Uncertainty Discourse and Applications

www.uda.reapress.com

Uncert. Disc. Appl. Vol. 2, No. 4 (2025) 318–330.

Paper Type: Original Article

Calculation Fire Risk Values of Forest Areas in Marmaris Region by Using Fuzzy Set Theory

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Citation:

Received: 16 May 2025 *Revised: 11 September 2025* *Accepted: 03 December 2025*	Yaylalı Umul, G., & Akdeniz, T. (2025). Calculation fire risk values of forest areas in marmaris region by using fuzzy set theory. *Uncertainty Discourse and Applications, 2*(4), 318-330.

Abstract

Fuzzy Set Theory (FST) is a new theory, introduced as an alternative to classical Set Theory (ST), provides a framework for handling uncertainty and imprecision by allowing membership rather than binary classification. In this study, we propose a novel approach to forest fire risk assessment by utilizing FST to overcome the limitations of classical ST based models. Forest fires cause destruction of thousands of hectares of forestland for Turkey located in the Mediterranean climate zone. As a result of forest fires, entire ecosystem damaged and results show themselves negatively in many dimensions. Therefore, preventing or intervening forest fires is an important situation. Fire risk maps are created in order to prevent forest fires or to be prepared in advance for intervention. Usually, fire risk maps are created with help of equations made by classical ST. However, creating a risk map with classical ST as yes-no may not lead us to exactly the right measures. These created risk maps are not flexible. For this reason, in this study, we aim to determine fire risks from a different perspective with the help of FST and create risk assessment with high efficiency and reality value. Our approach uses FST to assign risk levels based on degrees of membership and aims to allow for more nuanced and realistic risk assessment. By integrating various terrain-related factors into a fuzzy logic framework, it is designed to produce fire risk levels with higher accuracy and better reflect the dynamic nature of fire risk. This method aims to contribute to more effective fire management strategies and minimize potential environmental damage.

Keywords: Fuzzy set theory, Forest fire risk calculation, Forest fire risk evaluation in marmaris.

1 | Introduction

Forest fires can be disasters with very destructive effects, like causing thousands of hectares of productive forest areas to burn and causing many forest-related values not to be adequately utilized every year. Due to its location on the Mediterranean coast and within the Mediterranean climate zone, Türkiye faces a severe fire threat, particularly during the summer months. As a result, a significant amount of forested area is damaged annually by forest fires. Forest fires not only affect trees, but also bring disasters such as erosion, mass loss, degradation of water resources, air pollution, desertification, floods, landslides and avalanches [1]. In addition to causing increasing deforestation, forest fires also bring about great material and moral losses. Sometimes,

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https://doi.org/10.48313/uda.vi.67
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fires spread to very large areas and cause great damage due to factors such as bad weather conditions, unsuitable terrain for transportation, lack of air support because the fire broke out in the evening, or the fire could not be extinguished and continued in the evening or fire extinguishing teams coming from other regions who do not know the area. Considering these situations, precautions are taken before and/or during a fire. These precautions make it easier to prevent a fire from breaking out or to control or extinguish the fire during a fire. These precautions are taken by considering the fire zone's proximity to the residential area, its slope, distance to the road, vegetation and similar factors. Using these factors, a potential risk map can be created.

Classification of objects has an important place in real life problems, such as plants class, trees class. However, most of these classifications are not classes in the mathematical sense, but these classifications still have an important role in human thinking, information communication and abstraction. As a results of these thoughts, Fuzzy Set Theory (FST), which is a structure that can deal with the classes mentioned above, was introduced by Zadeh [2] as an alternative to classical ST. Zadeh [2] introduced FST, a new structure that is a family of membership degrees, for situations where the classical Set Theory (ST) is insufficient. With the help of the FST, the elements of a set are expressed not only as existing or not existing but also by rating them with numbers between 0 and 1.

Various methods have been proposed to create fire risk maps, some of them used FST due to its ability to handle uncertainty in environmental data. The developed decision support system utilized an inference mechanism grounded in FST and fuzzy machine learning methods in [3]. Soto [4] presented and applied a new method for assessing forest fire risk by integrating three territorial variables: the spatial localization of fires, the road network, and urban-wildland interface regions. Kant Sharma et al. [5] proposed forest fire risk zones based on knowledge-based information, using both crips and fuzzy Analytic Hierarchy Process (AHP) approaches. Jafarzadeh et al. [6] assessed forest fire risk in western Iran's Ilam Province using the Apriori algorithm and fuzzy c-means clustering, revealing strong correlations between wildfire occurrence and eight key variables among twelve inputs. Fuzzy sets were combined with the AHP within a Geographic Information System (GIS)-based decision-making algorithm to model fire risk in the study area in [7]. Toledo-Castro et al. [8] presented a forest fire controller based on fuzzy logic and decision-making methods aiming at enhancing forest fire prevention, detection, and fighting systems. Abedi Gheshlaghi et al. [9] examined the efficiency of combining the Analytical Network Process (ANP) and fuzzy logic for developing a fire risk map. Demir and Akay [10] develop a forest fire risk map by using the AHP method. Uçar et al. [11] mapped the forest fire probability in the Antalya Regional Directorate of Forestry (RDF), an area highly vulnerable to fires, using the GIS-based Fuzzy-AHP method.

This study adapts and implements an established fuzzy methodology in a regional and practical context—forest fire risk mapping in Marmaris, Türkiye. Unlike many previous studies that apply generic indices or deterministic models, this paper utilizes fuzzy logic to account for uncertainty and vagueness in environmental data. The main contribution lies in the regional adaptation and in demonstrating the practical use of fuzzy modeling in fire-prone areas. While fuzzy logic has been widely applied in various environmental risk assessments, few studies have focused on forest fire risk mapping in the Mediterranean region using region-specific parameters and geospatial data. This study addresses that gap by applying a fuzzy-based approach to fire risk analysis tailored for Marmaris, a high-risk forest region in Türkiye.

In previous studies, fire risk of regions has been classified only as risky, low risk or risk-free. In this study, intermediate values are found for the fire risk of the Marmaris region. This study aims to fill that gap by applying a fuzzy inference approach to fire risk modeling in Marmaris, Türkiye—a region known for its vulnerability to forest fires. Risk values in the interval I=[0,1] is determined with the help of membership functions of fuzzy set for Marmaris region. The development of membership function formula is based on the fire risk determination equations presented by Erten et al. [12] and Joaquim et al. [13] in environmental and forest fire risk modeling.

These functions were selected due to their relevance to the nature of the variables (e.g., temperature, slope, vegetation cover), and were modified to reflect the specific data range and conditions of the Marmaris region.

While the general form of the membership functions is based on earlier studies which are depend on classical mathematics, their contextual adaptation provides practical value for regional decision-making. As a result of our study, the forest areas of the Marmaris region have been numbered based on their locations, the fire risk calculations have been presented for each forest area in the Marmaris region, with the areas individually numbered according to their positions. According to the detailed risk values created, it is aimed to contribute to the prevention of fire or possible damage from fires.

2 | Method

2.1 | Risk Maps of Forest Fires

Forest fires are one of the main factors that endanger the continuity of forests. In Turkey, which is in the Mediterranean climate zone, more than 2000 forest fires occurred in every year cause the destruction of thousands of hectares of forest area due to the influence of the human-forest relationship [14]. It is a generally accepted fact that forest fires are one of the main causes of ecological degradation and limited natural resources in the Mediterranean climate zone [15].

Risk assessment can be defined as the probability of the probability of occurrence of events and their magnitude, as well as the nature and intensity of undesirable effects generated in spatial and temporal terms [16]. There are many factors in forest fires, such as how the fire started, what type of fire it is, the temperature of the region, slope of the region, humidity rate and the direction of the wind. Determining the risk of forest fire of the regions has an important place in preventing a fire or making it easier to intervention to a fire that may occur. Many studies have been made on the fire risk status of regions, for instance the Nesterov Ignition Index. This index uses temperature and relative humidity as inputs, as well as the effect of precipitation on combustible material moisture [17].

$$N_i = \sum_{i=1}^{w} (t_i - D_i) \times t_i, \quad (1)$$

In *Eq. (1)*, Nesterov Ignition Index, number of days since rainfall above 3 mm, temperature, dew point temperature (°C) are denoted by N_i, w, t_i, D_i, respectively. According to the *Eq. (1)*, if. $N_i < 300$, there is no fire risk;

$300 < N_i < 1000$, there is medium fire risk,

$1001 < N_i < 4000$, there is high fire risk,

$4001 < N_i$, there is an extreme fire risk.

In other words, this system of equations based on binary logic and the classical ST say that there is no fire danger at the ignition indexes which are close to 300 even at a value of 299. Since the resulting values are very close to each other, creating a risk map based on classical ST will not lead us to exactly the right precautions.

There are many studies done to create forest fire risk maps. However, in this study, we will specifically discuss the methods mentioned below.

Alkayış et al. [18] determined the potential risk map in the Menteşe region of Muğla with the help of *Eq. (2)* by using Geographic Information Systems (CBS) techniques.

$$RS = 7 \times FT + 5 \times (S + A) + 3 \times (DR + DS). \quad (2)$$

In this equation RS, FT, S, A, DR, DS represent fire risk level, the burn potential for vegetation depending on its moisture content, slope, slope exposure, distance to road, distance to residential area respectively. Similarly, Baltacı and Yıldırım [19] obtained the fire risk map for the Muğla region by using the parameters of tree type, stand closeness, slope, slope exposure, altitude, distance to agricultural areas, distance to settlements, distance to energy transmission lines.

In this study by using *Eq. (2)* from Erten et al. [12] and Alkayış et al. [18], a detailed fire risk assessment is made for the Muğla/Marmaris region with the help of FST.

2.2 | Fuzzy Sets

Zadeh [2] introduced the concept of fuzzy sets upon recognizing that classical ST was inadequate for modeling vague and imprecise terms frequently encountered in real-life contexts, such as 'high', 'medium', 'low', 'risky', and 'safe'. The fuzzy set definition which was introduced by Zadeh [2], is given in the following definition.

Definition 2 ([2]). Let $X \neq \emptyset$. $A = \{(x, \mu_A(x)) : x \in X\} \subset X \times I$ is called a fuzzy set in X which is characterized by the membership function $\mu_A : X \to I=[0,1]$ for all $x \in X$, $\mu_A(x) \in I \subseteq \mathbb{R}$. $\mu_A(x)$ is representing grade of membership of x in A. Therefore, a fuzzy set A on the universal set X can be written as set of pairs as:

$$A = \{(x, \mu A(x)) \mid x \in X, \mu A(x) \in I\}. \tag{3}$$

In this study, we introduce an equation by using fuzzy sets to develop *Eq. (2).*

2.3 | Membership Function Giving the Fire Risk

In this section, the membership function formula giving the fire risk value is obtained by using fuzzy sets. While developing the formula of the membership function of fire risk using fuzzy sets, the *Eq. (2)* which is the fire risk level determination formula used by Erten et al. [12] and Joaquim et al. [13] is taken as basis.

As a started point, to obtain a fuzzy set, the universal set X is defined as the set consisting of ordered quintiles obtained with the features of vegetation, slope, slope exposure, distance to road, distance to residential area. The membership function YR that we have developed from the set X to the closed interval I is given below.

$$YR=\frac{7t+5\left(\frac{m}{30}+b\right)+3\left(\frac{400-p}{400}+\frac{2000-c}{2000}\right)}{23}. \tag{4}$$

In this membership function YR, t, m, b, p, c represent fire risk, vegetation, slope, slope exposure, distance to road, distance to residential area respectively. The calculations of the t, m, b, p and c values in the YR membership function in *Eq. (4)* are as follows.

The vegetation parameter (t) is evaluated according to the type of plants as:

- *Very dry: 1.0*
- *Dry: 0.8*
- *Mesic: 0.5*
- *Moist: 0.3*
- *Perhumid: 0.1.*

Fire spreads faster in areas with high slope than in areas with low slope [18]. For this reason, the slope parameter (m) is calculated as slope/30, if the slope is greater than 30, the slope is taken as 30.

In the northern hemisphere, the risk of fire is higher in regions facing south than in those facing north, as they feel more sunlight [18]. The slope exposure (b) is evaluated as:

- *South: 0.9*
- *Southwest: 0.8*
- *West: 0.7*
- *Southeast: 0.6*
- *East: 0.5*

- *Northwest: 0.4*
- *Northeast: 0.3*
- *North: 0.2*
- *Flat: 0.1*

Closeness to the road is an important variable in the occurrence of forest fires [20], because the ease of people entering forest areas near the road allows fires to easily occur due to accidents or negligence [18]. In this study, the parameter of distance to the road (p) is calculated with (400-distance to the road)/400, where if the distance to the road is more than 400 meters, the distance to the road is taken as 400 meters.

As the distance of the region to the settlement increases, the risk level decreases [21]. The parameter of distance to residential area (c) is taken as (2000-distance to the settlement)/2000, if the distance to the settlement is more than 2000 meters, the distance to the settlement is taken as 2000 meters.

2.4 | Risk Data Obtained on Forest Areas of Marmaris Region

The data used in this section were obtained from the websites of the Marmaris Municipality, CBS of the General Directorate of Forestry and the Muğla Governorship [22–26] and the Muğla Regional Forest Directorate and the Marmaris Forest Sub-District Directorate.

All local administrations of Marmaris are listed below (See *Fig. 1*).

Table 1. List of administrative units of marmaris.

Adaköy	Armutalan	Bayır	Beldibi	Bozburun	Camiavlu	Çamdibi	Çamlı
Çetibeli	Çıldır	Gölenye	Hatipirimi	Hisarönü	İçmeler	Karaca	Karşıyaka
Kemeraltı	Orhaniye	Osmaniye	Sarıana	Selimiye	Sinan	Siteler	Söğüt
Taşlıca	Tepe	Turgut	Turunç	Yeşilbelde	Yeşilova		

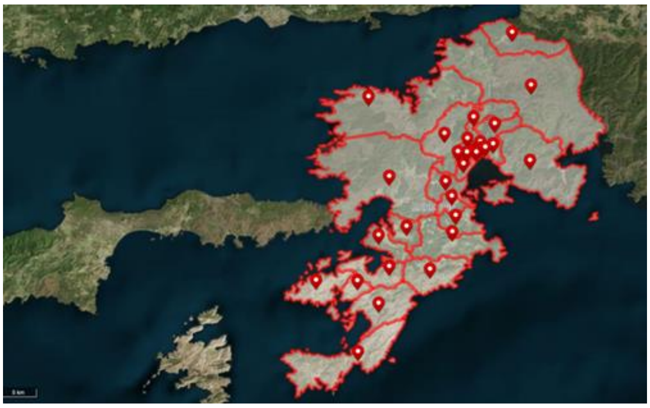

Fig. 1. Local administrations of marmaris.

Among the local administrations listed above, Armutalan, Beldibi, Camiavlu, Çamdibi, Çıldır, Gölenye, Hatipirimi, İçmeler, Kemeraltı, Karşıyaka, Sarıana, Sinan, Siteler, Tepe neighborhoods are located in the city center, while Armutalan, Beldibi, Camiavlu, Çamdibi, Gölenye, İçmeler, Karşıyaka, Sarıana, Sinan, Siteler neighborhoods are located on the edge of the forest area (See *Fig. 2*).

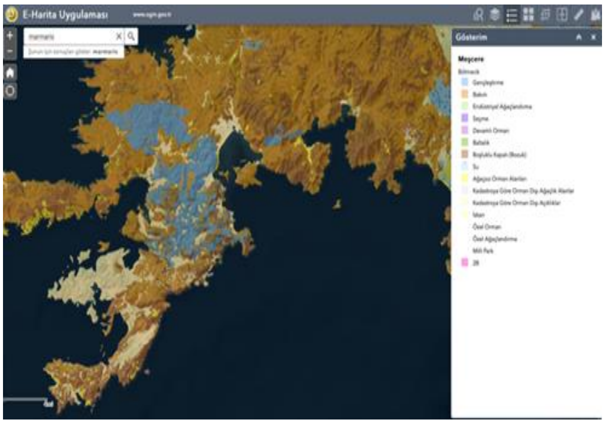

Fig. 2. Marmaris stand data map.

As can be seen from the stand data map in *Fig. 2* above, regeneration is being carried out in some forest areas in the Marmaris region due to the fires that occurred in 2021-2022. In this study, the regeneration sections were evaluated by taking into account the afforestations.

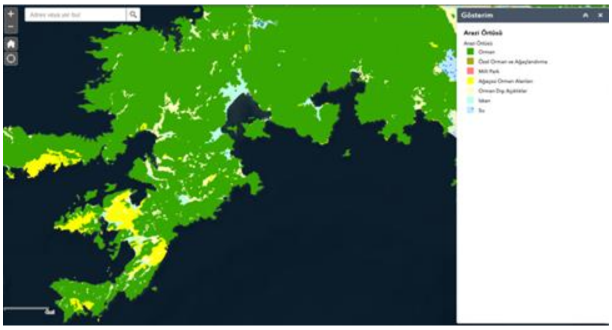

Fig. 3. Marmaris region land cover.

As seen in the Marmaris region land cover map in *Fig. 3* above, the Marmaris region is predominantly covered with forests, and there are also treeless forest areas in some regions.

3 | Results

3.1 | Interpretation of Data Obtained from Forest Areas in Marmaris Region

In this section to analyze the data, forest areas in Marmaris was divided into 33 separate subregions by examining the heights of the region and this numbering is shown in *Fig. 4*.

Fig. 4. Numbered regions.

The neighborhoods in which these 33 regions are located are approximately as follows (See *Table 2*).

Table 2. Approximate numbers of the neighborhoods shown in Fig. 4.

Numbers in Fig. 4	Neighborhoods	Numbers in Fig. 4	Neighborhoods	Numbers in Fig. 4	Neighborhoods
1, 2, 3, 4, 5	Taşlıca	18	Gölenye ve İçmeler	6, 7	Söğüt
19, 20, 21	Hisarönü	8	Yeşilova	22, 23, 24	Adaköy
9, 12	Selimiye	24	Sarıana ve Beldibi	10	Bozburun
25	Armutalan ve Karşıyaka	11, 12	Bayır	26	Yeşilbelde
13	Turgut	27, 28	Karaca	14	Orhaniye
29, 31, 33	Çamlı	15, 17	Osmaniye	30, 31, 32	Çetibeli
16	Turunç				

When we look at the forest areas in the Marmaris region, we see that the main tree species is the red pine, also there are tree species such as liquidambar orientalis (Sweetgum), pinus pinea, cypress, maritime pine, eucalyptus, carob bean tree, Datça date palm, olive tree. In addition to these, there are regions where maquis areas are dense and a small amount of treeless forest areas are observed.

When looking at the study of Bingöl [27], it is seen that the Red Pine, which is densely located in the Marmaris region, is evaluated as "Very Dry". Again, as stated in the study of Şengönül [28], maquis vegetation has high flammability properties, therefore it is described as "Very Dry".

In this study, the slope, distance to the road, distance to the settlement, slope exposure and vegetation of these 33 subregions shown in *Fig. 4* are examined and evaluated. In the evaluation, the slopes of the regions are obtained from the directions whose calculations are suitable. The obtained results are shown in *Table 3* and *Table 4*.

Table 3. Slope: m, distance to road: p, distance to residential area: c values.

	East Slope (M)	West Slope (M)	North Slope (M)	North East Slope (M)	North West Slope (M)	South Slope (M)	South West Slope (M)	South East Slope (M)	Distance To Road (P)	Distanace To Residential Area (C)
1		1	0,9			0,5			0	0
2	0,9					1			0	0
3			1						0	0
4	0,8	0,7				0,76			0	0
5		1	1						0	0,285
6		0,6				0,53			0	0,385
7	0,9								0	0
8		0,6	0,53						0	0
9	0,9		0,76						0	0,5
10		0,6	0,76			0,53			0	0
11	0,5					0,86			0	0,365
12		0,5							0	0,01
13		0,7	0,8			1			0	0,415
14		0,6							0,325	0,32
15	0,6								0	0,02
16	1		1						0	0,5
17				0,36					0,125	0,25

Table 3. Continued.

	East Slope (M)	West Slope (M)	North Slope (M)	North East Slope (M)	North West Slope (M)	South Slope (M)	South West Slope (M)	South East Slope (M)	Distance To Road (P)	Distanace To Residential Area (C)
18	0,6								0	0,395
19							0,53		0	0,205
20		0,3				0,5	0,26		0	0
21	0,2	0,3		0,13		0,33			0,09	0,61
22	1	1	1			1			0	0,55
23		0,7		0,66		1			0	0
24							0,56	0,46	0	0
25								0,4	0	0,29
26		0,2	0,36						0	0
27	0,2	0,2	0,33						0	0
28		0,7	0,33		0,83				0	0,025
29						0,23			0	0
30					0,23				0	0
31					0,23				0	0
32		0,3	0,72						0	0,29
33		0,3	0,5						0	0,1

Table 4. Vegetation: t, slope exposure: b values.

	East Slope Exposure (B)	West Slope Exposure (B)	North Slope Exposure (B)	North East Slope Exposure (B)	North West Slope Exposure (B)	South Slope Exposure (B)	South West Slope Exposure (B)	South East Slope Exposure (B)	Vegetation (T)
1		0,7	0,2			0,9			0,5
2	0,5					0,9			0,5
3			0,2						1
4	0,5	0,7				0,9			1
5		0,7	0,2						0,5
6		0,7				0,9			1
7	0,5								1
8		0,7	0,2						1
9	0,5		0,2						0,5
10		0,7	0,2			0,9			0,5
11	0,5					0,9			1
12		0,7							1
13		0,7	0,2			0,9			1
14		0,7							1
15	0,5								1
16	0,5		0,2						1
17				0,3					1
18	0,5								1
19							0,8		1
20		0,7				0,9	0,8		1
21	0,5	0,7		0,3		0,9			1
22	0,5	0,7	0,2			0,9			1
23		0,7		0,3		0,9			1
24							0,8	0,6	1
25								0,6	1
26		0,7	0,2						1
27	0,5	0,7	0,2						1
28		0,7	0,2		0,4				1
29						0,9			1
30					0,4				1
31					0,4				1
32		0,7	0,2						1
33		0,7	0,2						1

The values shown in *Table 3* and *Table 4* are used in the following membership function.

$$YR(t,m,b,p,c)=\frac{7t+5\left(\frac{m}{30}+b\right)+3\left(\frac{400-p}{400}+\frac{2000-c}{2000}\right)}{23}. \quad (5)$$

To calculate the membership degrees of 33 regions which are given in *Table 5*.

Table 5. Membership values according to directions.

	East YR	West YR	North YR	North east YR	North west YR	South YR	South west YR	South east YR
1		0,5	0,39			0,46		
2	0,5					0,57		
3			0,57					
4	0,6	0,6				0,67		
5		0,6	0,45					
6		0,6				0,67		
7	0,6							
8		0,6	0,46					
9	0,5		0,43					
10		0,4	0,36			0,46		
11	0,6					0,73		
12		0,6						
13		0,7	0,58			0,77		
14		0,7						
15	0,5							
16	0,7		0,63					
17				0,5				
18	0,6							
19							0,62	
20		0,5				0,61	0,53	
21	0,6	0,6		0,49		0,66		
22	0,7	0,7	0,64			0,79		
23		0,6		0,51		0,72		
24							0,6	0,53
25								0,56
26		0,5	0,43					
27	0,5	0,5	0,42					
28		0,6	0,42		0,58			
29						0,55		
30					0,44			
31					0,44			
32		0,6	0,54					
33		0,5	0,47					

The elements of the resulting fuzzy set consist of ordered pairs ((t,m,b,p,c),YR), where t, m, b, p, c, YR are the values in *Tables 3- 5*. This fuzzy set has 66 elements and the fire risk fuzzy set depending on the parameters of vegetation, slope, slope exposure, distance to the road and distance to the settlement is given below.

Fuzzy set of fire risk in the Marmaris region:

A={((0.5,1,0.7,0,9), 0,52173913), ((0.5, 0.9, 0.2, 0, 0), 0,39130435), ((0.5, 0.5, 0.9,0,0), 0,45652174), ((0.5, 0.9, 0.5, 0,0), 0,456521739), ((0.5, 1, 0.9, 0, 0), 0,56521739) , ((1, 1, 0.2, 0, 0), 0,56521739), ((1,0.8, 0.5, 0,0), 0,57826087), ((1,0.7, 0.7, 0, 0), 0.6), ((1, 0.76, 0.9, 0 ,0), 0,66521739), ((0.5, 1, 0.7, 0, 0.285), 0,55891304), ((0,5, 1, 0.2, 0, 0.285), 0,45021739), ((1, 0.6, 0.7, 0, 0.385), 0,62847826), ((1, 0.53, 0.9, 0, 0.385), 0,66543478) ((1,0.9, 0.5, 0, 0), 0,6), ((1, 0.6, 0.7, 0, 0), 0,58695652), ((1, 0.53, 0.2, 0, 0), 0,46304348), ((0.5, 0.9, 0.5, 0, 0.5), 0,513043478), ((0.5, 0.76, 0.2, 0, 0.5), 0,42608696), ((0.5, 0.6, 0.7, 0, 0), 0,42608696), ((0.5, 0.76, 0.2, 0, 0), 0,36086957), ((0.5, 0.53, 0.9, 0, 0), 0,46304348), ((1,0.5, 0.5, 0, 0.365), 0,569347826), ((1,0.86, 0.9, 0, 0.365), 0,73456522), ((1, 0.5, 0.7, 0, 0.01), 0,55782609), ((1, 0.7, 0.7, 0, 0.415), 0,66282609), ((1, 0.8, 0.2, 0, 0.415), 0,57586957), ((1, 1, 0.9, 0, 0.415), 0,77152174), ((1, 0.6, 0.7, 0.325, 0.32), 0,6623913), ((1, 0.6, 0.5, 0, 0.02), 0,546086957), ((1, 1, 0.5, 0, 0.5), 0,695652174), ((1, 1, 0.2, 0, 0.5), 0,63043478), ((1, 0,36, 0.3, 0.125, 0.25), 0,49673913), ((1, 0.6, 0.5, 0, 0.395), 0,601521739), ((1, 0.53, 0.8, 0, 0.205), 0,620217391), ((1, 0.3, 0.7, 0, 0), 0,52173913), ((1, 0.5, 0.9, 0, 0), 0,60869565), ((1, 0.26, 0.8, 0, 0), 0,534782609), ((1, 0.2, 0.5, 0.09, 0.61), 0,554347826), ((1, 0.3, 0.7, 0.09, 0.61), 0,61304348), ((1, 0.13, 0.3, 0.09, 0.61), 0,48913043), ((1, 0.33, 0.9, 0.09, 0.61), 0,66304348), ((1, 1, 0.5, 0, 0.55), 0.702173913), ((1, 1, 0.7, 0, 0.55), 0,74565217), ((1, 1, 0.2, 0, 0.55), 0.63695652), ((1, 1, 0.9, 0, 0.55), 0.78913043), ((1, 0.7, 0.7, 0, 0), 0,6), ((1, 0.66, 0.3, 0, 0), 0.51304348), ((1, 1, 0.9, 0, 0), 0.7173913), ((1, 0.56, 0.8, 0, 0), 0.6), ((1, 0.46, 0.6, 0, 0), 0,53478261), ((1, 0.4, 0.6, 0, 0.29), 0.55956522), ((1, 0.2, 0.7, 0, 0), 0.5), ((1, 0.36, 0.2, 0, 0), 0.42608696), ((1, 0.2, 0.5, 0, 0), 0.463043478), ((1, 0.2, 0.7, 0, 0), 0.5), ((1, 0.33, 0.2, 0, 0), 0,41956522), ((1, 0.7, 0.7, 0, 0.025), 0,61195652), ((1, 0.33, 0.2, 0, 0.025), 0,42282609), ((1, 0.83, 0.4, 0, 0.025), 0,575), ((1, 0.23, 0.9, 0, 0), 0.55), ((1, 0.23, 0.4,0 ,0), 0,44130435), ((1, 0.23, 0.4, 0, 0), 0,44130435), ((1, 0.3, 0.7, 0, 0.29), 0,56608696), ((1, 0.72, 0.2, 0, 0.29), 0,54217391), ((1, 0.3, 0.7, 0, 0.1), 0,53478261), ((1, 0.5, 0.2, 0, 0.1), 0,46956522)}.

The membership degrees (YR) are evaluated as fire risk values of the region which is given in *Table 5*. The closer the YR value is to 0, the lower the fire risk of that region, and similarly, the closer the YR value is to 1, the higher the fire risk. For example, according to the membership degrees obtained, the fire risk in the western part of the first region is higher than the fire risk in the northern part. Similarly, in the Marmaris region, the region with the highest fire risk is the southern part of the twenty-second region, and the region with the least risk is the northern part of the tenth region.

Table 6 shows the fire risks of the 33 regions numbered on the map in *Fig. 4*, ranked from low risk to high risk. As can be seen from *Table 6*, fire risk levels of the entire region examined have been obtained. For example, the most risky area for fire is the forested areas in Adaköy neighborhood and the least risky area is the forested area in Bozburun neighborhood.

Table 6. Ordering regions according to fire risk from low to high risk.

	Region	YR		Region	YR		Region	YR
1	10 north	0,36086957	23	1 west	0,5217391	45	23 west	0,6
2	1 north	0,39130435	24	20 west	0,5217391	46	24 south	0,6
3	27 north	0,41956522	25	20 south west	0,5347826	47	18 east	0,60152174
4	28 north	0,42282609	26	24 south east	0,5347826	48	20 south	0,60869565
5	9 north	0,42608696	27	33 west	0,5347826	49	28 west	0,61195652
6	10 west	0,42608696	28	32 north	0,5421739	50	21 west	0,61304348
7	26 north	0,42608696	29	15 east	0,546087	51	19 south west	0,62021739
8	30 north west	0,44130435	30	29 south	0,55	52	6 west	0,62847826
9	31 north west	0,44130435	31	21 east	0,5543478	53	16 north	0,63043478
10	5 north	0,45021739	32	12 west	0,5578261	54	22 north	0,63695652
11	2 east	0,456521739	33	5 west	0,558913	55	14 west	0,6623913
12	1 south	0,45652174	34	25 south east	0,5595652	56	13 west	0,66282609
13	27 east	0,463043478	35	2 south	0,5652174	57	21 south	0,66304348
14	8 north	0,46304348	36	3 north	0,5652174	58	4 south	0,66521739
15	10 south	0,46304348	37	32 west	0,566087	59	6 south	0,66543478
16	33 north	0,46956522	38	11 east	0,5693478	60	16 east	0,69565217
17	21 north east	0,48913043	39	28 north west	0,575	61	22 east	0,70217391
18	17 north east	0,49673913	40	13 north	0,5758696	62	23 south	0,7173913
19	26 west	0,5	41	4 east	0,5782609	63	11 south	0,73456522
20	27 west	0,5	42	8 west	0,5869565	64	22 west	0,74565217
21	9 east	0,513043478	43	4 west	0,6	65	13 south	0,77152174
22	23 north east	0,51304348	44	7 east	0,6	66	22 south	0,78913043

According to data from 2023, 27 forest fires occurred in the Marmaris region [29], and according to data from 2021, 26 forest fires occurred [30]. In the last 5 years, the Marmaris region has experienced several wildfires, including incidents in Adaköy (2025), Yeşilbelde (2025), Hisarönü (2025), Sarınana (2023), Adaköy (2022), İçmeler (2021), and Bördübet (2022). Among those, the fire in İçmeler in 2021 burned 9,051.6 hectares, making it the sixth largest fire in Türkiye since 1970. Similarly, the fire in Bördümet in 2022 burned 4,392 hectares, making it the seventeenth largest fire in Türkiye since 1970 [31]. As can be seen from the results we obtained in this study, the Adaköy region is the region with the highest fire risk, with a fire risk membership value of 0.78913043, and fires have occurred in this region in recent years. Similarly, it is seen that the forest fires that have occurred in recent years have occurred in regions with a membership degree above 0.6 which is close to the highest degree 0,78913043.

4 | Conclusion

FST is widely applied for risk assessment in engineering, economics, environmental, social, medical and management fields. In this study, the universal set is determined as the characteristics of neighborhoods and villages containing forests in the Marmaris region that affect the fire risk. As a result of this study, a membership function that determine the risk value is defined by using the studies previously conducted for forest fire risk maps that we mentioned above, so the riskiness of forest areas in the Marmaris region is determined differently from the approaches in the literature by using the FST, which is used for situations that classical mathematical approaches cannot handle.

According to the results obtained, it is seen that the region with the highest fire risk in the Marmaris region is the forested areas in Adaköy neighborhood, which is closest to the settlements and has dense forests, and the forested areas in Turgut and Bayır neighborhoods. It is seen that the regions with the lowest fire risk are the forested areas in Taşlıca and Bozburun neighborhoods, which are far from the settlements and do not have dense forests. As can be seen from *Table 6*, fire risk assessments of forested areas can be made with membership degrees with the help of fuzzy sets, thus, instead of saying that below a certain number is not risky and above is risky, the degree to which the regions are risky is obtained.

In summary, this study contributes to the existing body of research by demonstrating how FST can be adapted for localized fire risk analysis with limited yet targeted environmental data, offering a framework that can be applied in other fire-prone regions with similar data limitations.

Acknowledgments

This work is supported by TÜBİTAK 2209-A University Students Research Project Support Program (N:1919B01209776).

Author Contributaion

G. Y. U.: conceptualization, methodology, formal analysis, investigation, visualization, writing-original draft preparation, validation. T. A.: conceptualization, resources, writing-review and editing. All authors have read and agreed to the published version of the manuscript.

Funding

This research received no external funding. The study was initially proposed as a project and supported by TÜBİTAK 2209-A University Students Research Project Support Program (n:1919B01209776) in principle, but no financial support was provided.

Data Availability

The data that support the findings of this study are contained in the article. No additional datasets were generated or analyzed during the current study.

Conflicts of Interest

The authors declare no conflict of interest.

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