ve cevresinde meydana gelen depremlerin veri madenciligi ve istatistiksel yontemlerle incelenmesi. Journal of International Social Research, 9. 353-363. DOI: 10.17719/jisr.2016.1383. https://www.sosyalarastirmalar.com/articles/the-investigation-of-the-earthquake-occured-in-the-province-and-theenviroment-of-karabuk-residing-on-the-north-anatolian.pdf

Géli, L., Henry, P., Grall, C. and et al., 2018. Gas and seismicity within the Istanbul seismic gap. Scientific Reports, 8, 6819. https://doi.org/10.1038/s41598-018-23536-7

Generali Sigorta. Riskli Bolgeleri Taniyalim: Turkiye Deprem Haritasi 2021. Access Date: 13.07.2022 https://www.generali.com.tr/sigorta-rehberi/zorunlu-deprem-sigortasi/riskli-bolgeleri-taniyalim-turkiye-deprem-haritasi

Gourain, Y., 2022. Containing the earthquake risk in Istanbul's city planning: perspectives from scientists. SHS Web of Conferences, 136, 03002. https://doi.org/10.1051/shsconf/202213603002

Guven, I.T., Gercek, D., 2017. Degirmen dere'nin CBS Tabanlı Deprem Risk ve Erisebilirlik Analizi. Resilience, 1 (1),31-45. https://doi.org/10.32569/resilience.364276

Kinney, G.F., Wiruth, A.D., 1976. Practical risk analysis for safety management. NWC Technical publication 5865, Naval Weapons Center, China Lake CA, USA.

Kivrak, O., Ersoz, F., Ersoz, T., 2018a. Karabuk Ilinde Deprem Farkındalıgına Yonelik

Deprem Egitiminin Ogrenciler Uzerindeki Etkisinin Arastirilmasi. 1. Uluslararası Afet Yonetimi Kongresi. Congress Proceedings Book. 478-488. https://www.academia.edu/109795380/Karab%C3%BCk_%C4%B0lindeDepremFark%C4%B1ndal%C4%B1%C4%9F%C4%B1naY%C3%B6nelikDepremE%C4%9Fitiminin%C3%96%C4%9Frenciler%C3%9CzerindekiEtkisininAra%C5%9Ft%C4%B1r%C4%B1lmas%C4%B1

Kivrak, O., Ersoz, T., Ersoz, F., 2018b. Deprem Guvenirlilik Gecerlilik. 1. Uluslararası Afet Yonetimi Kongresi. Congress Proceedings Book. 489-496. https://www.academia.edu/105581587/DepremG%C3%BCvenirlilikGe%C3%A7erlilik

Knopoff, L., 1996. Earthquake prediction: the scientific challenge. Proceedings of the National Academy of Sciences, 93(9), 3719-3720. https://doi.org/10.1073/pnas.93.9.3719

Kulkarni, R., 2012. A Review of Application of Data Mining in Earthquake Prediction. International Journal of Computer Science and Information Technology (IJCSIT).

Kundak, S., Turkoglu, H., 2007. Istanbul'da deprem riski analizi. İTU Dergisi, Seri A: Mimarlik, Planlama, Tasarim, 6, 37- 46. https://search.trdizin.gov.tr/tr/yayin/detay/73054

Li, L., Shi, Y., Cheng, S., 2022. Exploration of long short-term memory neural network in intermediate earthquake forecast: A case study in Sichuan-Yunnan region. Chinese Journal Geophysics, Chin, Ed, 65, 12–25. http://www.geophy.cn/en/article/doi/10.6038/cjg2022Q0521

Li, Z., Meier, M., Hauksson, E., Zhan, Z., Andrews, J., 2018. Machine Learning Seismic Wave Discrimination: Application to Earthquake Early Warning. Geophysical Research Letters. 45, 4773 – 4779. https://doi.org/10.1029/2018GL077870

Mining Technical and Exploration General Directorate (MTA). Diri fay ve paleosismoloji arastirmalari. Access Date: 09.02.2020). https://www.mta.gov.tr/v3.0/arastirmalar/diri-fay-ve-paleosismoloji-arastirmalari.

PaintMaps. Automate Manual Processes. Access Date: 11.05.2019. https://paintmaps.com.

Parsons, T., Toda, S., Stein, R.S., Barka, A., Dieterich, J.H., 2000. Heightened Odds of Large Earthquakes near Istanbul: An Interaction-Based Probability Calculation. Science, 288(5466), 661–665. http://www.jstor.org/stable/3075061

Pura, T., Gunes, P., Gunes, A., Hameed, A.A., 2023. Earthquake prediction for the Duzce province in the Marmara region using artificial intelligence. Applied Sciences,13, 8642. https://doi.org/10.3390/app13158642

Rouet-Leduc, B., Hulbert, C., Lubbers, N., Barros, K., Humphreys, C., Johnson, P., 2017. Machine Learning Predicts Laboratory Earthquakes. Geophysical Research Letters, 44. https://doi.org/10.1002/2017GL074677

Sibson, R.,1994. Crustal stress, faulting and fluid flow. Geological Society, London, Special Publications. 78. 69-84. https://doi.org/10.1144/gsl.sp.1994.078.01.07

Sonmez, M., 2014. Cografi bilgi sistemleri (CBS) tabanli deprem hasar riski analizi: Zeytinburnu (İstanbul) ornegi. Turk Cografya Dergisi, 0 (56), 11-22. https://dergipark.org.tr/tr/pub/tcd/issue/21225/227787

Tang, L., Zhang, M., Wen, L., 2020. Support vector machine classification ofseismic events in the Tianshan orogenicbelt. Journal of Geophysical Research:Solid Earth,125, e2019JB018132. https://doi.org/10.1029/2019JB018132

Turkish Chamber of Mechanical Engineers (TMMO). 1900 Sonrasi Turkiye'deki Depremler. Access Date: 12.09.2021. http://www1.mmo.org.tr/resimler/dosya_ekler/8273773702779a0_ek.pdf

USGS Government. Earthquake facts and Earthquake fantasy. Access Date: 23.05.2023. https://www.usgs.gov/programs/earthquake-hazards/earthquake-facts-earthquake-fantasy

UTNEWS. AI-Driven Earthquake Forecasting Shows Promise in Trials. Access Date: 15.10.2023. https://news.utexas.edu/2023/10/05/ai-driven-earthquake-forecasting-shows-promise-in-trials/

Wyss, M., Aceves, R.L., Park, S.K., Geller, R.J., Jackson, D.D., Kagan, Y.Y., Mulargia, F., 1997. Cannot Earthquakes be Predicted? Science, 278, (5337), 487–490. http://www.jstor.org/stable/2894929

Yair S., Nathan, I., 1998. Classification of seismic signals by integrating ensembles of neural networks. IEEE Transactions on Signal Processing, 46(5):1194-1201. https://ieeexplore.ieee.org/document/668782