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Original Article

Revision of Fuzzified Fine-Kinney Method, an Adaptive Method for Natural Disaster Risk Management

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Abstract

Natural disasters are rather unpredictable and can interrupt human life, cause economic damage and even take lives. Even though they are mostly unpredictable, there are methods for assessing the risks of natural disasters, one of which is the Fine-Kinney, which was originally used for assessing industrial accident risks. Even though the method has been applied to natural disasters, the results are not very rational and precise because of the dissimilarity between both phenomena. Here we adapt the Fine-Kinney method by fuzzification to produce fast and reliable results in the building environment for natural disasters, even in situations where there is limited data. Both standard and fuzzy Fine-Kinney methods are applied to the Mustafakemalpaşa district in Bursa, Turkey, as a case study. The results of this case study are compared with the risk maps provided by the local government, to prove the accuracy and reliability of the method. While both methods produced similar and reliable results when compared to the risk maps, the Fuzzy Fine-Kinney results were more realistic because of the nature of fuzzy logic.

Keywords: Fuzzy Logic, Fine-Kinney, Risk Assessment, Natural Disasters.

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Introduction

Turkey is vulnerable to multiple natural disasters because of its geological location. There are three major faults in Turkey, the Northern Anatolian Fault, the Western Anatolian Fault, and the Eastern Anatolian Fault. Because these faults are seismically very active and affect quite a large area, making 42% of Turkey a first-degree earthquake zone and 24% second-degree (Türkoğlu 2001). Turkey is also surrounded by the Mediterranean Sea, Black Sea, and Marmara Sea while hosting lots of streams and basins and having high rainfall in some regions, and therefore being vulnerable to floods. Turkey is also vulnerable to landslides, avalanches, and forest fires. Even though the vulnerability to these natural disasters except earthquakes is more area-specific, their impacts generally overlap with earthquake zones making a considerable amount of Turkey liable to multiple hazards.

Governments prepare risk maps (AFAD 2021), uniform non-governmental organizations (AFAD, T.C. İç İşleri Bakanlığı Afet Ve Acil Durum Yönetimi Başkanlığı), and manage disasters through policies, funds, and insurance (DASK, Doğal Afet Sigortaları Kurumu). They also set regulations as a precaution (Resmi Gazete 2007 as cited in DEPREM BÖLGELERİNDE YAPILACAK BİNALAR HAKKINDA YÖNETMELİK). Municipalities apply every policy determined by governments and carry out local activities (Nilüfer İlçe Afet ve Acil Durum Yönetim Merkezi) to prevent disaster losses.

For some countries, even though they have plans and precautions for natural disaster situations, these may not be sufficient to prevent disaster losses. The purpose of the present research is to modify a risk-assessment method called “Fine-Kinney” which is used for industrial accidents. The main goal of the modification is to make the method applicable, easy to use, and reliable in natural disaster risk assessment for architects and civil engineers. The Fine-Kinney method is a risk assessment tool that needs very basic data to evaluate the risk level. By taking Fine-Kinney as a base and keeping its advantages, this method will be favorable not only for regions that have insufficient or no data on natural disasters but also for local and rural buildings, which may be constructed in the future.

In this research, the default version of Fine-Kinney is reviewed through each parameter in turn. It turns out that the frequency parameter of the default Fine-Kinney prevents results from being accurate when the method is applied to natural disasters. To solve this problem, the frequency parameter is adapted for natural disasters, taking a building’s industrial lifespan as a baseline for creating a new frequency parameter with new multipliers. To evaluate the method’s reliability and accuracy in natural disaster environments, an adapted version of Fine-Kinney was tested, along with its “fuzzy” version, which is created in MATLAB, a proprietary multi-paradigm programming language and numeric computing environment developed by MathWorks.

For the test, we assess the vulnerability against multiple disasters (avalanches, rockfall, landslide, earthquake, flood) in Karaköy Village in the Mustafakemalpaşa District (Bursa, Turkey). To evaluate frequency, severity, and probability parameters and to see the clarity of the results, we used risk maps and disaster records provided by the Disaster and Emergency Management Presidency (Aka. AFAD, a governmental disaster management agency operating under the Turkish Ministry of Interior). After comparison, it is shown that both methods produce results similar to the risk maps, but because the fuzzy results are more soft-edged compared to the standard Fine-Kinney, the Fuzzy Fine-Kinney results can be considered more applicable.

Literature Review

Researchers have used several methods to assess risks and vulnerability in different situations, including natural disasters (Du & Lin 2012). There are methods based on risk uncertainty, which include probability and statistics (Deng *et al.* 2001), the fuzzy mathematical method, which was introduced to natural disaster risk analysis by Huang *et al.* (2018), the gray system method, which is useful for minor data and poor information, used in meteorological disaster risk analysis by Gong & Forrest (2014), and the comentropy method, which is a way of describing "uncertainty" for information sources, was adapted to soil erosion and natural disasters by Ai (1987).

The literature also includes methods based on risk disadvantage. Qualitative risk analysis is a method where experience and theoretical knowledge are used. This method was first used for disaster risk and vulnerability by Eldeen (1980). GIS (geographic information system) is a series of computer-spatial analysis tools that can analyze information to create map data, and these methods were used in the risk analysis of geological disasters by Zhu *et al.* (2002). Modeling is another effective method for quantifying disaster risk (Peduzzi *et al.* 2009). Analysis methods are based on risk future, and they consider future hazard effects too. Risk characterization is a method that presents disaster risk results in the form of risk mapping or risk curves or risk index construction (Ma 2015). Ensemble forecast technology is based on weather forecasting and was used to forecast water-based disasters by Deng *et al.* (2006). Scenario analysis is a method that was first used in the military, and it tries to predict the future by finding and analyzing possible scenarios. Ranger *et al.* (2010) evaluated future flood risk for Mumbai with this method.

Some of these methodologies have been improved with the help of fuzzy logic systems (Pamučar *et al.* 2016), while some research has relied solely on fuzzy logic to assess risk (Karimi & Hüllermeier 2007).

Few studies adapted the Fine-Kinney risk assessment method for natural disasters (Derse 2021; Işık *et al.* 2022), which was originally a method for assessing industrial accidents. Some research has applied fuzzy logic on Fine-Kinney for dam risks (Daneshvar Rouyendegh & Gür 2020), which include several natural disasters.

When these methods are implemented in an environment at the scale of a building, settlement, or region for a natural disaster, however, the frequency parameter starts to cause inaccuracy in results. For example, in Daneshvar Rouyendegh & Gür's (2020) method, the lowest multiplier of the frequency parameter is 0.5, corresponding to "very sparse" and is defined as "once in a year". Defining the lowest multiplier as "once in a year" can cause problems because earthquakes occur at multiple magnitudes and severities. Even though bigger and more destructive earthquakes usually happen less than once a year in a region, "big and destructive" or "major" is a very broad definition of an earthquake. All earthquakes at a Richter scale value of 5 or higher can be considered major. If two earthquakes with a Richter scale of 5 and 8 respectively are multiplied with the same frequency multiplier, their risk scores can come out close and this can provide a false sense of security. Derse (2021) found that the least frequent multiplier is defined as "very rare" and "yearly". However, because evaluations are not limited to a region, the quantity and frequency of natural disaster is greatly increased. Derse (2021) showed that the size of the measured area can vastly change the reliability of the frequency scale. For example, while there have been only 34 earthquakes with a magnitude higher than 6 in the last 600 years in the Marmara Region (AFAD 2021), an average of 128 earthquakes occur around the world each year with a magnitude higher than 6.

For these reasons and the lack of research on the adaptation of the Fuzzy Fine-Kinney method to a pure building-oriented environment for natural disasters in a building, settlement, or region scale, the need for a new method was established.

Method

Fine-Kinney is a quantitative risk assessment method that is derived from a safety system (Department of Defense Standard Practıce) whose purpose is to minimize and eliminate hazards in the work field. This method was developed by Wiruth and Kinney (1976). In this method, each hazard is associated with three parameters (likelihood, exposure, and possible consequences), and the "Risk Score" is calculated by multiplying these three parameters (Kokangül *et al.* 2017) (Kinney & Wiruth 1976).

Equation of risk score in Fine-Kinney

"Risk Score = Possibility x Frequency x Severity"

According to the risk score, the risk is evaluated at five levels. These are acceptable risk, possible risk, substantial risk, high risk, and very high risk. Acceptable risk demands no action, possible risk needs to be taken into account and must be corrected in the long term, substantial risk needs correction in the mid-term, high risk needs to be corrected as soon as possible, and very high risk demands the stoppage of the process until the correction is made (Oturakçı 2017).

Probability: In the original study by Kinney and Wiruth (1976), the probability scale includes ten divisions, and "might well be expected" which is used for events that happened before and can reoccur in the future, taken as a reference point and given the value of 10. "Only remotely possible" is given the value of 1 and "virtually impossible" is given the value of 0.1. The scale is completed with intermediate values given depending on experience, as displayed in Table 1.

Table 1. Fine-Kinney Probability Scale.

Probability	Multiplier
*Might well be expected	10
Quite possible	6
Unusual but possible	3
*Only remotely possible	1
Conceivable but very unlikely	0.5
Practically impossible	0.2
*Virtually impossible	0.1

Frequency: Kinney and Wiruth (1976) used a scale of ten for frequency, and the reference points are 1 to 10. In the scale, risks are rated by their occurrence frequency. The value "10" is given to events that happened on an hourly basis and are considered "continuous". The reference point "1" is given to events that happen a few times per year and are considered "rare". Intermediate values are given according to experience (Table 2).

Severity: Severity is evaluated based on casualties and the damage they cause in dollars ($). The scale (Table 3) sets the loss of life and property against a scale of 100. The endpoints are "catastrophe" with a value of "100" and "noticeable" with a value of "1".

Table 2. Fine-Kinney Frequency Scale.

Probability	Multiplier
*Hourly (Continuous)	10
Frequent (Daily)	6
Occasional (Weekly)	3
Unusual (Monthly)	2
*Rare (a few per year)	1
Very rare (yearly)	0.5

Table 3. Fine-Kinney Severity Scale.

Severity	Multiplier
*Catastrophe (many fatalities or >$\$10^7$ damage)	100
Disaster (few fatalities, or >$\$10^6$ damage)	40
Very serious (fatality, or >$\$10^5$ damage)	15
Serious (serious injury, or>$\$10^4$ damage)	7
Important (disability, or >$\$10^3$ damage)	3
*Noticeable (minor first aid accident, or >$100 damage)	1

Table 4. Fine-Kinney Risk Score Scale.

Risk Score	State of Risk
R<20	Risk; perhaps acceptable
R<70>20	Possible risk; attention indicated
R<200>70	Substantial risk; correction needed
R<400>200	High risk; immediate correction required
R>400	Very high risk; discontinuing operation

Risk Score: When these three parameters are multiplied, the risk score is determined (Table 4).

Problems with Fine-Kinney: When the Fine-Kinney method is applied to natural disasters without any changes, several errors can be expected. The probability parameter is rather qualitative and can be evaluated with common knowledge when it comes to natural disasters. Severity requires only a minor change: economic damage depends on the scale of the environmental impact of the disaster, but not every disaster loss is calculated as “tangible damage” in developing or underdeveloped countries. Environmental impact is a scale that is far easier to measure than cost and can be made in the field. The parameter frequency is where a major error occurs because natural disasters are unpredictable, and their frequency is very different from industrial accidents. For example, if we take a destructive earthquake as an example, which happens once every few years or more often, its frequency multiplier will be 0.5. These earthquakes can generate a disaster and are quite possible, which makes their severity and possibility score 40 and 10 respectively. This makes a total risk score of 120 (40 x 0.5 x 6 = 120) which means they are a substantial risk and will be very inaccurate. Destructive earthquakes can easily be high risk and can go as far as a very high risk depending on conditions. Depending on the result of these calculations, a revision of the frequency scale becomes mandatory. In the frequency scale, a building's rough lifespan, assumed to be 50 years, is taken as a reference point, and given the value of "1," which means a building will definitely face a disaster with a frequency value of "1". Another reference point set for value "10" is "more than once in a year" to evaluate frequent hazards like earthquakes. Therefore, intermediate values are given to generate a revised scale (Tables 5, 6).

Table 5. Revised Fine-Kinney Severity Scale.

Severity	Multiplier
Catastrophe (many fatalities, or complete environmental destruction)	100
Disaster (few fatalities, or critical environmental impact)	40
Very serious (fatality, or considerable environmental impact)	15
Serious (serious injury, or wide environmental impact)	7
Important (disability, or environmental impact)	3
Noticeable (minor accident, or very small/no environmental impact)	1

Table 6. Revised Fine-Kinney Frequency Scale.

Frequency	Multiplier
*More than once a year	10
Once a year	6
Once in a decade	3
Once in 25 years	2
*Once in 50 years	1
Once in a century	0.5

Fuzzy Fine-Kinney: To prevent uncertainties in the evaluation of parameters, frequency, possibility, and severity multipliers are converted to fuzzy numbers and a new set of rules has been set. As shown in Fig. 1, frequency, severity, and possibility are set as input, while risk is set as output. Here, we use the Mamdani inference process method and is coded in MATLAB, a proprietary multi-paradigm programming language and numeric computing environment developed by MathWorks, Fuzzy Logic Designer (Gul & Celik 2018).

The membership functions of probability, frequency, and severity are given in Tables 7, 8, and 9 respectively. When determining this membership function, adjacent values of each value have been used. For example, in the fuzzification process of "Once in 25 years", "Once in 50 years" and "Once in a decade" values are added, and the membership function is set as (1,2,3). Fuzzification values are given in Tables 7–10.

Every member's membership function is a domain starting with the value of the member below and ending with the value of the member above (Figs. 2–5; Tables 7–10). The first member's domain starts with its value and the last member's domain ends with its own because they have no other member below and above respectively.

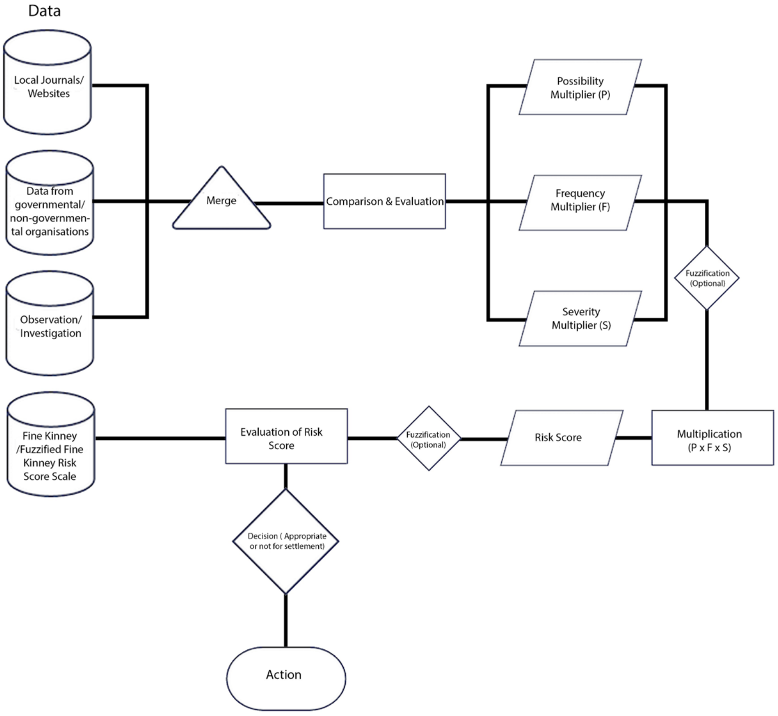


Figure 1. Flowchart of the method.

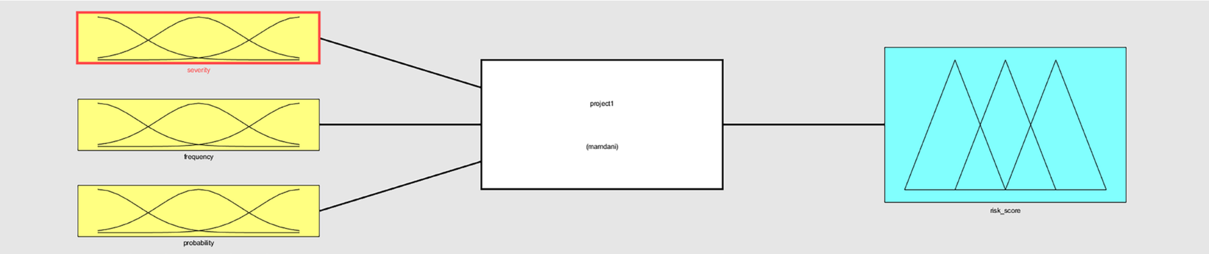


Figure 2. Fuzzy fine-kinney design.

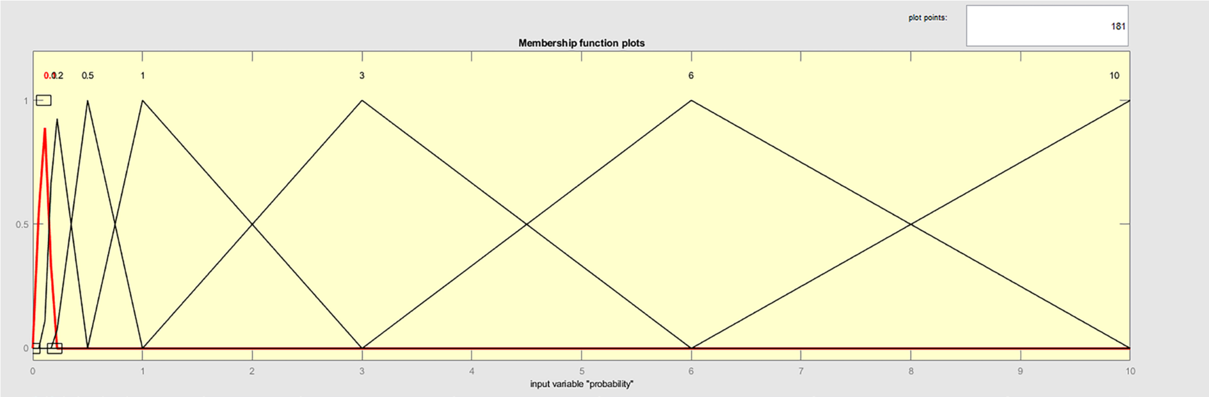


Figure 3. Fuzzy diagram of Probability.

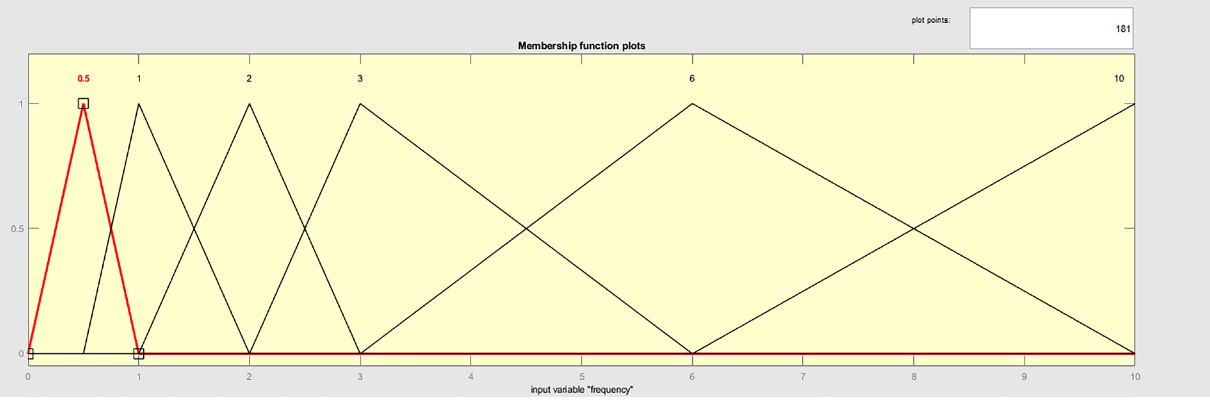


Figure 4. Fuzzy diagram of frequency.

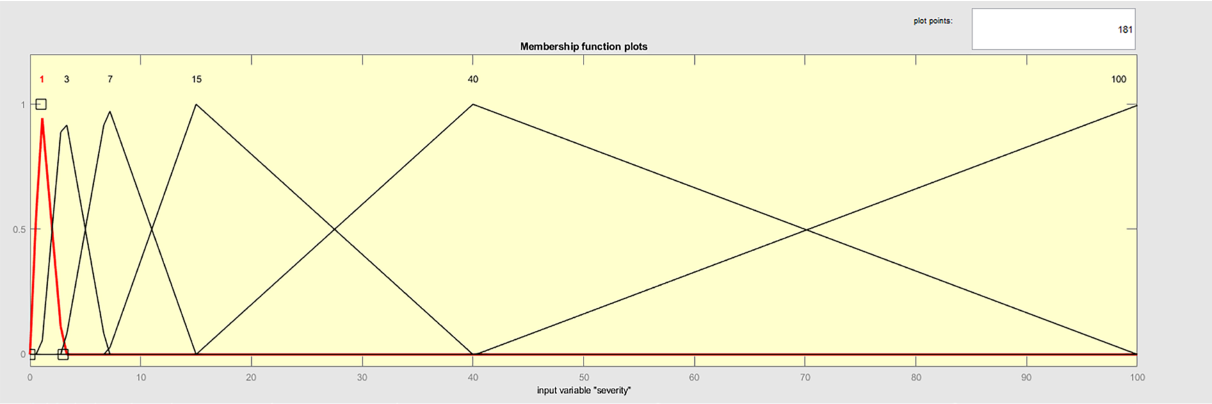


Figure 5. Fuzzy diagram of severity.

Table 7. Fuzzy Fine-Kinney Probability Scale.

Probability	Multiplier	Fuzzy Membership Function
*Might well be expected	10	(6, 10, 10)
Quite possible	6	(3, 6,10)
Unusual but possible	3	(1, 3, 6)
*Only remotely possible	1	(0.5, 1, 3)
Conceivable but very unlikely	0.5	(0.2, 0.5, 1)
Practically impossible	0.2	(0.1, 0.2, 0.5)
*Virtually impossible	0.1	(0, 0.1, 0.2)

Table 8. Fuzzy Fine-Kinney Frequency Scale.

Frequency	Multiplier	Fuzzy Membership Function
More than once in a year*	10	(6, 10, 10)
Once in a year	6	(6, 10, 10)
Once in a decade	3	(2, 3, 6)
Once in 25 years	2	(1, 2, 3)
Once in 50 years*	1	(0.5, 1, 2)
Once in a century	0.5	(0, 0.5, 1)

Table 9. Fuzzy Fine-Kinney Severity Scale.

Severity	Multiplier	Fuzzy Membership Function
Catastrophe	100	(40, 100, 100)
Disaster	40	(15, 40, 100)
Very serious	15	(7, 15, 40)
Serious	7	(3, 7, 15)
Important	3	(1, 3, 7)
Noticeable	1	(0, 1, 3)

Table 10. Fuzzy Fine-Kinney Risk Score Scale.

Risk Score	State of Risk	Fuzzy Membership Function
R<20	Risk; perhaps acceptable	(0, 20, 70)
R<70>20	Possible risk; attention indicated	(20, 70, 200)
R<200>70	Substantial risk; correction needed	(70, 200, 300)
R<400>200	High risk; immediate correction required	(200, 300, 400)
R>400	Very high risk; consider discontinuing operation	(300, 400, 400)

In this study, both Adapted Fuzzy Fine Kinney and Adapted Fine Kinney methods are applied to Karaköy Village in Mustafakemalpaşa/Bursa district. Bursa is one of the most developed cities in Turkey. Bursa is very important for Turkey both economically and historically, being one of the biggest industrial cities of Turkey and the first capital of the Ottoman Empire. These assets make Bursa suitable for the case study.

Results for both methods are evaluated individually and comparatively, to see if they are reliable for natural disaster risk assessment. The reasons behind choosing Karaköy Village for this case study were the exposure of Karaköy to multiple natural disasters and the existence of casualty and date data of five disasters provided by AFAD, a national organization in Turkey that carries out the necessary studies for the effective management of disaster and emergency processes while ensuring coordination between relevant institutions and organizations and to producing policies in this field. Locations of Mustafakemalpaşa, Karaköy and Bursa are shown in Fig. 6.

To make the analysis more specific and pinpoint

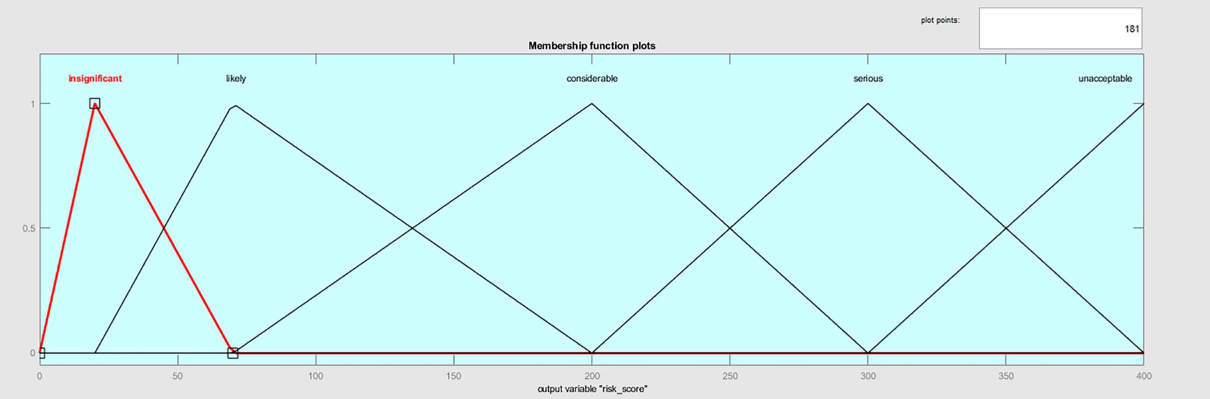


Figure 6. Fuzzy diagram of risk score

the results, Karaköy quarter in Mustafakemalpaşa was selected. The reason for choosing this quarter is because Karaköy has been exposed to several landslides in recent years and it caused disturbed daily life and damaged many buildings in the region, which makes these landslides a disaster. Its geolocation makes Karaköy vulnerable to earthquakes which makes it a multihazard area. Even though the region is not vulnerable to all of them, all five disasters (avalanche, rockfall, landslide, earthquake, and flood) risk scores will be evaluated for authentication of the method. After risk scores are calculated they will be compared to risk maps produced by AFAD.

Avalanche: There isn't any snow mass to cause an avalanche at any time of year near the Karaköy. That makes the probability of an avalanche disaster next to impossible which is equal to a multiplier of "0.1". There are no records of avalanches in Karaköy which makes frequency "more than once in a century" with a multiplier of "0.5". Because there is no significant snow mass, even if an avalanche occurs, it will hardly cause any damage and that makes the severity "barely miss, no environmental impact" with a score of "1".

Flood: As with avalanches, no flood disasters happened at Karaköy in recent history. So, we can use the same multipliers we used for avalanches.

Rockfall: As seen in Table 11, there is only one rockfall event recorded in M. Kemalpaşa which was not in Karaköy. This means the same multipliers as avalanches can be used again. In both rockfall and flood situations, possibility and severity can be changed depending on conditions. However, if there is no drastic change in either parameter, as the multipliers for other parameters are at a minimum, the Risk Score will still be very low.

Landslide: Even though it was stated only once in AFAD's records, according to local journals (Milliyet 2015, Ensonhaber 2015, and Dostmedya n.d 2015), Karaköy seems to be exposed to landslides quite often because of groundwater under the soil and it disturbs local people's daily life while damaging several buildings. This turns these landslides into disasters. Groundwater under the soil means that landslides in Karaköy can be considered "Quite possible." This makes the possibility multiplier "6". Local journals state that Karaköy was exposed to landslides in winter multiple times. This makes the frequency "more than once in a year" with a multiplier of "10". Disturbing daily life and damaging buildings to the extent that making them "unusable" can be considered as "considerable environmental impact" and that makes the severity multiplier "15".

Earthquake: When it comes to earthquakes, they have a wide variation in frequency, possibility, and severity, and they cannot be specified for

Table 11. AFAD's rockfall event records for Bursa (AFAD, 2021).

District	Report Date	Disaster Type	Buildings Affected	Year
Gürsu	10.09.2009	Rockfall	4	2009
Osmangazi	10.09.1997	RF+ Landslide	-	1997
Osmangazi	3.02.1995	Rockfall	20	1995
Osmangazi	19.07.2017	RF+ Landslide	1	2017
İznik	6.06.2000	RF+ Landslide	3	2000
Orhaneli	5.09.1990	Rockfall	3	1990
İznik	29.07.1987	RF+ Landslide	-	1987
Osmangazi	21.11.1980	Rockfall	7	1980
Kestel	15.12.2003	Rockfall	-	2003
M. Kemalpaşa	16.06.2020	Rockfall	1	2020
İznik	17.06.2020	Rockfall	4	2020
Yıldırım	24.04.2012	Rockfall	-	2012
Kestel	28.08.2020	Rockfall	-	2020

Table 12. AFAD's Landslide records for M. Kemalpaşa (AFAD, 2021).

District	Village/Quarter	Report Date	Disaster Type	Buildings Affected	Year
M. Kemalpaşa	Keltaş	30.11.1968	Landslide	5	1968
M. Kemalpaşa	Keltaş	6.12.1984	Landslide	6	1984
M. Kemalpaşa	Yukarıbali	27.04.1983	Landslide	-	1983
M. Kemalpaşa	Güvem	12.06.2015	Landslide	1	2015
M. Kemalpaşa	Karaköy	1.06.2016	Landslide	29	2016

districts because of their very wide effect range. Considering these facts, only significant earthquakes in Marmara's history (>Magnitude 6) have been evaluated. Recorded seismic activities which have a magnitude greater than 6 in Anatolia's history since the 15th century are shown in Table 13. There were 34 major earthquakes in Marmara's 600-year history, which can be considered as "quite possible" with a multiplier of "6". If we divide 34 earthquakes by 600 years, the outcome is 17.6 which is closest to the term "once in 25 years". This makes the frequency multiplier "2". Earthquakes bigger than Magnitude 6 often result in disasters in Turkey. That makes severity "disaster" with a multiplier of "40".

Results

The results from Mustafakemalpaşa's risk analysis show that both methods produce quite reliable and accurate results when compared with risk maps (Tables 14, 15).

Discussion

According to the results of both methods, Mustafakemalpaşa is vulnerable to earthquakes and landslides but with virtually no risk against rockfall, flood, and avalanche. When results are superimposed on risk maps, both results seem to be very accurate. However, the difference between the two methods can be seen in their maximum and minimum values. With the standard Fine-Kin-

Table 13. AFAD’s record for major earthquakes in the Marmara region (AFAD, 2021).

Date	Time	Latitude(0)	Longitude (0)	Magnitude	Fault Length (km)
15.03.1419	00:00	40.40	29.30	7.2	
10.09.1509	22:00	40.90	28.70	7.2	74
10.05.1556	00:00	40.30	27.80	7.2	66
25.05.1719	12:00	40.70	29.80	7.4	102
06.03.1737	07:30	40.10	27.30	7	49
02.09.1754	03:30	40.80	29.20	6.8	36
22.05.1766	05:00	40.80	29.00	7.1	58
05.08.1766	05:30	40.50	26.60	7.4	90
07.02.1809	00:00	40.00	27.00	6.1	
08.02.1826	20:30	39.80	26.40	6.2	
06.10.1841	02:30	40.85	29.50	6.1	
19.04.1850	23:30	40.10	28.30	6.1	
28.02.1855	02:30	40.10	28.60	7.1	59
11.04.1855	19:40	40.20	28.90	6.3	
21.08.1859	11:30	40.30	26.30	6.8	34
22.08.1860	10:09	40.50	26.00	6.1	
09.02.1893	17:16	40.50	26.20	6.9	41
10.07.1894	12:24	40.70	29.60	7.3	80
9.08.1912	01:28	40.70	27.20	7.3	84
10.08.1912	09:23	40.80	27.50	6.2	
13.09.1912	23:31	40.70	27.00	6.8	37
4.01.1935	14:41	40.50	27.60	6.4	
4.01.1935	16:20	40.55	27.75	6.3	
20.07.1943	15:32	40.68	30.48	6.4	
6.10.1944	02:34	39.70	26.50	6.8	
18.03.1953	19:06	40.00	27.40	7.1	55
20.02.1956	20:31	39.84	30.41	6.2	
26.05.1957	06:33	40.60	31.00	7.2	66
18.09.1963	16:58	40.70	28.95	6.4	
6.10.1964	14:31	40.10	28.20	6.8	35
22.07.1967	16:57	40.70	30.70	7.2	71
27.03.1975	05:15	40.45	26.20	6.5	
5.07.1983	12:01	40.28	27.76	6.1	
17.08.1999	00:01	40.70	30.00	7.4	98

Table 14. Fine Kinney Risk Scores.

Disaster	Possibility	Frequency	Severity	Risk Score	Evaluation
Avalanche	0.1	0.5	1	0.05	Acceptable risk
Flood	0.1	0.5	1	0.05	Acceptable risk
Rockfall	0.1	0.5	1	0.05	Acceptable risk
Landslide	6	10	15	900	Very high risk
Earthquake	6	2	40	480	Very high risk

Table 15. Fuzzy Fine Kinney Risk Scores.

Disaster	Possibility	Frequency	Severity	Risk Score	Evaluation
Avalanche	0.1	0.5	1	30	Possible risk
Flood	0.1	0.5	1	30	Possible risk
Rockfall	0.1	0.5	1	30	Possible risk
Landslide	6	10	15	368	high risk
Earthquake	6	2	40	368	high risk

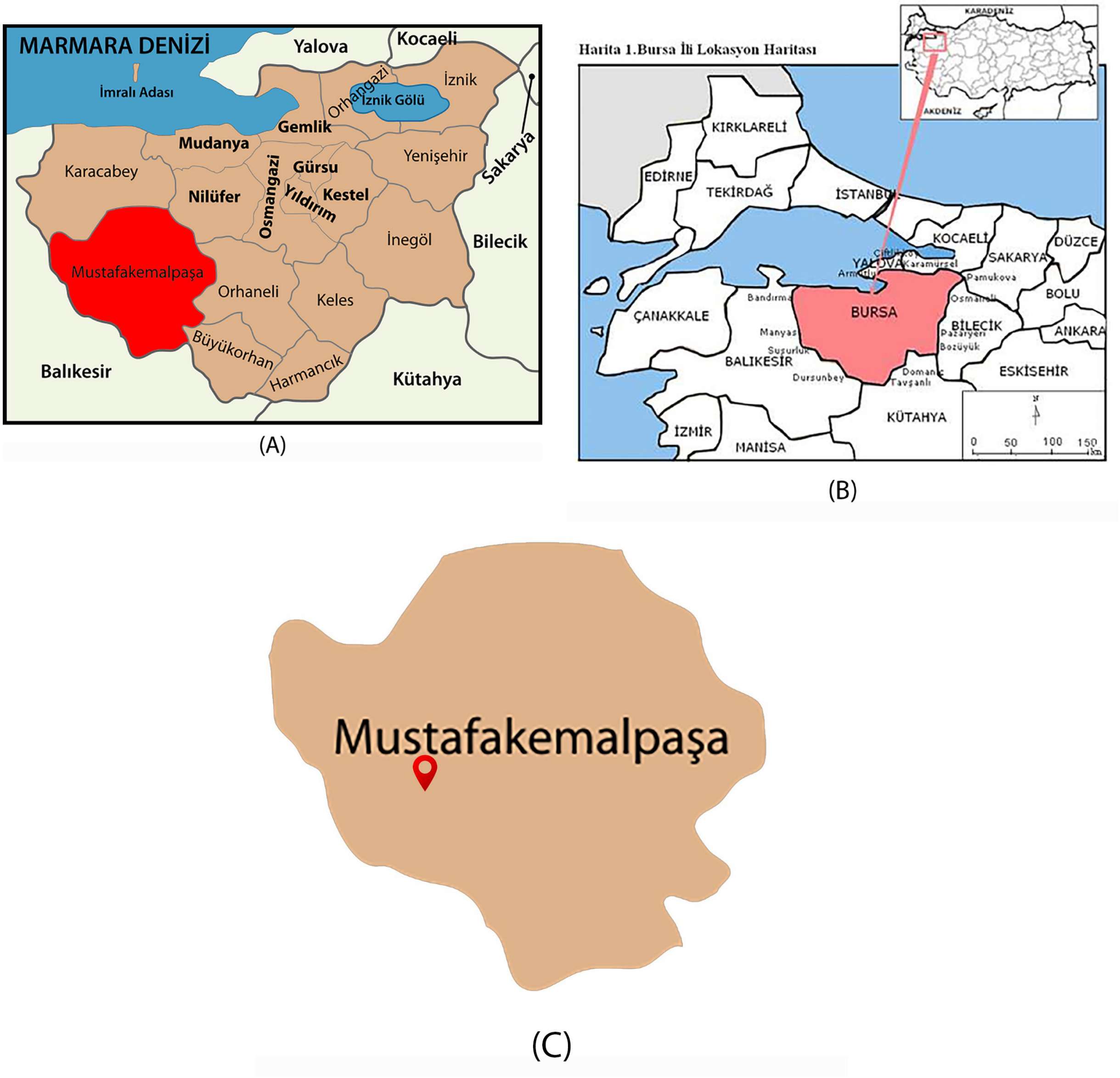
ney method, landslides and earthquakes possess such a high threat that stoppage of other actions is recommended. The Fuzzy Fine-Kinney method identifies these disasters as high risk, so they still need immediate precautions but daily life does not need to be suspended. For avalanches, rockfalls, and floods, according to the standard Fine-Kinney, they possess practically no threat and therefore require no precaution. However, when parameters are fuzzified, these disasters are identified as not associated with substantial threat but should be considered nonetheless.

The standard Fine-Kinney has sharper edges than the Fuzzy Fine-Kinney when it comes to very low and very high risks (Figs. 7, 8, 9; Table 16). However, “taking precautions without disturbing daily life” and “it should be on consideration even though the risk is very low” can be considered more rational and safe than “suspending daily life to take measures” and “no need to take any precaution” in disaster situations.

It is important to note that, when using these methods, extreme results should be evaluated by architects and civil engineers. For example, in a region that is exposed to earthquakes, if the risk score is very high, this does not mean that there should not be any settling at all in the region. The very high-risk score should be interpreted as “If there are any existing buildings which are at very high risk, precautions should be taken in that manner, and if there will be a new settlement in the area, the earthquake must be one of the biggest considerations in the design process.”. This highlights the need to recall that this method is only an evaluation tool for the assessment of the risks of natural disasters, and with the results of the method, civil engineers’/architects’ knowledge, scientific facts, and local regulations must be taken into consideration too. For example, in a tropical climate, even if the fuzzy risk score is 30 for an avalanche, which is the result of minimum parameters, even though the method recommends considering the disaster, taking precautions for an avalanche in a zone where there is no snow will be a waste of both money and time.

Table 16. Comparison among Risk Maps and Risk Scores of Fuzzy and Standard Fine-Kinney.

Disaster	Fine-Kinney	Fuzzy Fine-Kinney	Risk Map
Avalanche	Acceptable	Possible Risk	No Risk
Flood	Acceptable	Possible Risk	No Risk (Karaköy)
Rockfall	Acceptable	Possible Risk	No Risk
Landslide	Very High Risk	High Risk	High risk
Earthquake	Very High Risk	High Risk	High risk



(A)

(B)

(C)

Figure 7. Locations: A) Mustafakemalpaşa (Turkiyebilgi n.d.). B) Bursa (Pekel S 2010). C) Karaköy (highlighted with red, reteived from Turkiyebiligi).

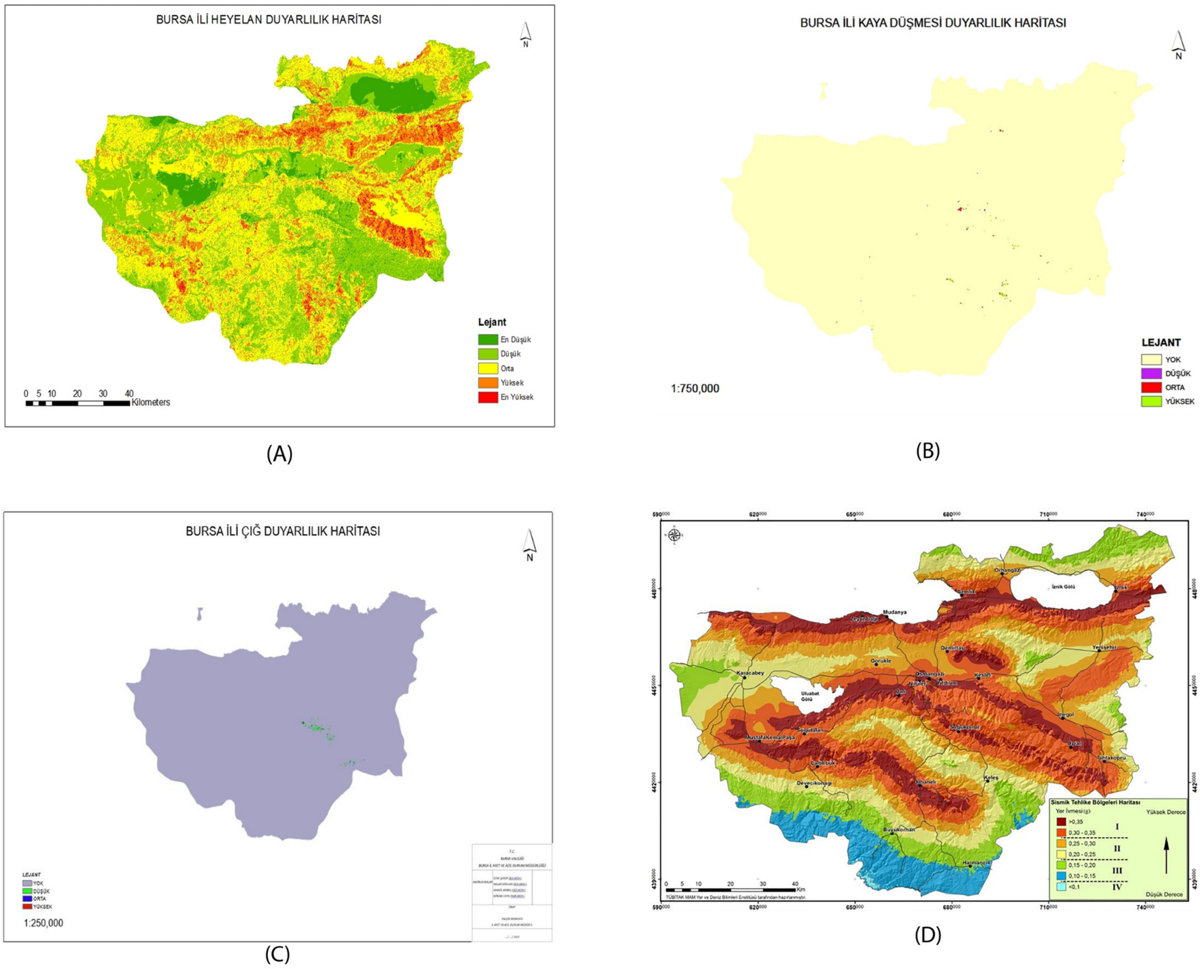


Figure 8. Risk maps. A) Bursa Landslide Risk Map (AFAD n.d.), Green-Low Risk, Red-High Risk. B) Bursa Rockfall Risk Map (AFAD n.d.), Yellow-Low Risk, Green-High Risk. C) Bursa Avalanche Risk Map (AFAD n.d.), Purple-Low Risk, Red-High Risk. D) Bursa Earthquake Risk Map (AFAD n.d.), Blue-Low Risk, Brown-High Risk (Afet Haritaları.2023)

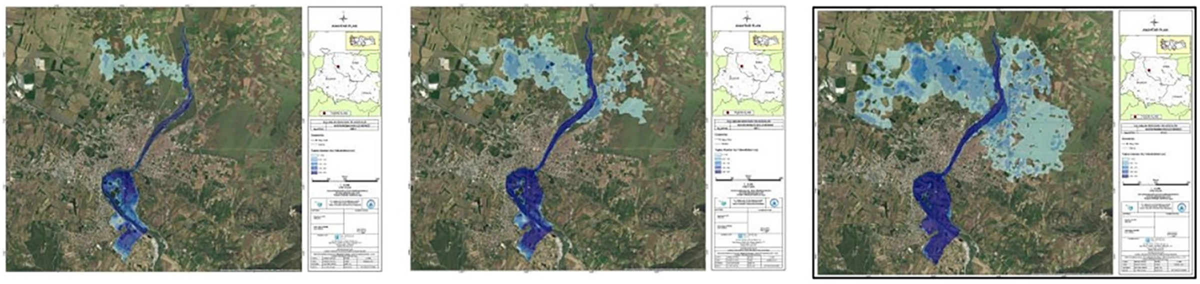


Figure 9. Mustafakemalpaşa Flood Risk Map (AFAD n.d.), Light Blue-Low Risk, Dark Blue-High Risk

Conclusion

We aimed to produce a fast and reliable natural disaster risk-assessment method for underdeveloped and developing countries that could produce rather precise results even with limited data. For this reason, the severity parameter's economic loss aspect has been replaced with the environmental damage scale. Another problem was the drastic gap between the periods of recurrence of industrial accidents and natural disasters. To adapt the frequency parameter to natural disasters, “once in 50 years” has been taken as a reference point because a building’s life span is considered as roughly 50 years. Another decision was to fuzzify the parameters, which allowed us to set our inputs not as definitive numbers but as a range and compensate for the unpredictability and diversity of natural disasters.

The new method made results less sharp but more accurate. While landslides and earthquakes are “very high risk” in Standard Fine-Kinney they become “high risk” in Fuzzy Fine-Kinney which means their risk score decreased, while avalanche, flood, and rockfalls risk scores increased and they became “possible risks”. This means in the Standard Fine-Kinney avalanche, rockfall, and flood risks were so insignificant that they will probably be ignored, and earthquakes and landslides had such a risk score that they required stoppage of current activity. In the Fuzzy Fine-Kinney model, on the other hand, avalanches, rockfalls and floods can be ignored, and earthquakes and landslides are still high risks but there is no need to stop any events. When the two methods’ results are compared with the risk maps of the region, they both produce accurate results, but the Fuzzy Fine-Kinney results are more rational and reliable.

Conflict of Interest

The authors declare that they have no competing interests. The view expressed in this short paper does not necessarily reflect those of their institutions

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