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GIS-BASED FOREST FIRE RISK ASSESSMENT USING THE AHP AND FUZZY AHP METHODS

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ABSTRACT

Forest fires have caused irreparable environmental and economic losses in all around the world due to global warming. In order to take necessary measures and make fire prevention and response strategies, forest fire risk assessment is curial. This study aims to make forest fires risk assessment in the largest forest area in İstanbul, Turkey. Fire risk assessment was carried out by integrating Multi-Criteria Decision-Making (MCDM) methods and Geographical Information Systems (GIS). The criteria weights were calculated using the Analytical Hierarchy Process (AHP) and Fuzzy Analytical Hierarchy Process (Fuzzy AHP) methods. Forest fire risk assessment was carried out in the Geographical Information Systems (GIS) environment by using the required data and calculated criteria weights. It is found that although the fire risk limit values differs in some areas, the evaluation results based on the AHP and Fuzzy AHP methods overlap to a large extent. The AHP and Fuzzy AHP methods provided valid, reliable and very useful results in the forest fire risk assessment. This study shows that integrating the AHP and Fuzzy-AHP methods with GIS for forest fire risk assessment provides very important guidance in making the necessary planning and taking measures for forest fires.

KEYWORDS:
Forest fire risk assessment, geographic information systems, multi-criteria decision-making, AHP, Fuzzy AHP

INTRODUCTION

Global climate change and global warming increase the risk of extreme weather events [1]. The extreme weather events may cause fires and damage the forest [2]. Climate change and global warming cause forest fires in many countries including Turkey. In turkey, The General Directorate of Forestry has achieved successful results by taking important measures to prevent forest fires. Despite successful results in preventing and responding to forest fires, the number of forest fires has not been reduced [3]. Approximately 22 million hectares of forest area in the Turkey [3] show a rich diversity with its tree species diversity, stand-type mixtures and structural differences. However, fires pose great threats to these forests [4]. Forest not only maintain important life cycles but also have economic, tourism and trade related benefits [5]. In this regard, the decisions taken to prevent and fight forest fires are some of the most important decisions in terms of the sustainability of the forest areas. Fire prevention and response strategies are necessary to preserve the forests and minimize the damages by determining spatial distribution of the fires [6, 7]. The first step in designing these strategies is to detect fire risk and take necessary measures. For instance, the locations of fire watchtowers can be determined by Multiple-Criteria Decision-Making (MCDM) methods and Geographical Information Systems (GIS) [8-10].

This study aims to analyze and map forest fires risk in a forest area in İstanbul, Turkey. Within the scope of this study, first, the criteria that trigger forest fires were determined. Then, weights of the criteria required for the analysis were calculated using the Analytical Hierarchy Process (AHP) and Fuzzy Analytical Hierarchy Process (FAHP) methods. Forest fire risk analysis was carried out in the Geographical Information Systems (GIS) environment by using the calculated criteria weights in the evaluations.

MATERIALS AND METHODS

Study Area. The study area (Figure 1) is a region defined as the northern forests of the city within the borders of the province of Istanbul, Turkey. This forest area is located on the European side of Istanbul, lying between the existing residential areas and the Black Sea coast. This forest area is the largest forest area in the European side of İstanbul. This forest area is a holistic ecological area where many endemic plants and animal species coexist. This area contains water basins, dams and embankments and thus meets the drinking and utility water needs of the city. Besides, Istanbul and its surroundings are part of the first and second-degree fire-sensitive areas. Thus preserving of this crucial forest area is necessary for the sustainable development of Istanbul.

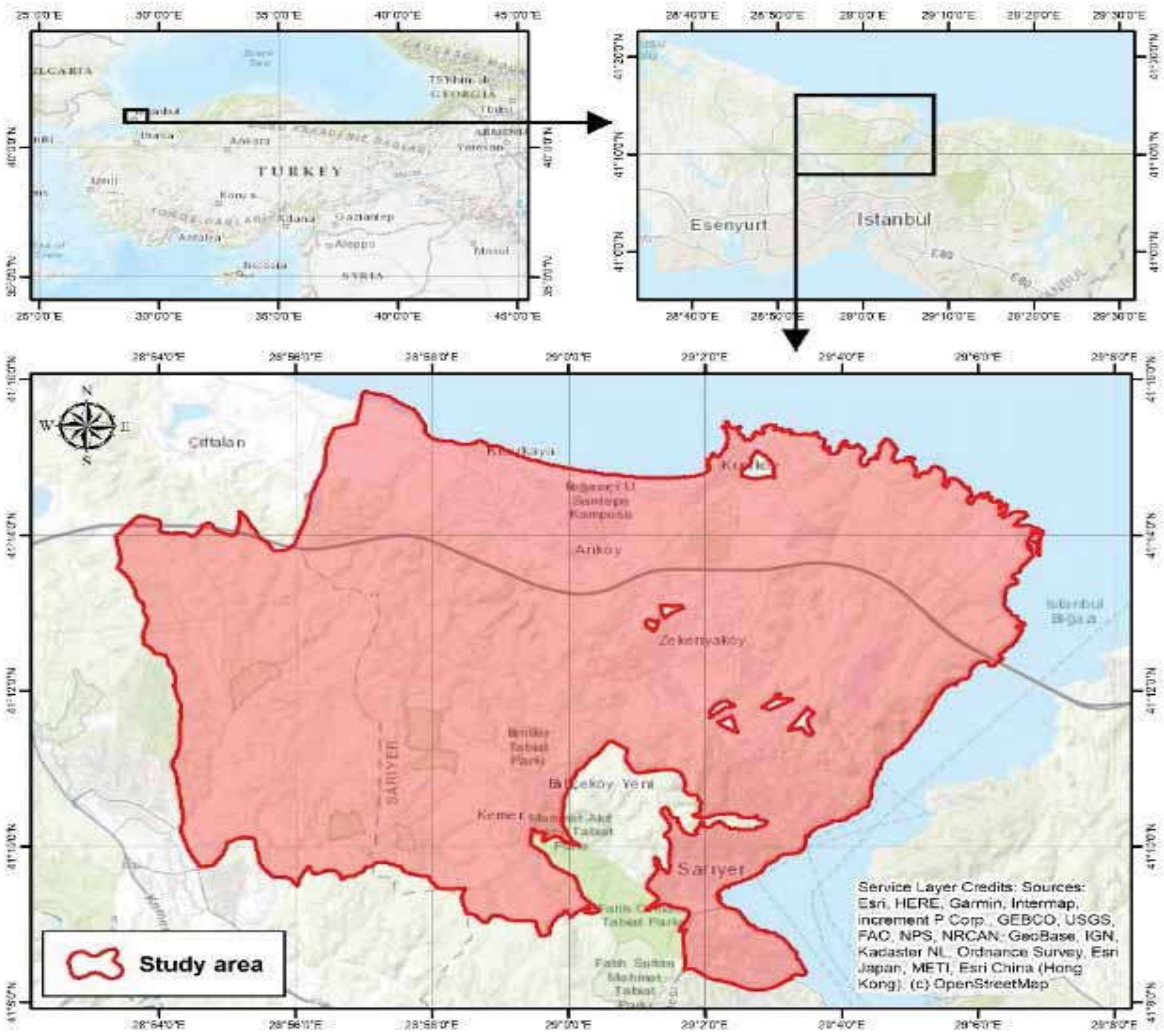


FIGURE 1
Study area

The region is under the influence of the Mediterranean, Black Sea, Balkan and Anatolian continental climates. In the winter, warmth southwesterly coming from the Mediterranean is followed by cold coming from the Balkans, cold coming from the Black Sea and rainy weather from the Black Sea. The average number of rainy days is 128 days. The driest month is July, with 24 mm of rainfall. The most precipitation occurs in December with an average of 124 mm. The annual average precipitation is 720-788 mm. 40% of precipitation falls in winter, and 20% of rain falls in spring. Summer precipitation is half of that in autumn. In general, summers are hot and dry, and winters are rainy and warm. The temperature varies between -14 C° and +41 C° for a year and the average annual temperature is 13.5 C°. The number of snowy days does not exceed 10 days. In terms of vegetation, it resembles Mediterranean vegetation. It has a rich flora due to climatic conditions. 280 thousand hectares (60% of the province) are also rich in forest areas. Its forests are in the north of the city (Northern Forests and Belgrade Forests).

Data and Software. Some studies in the literature [11-14] were tried to determine which criteria trigger forest fires. Jaiswal et al. [11] developed a formula for the fire risk index that matches the conditions of the study area. The special conditions of the study area require privatization of the variables to which the fire risk values are related. For example, the variables of elevation or vegetation type may vary considerably. The variables of proximity to roads, energy transmission lines, settlements and agricultural areas, which are related to human behavior, were determined by considering the approach specified in the study by You et al. [12] and Çoban and Erdin [13]. Çoban and Erdin [13] proposed to use human behaviors, structural properties of forests, topographic structure and climate as main criteria and 13 sub-criteria for forest fire risk assessment. In this study, the criteria and sub-criteria proposed by Çoban and Erdin [13] were used [13]. These criteria and sub-criteria for the purpose of forest fire risk assessment are shown in Table 1.

TABLE 1
Criteria and Sub-criteria for Forest Fire Risk Assessment

Criteria	Sub-criteria
Human Behaviors	Proximity to the settlement Proximity to the road network Proximity to agricultural fields Proximity to energy transmission lines
Structural Properties of Forests	Vegetation type The age of stand development Stand closure
Topographic Structure	Elevation Slope Aspect
Climate	Average temperature Average precipitation Average wind speed

Source: Çoban and Erdin [13]

The required data was gathered from SRTM (Version 3) with a resolution of 30m x 30m pixels [15]. Then elevation, slope and aspect maps were produced and the forest was divided into vegetation type, stand development age, stand closure, agricultural areas and settlement geographical layers in the ArcGIS environment. Climate data were gathered from Worldclim [16] as a raster data with a resolution of approximately 1 km x 1 km pixels. The GIS-based evaluation of the study was carried out with the facilities provided at the Istanbul University Faculty of Forestry GIS laboratory. The ESRI - ArcGIS 10.7 software was used in the evaluations.

Method. The wide range of opportunities that Geographical Information Systems (GIS) provide for decision-makers enable inevitable collaboration in studies based on Multiple-Criteria Decision-Making (MCDM) techniques, especially in realization of projects based on geographical (spatial) data. Since, GIS-based evaluations improve the efficiency of fire risk management [17], GIS-based MCDM techniques have been widely used for fire risk assessment [18]. The Analytic Hierarchy Process (AHP) is one of the most used MCDM techniques. There are some studies in the literature where the GIS and the AHP / Fuzzy AHP techniques are integrated to assess the fire risk (forest fires, wildfires etc.) [7, 13, 19-25]. In this study, the GIS was integrated with the AHP and Fuzzy AHP methods to determine forest fire risk. Criteria weights were calculated using the AHP and Fuzzy AHP methods, and the results on the forest fires risk were evaluated in the GIS environment.

The Analytic Hierarchy Process (AHP). The AHP is a practical multi criteria decision-making technique to solve complex selection and / or prioritization problems [26, 27]. The AHP allows both objective information and subjective judgments to be included in the decision-making process. The AHP turns complex decision-making problems into simple problems by handling them in a hierarchical structure. The AHP is based on three basic steps [28]: creating the hierarchical structure, determining the preferences and logical and numerical consistency check.

In the AHP, scores called priorities, which rank the importance of the alternatives and criteria, are established using pairwise comparisons and judgments [29-31]. In pairwise comparison, the Fundamental Scale [32] is used to compare homogeneous (close) elements (criteria and alternatives) in pairs. The Fundamental Scale is a 1 to 9 scale where 1 represents equal importance between the two elements and a score of 9 indicates the extreme importance of one element in comparison to the other one [29]. Decision-makers (or experts) are asked to respond to all of the pairwise comparisons with respect to the Fundamental Scale. A scale of relative values for the priorities are derived from all pairwise comparisons [29]. In order to verify the validity of the model, the consistency ratio (CR) of the pairwise comparison matrices are examined [33]. If the CR value is less than 0.10, the pairwise comparison matrix is considered to have an acceptable consistency and the calculated weights are valid and can be used [34]. Decision makers must be consistent in pairwise comparisons. If the decision-makers acted inconsistently when making comparisons between criteria or between alternatives according to the criteria, this inconsistency is determined by calculating the coefficient of consistency ratio (CR). In case of inconsistency, the decision maker must review the pairwise comparisons.

Fuzzy Analytic Hierarchy Process (FAHP). The Fuzzy AHP method can be used in criteria evaluations if the decision-makers have difficulty in using the numbers (1 to 9) in the classical AHP method. Fuzzy numbers are used in the Fuzzy AHP method. In pairwise comparisons, triangular and trapezoidal fuzzy numbers are generally used. There are different methods related to Fuzzy AHP technique. In this study, the "Extended Analysis Method" will be discussed and briefly introduced. In the Extended Fuzzy Analytic Hierarchy Process Method algorithm [35] we consider:

$X = \{x_1, x_2, \dots, x_n\}$ a set of object
$U = \{u_1, u_2, \dots, u_n\}$ a set of purpose

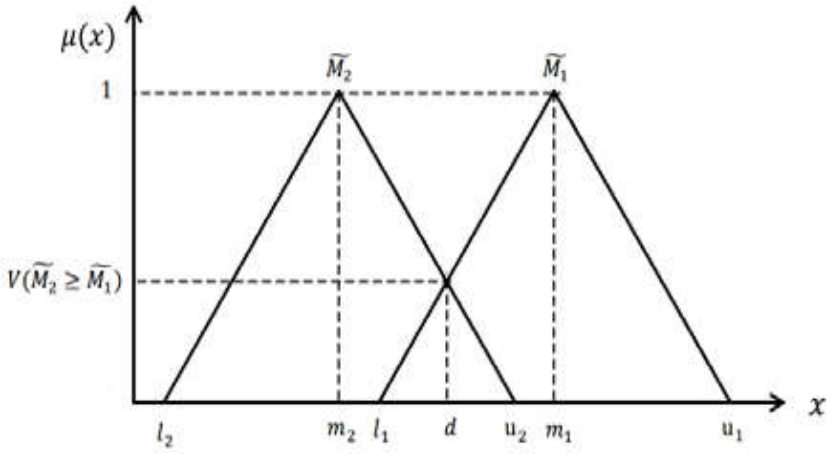


FIGURE 2
Comparison of the sizes of M̃1 and M̃2 numbers [35]

According to the extended analysis method [35], each object is considered to achieve a purpose. Expanded expression describes how much this object accomplished its purpose. Thus, expanded analysis value of m is obtained. Extended analysis values are shown as:

$$M_{g_i}^1, M_{g_i}^2, \dots, M_{g_i}^m \qquad i = 1, 2, 3, \dots, n \tag{1}$$

Where, $M_{g_i}^j$ $(j = 1, 2, 3, \dots, m)$ values are triangle fuzzy numbers. Chang's [35] extended analysis steps can be listed as follows [36-38]:

Step 1. Fuzzy magnitude value for the object i

$$S_i = \sum_{j=1}^{m} M_{g_i}^j \otimes \left[\sum_{i=1}^{n}\sum_{j=1}^{m} M_{g_i}^j\right]^{-1} \tag{2}$$

S_i= The synthesis value of the object i

$M_{g_i}^j$ = Expanded value for each purpose.

The process in Equation (2) can be defined as a type of normalization process performed in fuzzy numbers. To obtain the $\sum_{j=1}^{m} M_{g_i}^j$ value, m expanded analysis value is found with the help of fuzzy addition process and a matrix is obtained. Elements of this matrix is obtained using the following equation:

$$\sum_{j=1}^{m} M_{g_i}^j = \left(\sum_{j=1}^{m} l_j, \sum_{j=1}^{m} m_j, \sum_{j=1}^{m} u_j\right) \tag{3}$$

The fuzzy addition of $M_{g_i}^j$ $(j = 1, 2, 3, \dots, m)$ values is obtained by Equation (4).

$$\left[\sum_{i=1}^{n}\sum_{j=1}^{m} M_{g_i}^j\right]^{-1} = \left(\frac{1}{\sum_{j=1}^{m} u_j}, \frac{1}{\sum_{j=1}^{m} m_j}, \frac{1}{\sum_{j=1}^{m} l_j}\right) \tag{4}$$

Step 2. This step is based on comparing the synthesis values obtained by the method suggested by Chang [35] and obtaining the weight values from these comparison values. Comparison of two fuzzy numbers is done as follows:

While $\tilde{M}1 = (l_1, m_1, u_1)$ and $\tilde{M}2 = (l_2, m_2, u_2)$ are two triangular fuzzy numbers, the likelihood degree of the $\tilde{M}2 \geq \tilde{M}1$ equation is expressed as follows:

$$V(\tilde{M}2 \geq \tilde{M}1) = sup_{y \geq x}\left[min\left(\mu_{M_1}(x),\ \mu_{M_2}(y)\right)\right] \tag{5}$$

When $\tilde{M}1 = (l_1, m_1, u_1)$ and $\tilde{M}2 = (l_2, m_2, u_2)$ fuzzy numbers;

$$V(\tilde{M}2 \geq \tilde{M}1) = \text{height}(\tilde{M}1 \cap \tilde{M}2) = \mu_{M_2}(d) \tag{6}$$

$$\begin{cases} 1, & if\ m_2 \geq m_1 \\ 0, & if\ l_1 \geq u_2 \\ \dfrac{l_1 - u_2}{(m_2 - u_2) - (m_1 - l_1)}, & otherwise \end{cases} \tag{7}$$

The expression V ($\tilde{M}2 \geq \tilde{M}1$) in Figure 2 is the ordinate of the intersection points of triangular fuzzy $\tilde{M}1 = (l_1, m_1, u_1)$ and $\tilde{M}2 = (l_2, m_2, u_2)$. In other words, it is the value of the membership function. To compare M1 and M2, both the values of V (M2 ≥ M1) and V (M1 ≥ M2) must be found.

Step 3. The likelihood of a convex fuzzy number greater than k fuzzy numbers M_j $(j = 1, 2, \dots, k)$ is defined as follows:

$$V(M \geq M_1, M_2, \dots, M_k) - V[(M \geq M_1)\ and\ (M \geq M_2)\ and \dots\ (M \geq M_k)] = \min V\ (M \geq M_i), i = 1, 2, \dots, k \tag{8}$$

In this case, for S_j, $k = 1, 2, \dots, n$ $k \neq j$ and $d'(A_j) = \min V(S_i \geq S_k)$ assumptions are made. Then, the weight vector A_i $(i = 1, 2, \dots, n)$ is made up of n elements is given as

$$W' = \left(d'(A_1), d'(A_2), .., d'(A_n)\right)^{\tau} \tag{9}$$

Step 4. Obtaining the normalized weight vector W which is not a fuzzy number.

Geographical Information Systems (GIS). Geographical Information Systems (GIS) are the most widely used systems in studies based on spatial data. The Geographical Information Systems are computer systems that realize the stages of data entry, data analysis and data presentation while working with georeferenced data [39]. With a general definition, Geographical Information Systems are systems designed to store, obtain, process, match and analyze geographical data [40]. They consist of data obtained by many different methods and evaluations based on geographical data (vector and raster) which are the basis of GIS evaluations. Obtaining all spatial

assets of the earth surface, geographical regions and places as a qualitative, quantitative and attribute of georeferenced data is provided through engineering measurements (geodesy), evaluation of aerial and ground photographs (photogrammetry), detection with sensors (remote sensing) placed in spacecraft (aircraft, helicopters, satellites), and sensors placed on platforms that make point-based records (drone).

RESULTS AND DISCUSSION

For fire risk assessment, first criteria weights were calculated. This process is done using the AHP and Fuzzy AHP methods separately. Criteria and sub-criteria weights calculated by Çoban and Erdin [13] using the AHP is directly gathered from their study. Then, Fuzzy AHP is used to determine the criteria and sub-criteria weights. Finally, calculated criteria weights were used in GIS-based forest fire risk assessment.

Calculation of Criterion Weights using the AHP and Fuzzy AHP Methods. In determining the criteria, different evaluations may be suggested by considering the structure and condition of a geographical region. However, the general validity of the main criteria may be accepted on the country level. In this study, at the stage of determination of weights using the AHP method, the criteria and sub-criteria proposed by Çoban and Erdin [13] were used. Criteria weights, sub-criteria weights and consistency ratios (CR) calculated using the AHP are given in Table 2.

As can be seen from Table 2, consistency ratios (CR) are below 0.10. Thus the pairwise comparisons are valid and can be used for forest fire risk assessment.

In this study, evaluations were carried out using the "Extended Analysis Method [35]" in the stage of criteria weights calculation based on Fuzzy AHP. The evaluations were carried out step by step.

Step 1. Extended Synthesis Values were calculated using the Equation 2, 3 and 4.

	K1	K2	K3	K4			
K1	(1, 1, 1)	(1, 3, 5)	(3, 5, 7)	(5, 7, 9)	10	16	22
K2	(0.2, 0.3, 1)	(1, 1, 1)	(1, 3, 5)	(3, 5, 7)	5.2	9.3	14
K3	(0.1, 0.2, 0.3)	(0.2, 0.3, 1)	(1, 1, 1)	(1, 1, 3)	2.3	2.5	5.3
K4	(0.1, 0.2, 0.3)	(0.1, 0.2, 0.3)	(0.3, 1, 1)	(1, 1, 1)	1.5	2.3	2.5
				$\sum$	19	30.1	43.8

$$\frac{10}{43.8}\ \frac{16}{30.1}\ \frac{22}{19}$$
$$\frac{5.2}{43.8}\ \frac{9.3}{30.1}\ \frac{14}{19}$$
$$\frac{2.3}{43.8}\ \frac{2.5}{30.1}\ \frac{5.3}{19}$$
$$\frac{1.5}{43.8}\ \frac{2.3}{30.1}\ \frac{2.5}{19}$$

$$S_1 = (0.2283, 0.5315, 1.1578)$$
$$S_2 = (0.1187, 0.3089, 0.7368)$$
$$S_3 = (0.00525, 0.0830, 0.2789)$$
$$S_4 = (0.0342, 0.0764, 0.1315)$$

TABLE 2
Weights of the criteria and sub-criteria calculated using the AHP

CR	Criteria	Weights	CR	Sub-criteria	Local Weights	Global Weights
0.037	Human Behaviors	0.5646	0.058	Proximity to the settlement	0.1993	0.1125
				Proximity to the road network	0.6535	0.3690
				Proximity to agricultural fields	0.0860	0.0486
				Proximity to energy transmission lines	0.0612	0.0345
	Structural Properties of Forests	0.2691	0.075	Vegetation type	0.6194	0.1667
				The age of stand development	0.2842	0.0765
				Stand closure	0.0964	0.0259
	Topographic Structure	0.0911	0.033	Elevation	0.6334	0.0557
				Slope	0.1061	0.0097
				Aspect	0.2605	0.0237
	Climate	0.0752	0.016	Average temperature	0.6233	0.0469
				Average precipitation	0.2394	0.0180
				Average wind speed	0.1373	0.0103

Source: Çoban and Erdin [13]

Step 2 and 3. Sorting of fuzzy numbers S_1, S_2, S_3, S_4. These fuzzy number are calculated Extended Synthesis Values in the first step. The geometric mean and weighted arithmetic mean methods are widely used as "Sorting with Fuzzy Mean Value Methods". However, it is likely that the criteria weights will be 0.00 as a result of the operations that will be carried out with very small numbers [35]. This will have a negative impact on the results. For this reason, in order to overcome the weak and controversial aspects of the Extended Analysis Method, the "Mean Squared Method" was used [41]. The Mean Squared algorithm for a fuzzy number $\tilde{A} = [a_{ij}]$ $i = 1, 2, \ldots, n$ and $j = 1, 2, \ldots, m$ is:

$$K(A) = \sqrt{\frac{\sum(a_{ij})^2}{n}} \quad (10)$$

For the triangle fuzzy number $\tilde{A} = (m, n, u)$, $K(A)$ is calculated as follows:

$$K(A) = \sqrt{\frac{m^2+n^2+u^2}{3}} \quad (11)$$

After calculating the $K(A)$s, these values are sorted. Based on this, S_1, S_2, S_3, S_4 expanded (synthetic) values are calculated as follows:

$$K(S_1) = \sqrt{\frac{(0.2283)^2 + (0.5315)^2 + (1.1578)^2}{3}} = \sqrt{\frac{0.0521 + 0.2824 + 1.3405}{3}} = \sqrt{\frac{1.6750}{3}} = \sqrt{0.5583} = 0.7471$$

$$K(S_2) = \sqrt{\frac{(0.1187)^2 + (0.3089)^2 + (0.7368)^2}{3}} = \sqrt{\frac{0.0141 + 0.0954 + 0.5428}{3}} = \sqrt{\frac{0.6524}{3}} = \sqrt{0.2174} = 0.4663$$

$$K(S_3) = \sqrt{\frac{(0.0521)^2 + (0.0830)^2 + (0.2789)^2}{3}} = \sqrt{\frac{0.0027 + 0.0069 + 0.0777}{3}} = \sqrt{\frac{0.0873}{3}} = \sqrt{0.0291} = 0.1706$$

$$K(S_4) = \sqrt{\frac{(0.0342)^2 + (0.0764)^2 + (0.1315)^2}{3}} = \sqrt{\frac{0.0012 + 0.0058 + 0.0173}{3}} = \sqrt{\frac{0.0243}{3}} = \sqrt{0.0080} = 0.0894$$

As a results, the weight vector is:
$W = (0.7471, 0.4663, 0.1706, 0.0894)$

Step 4. Normalization.
If the weight vector W is normalized:

	W		Normalized W
$K(S_1)$	0.7471	$\left(\frac{0.7471}{1.4736}\right)$	0.5054
$K(S_2)$	0.4663	$\left(\frac{0.4663}{1.4736}\right)$	0.3173
$K(S_3)$	0.1706	$\left(\frac{0.1706}{1.4736}\right)$	0.1161
$K(S_4)$	0.0894	$\left(\frac{0.0894}{1.4736}\right)$	0.0612
$\sum$	1.4736		

TABLE 3
Weights of the criteria and sub-criteria calculated using the Fuzzy-AHP

Criteria	Weights	Sub-criteria	Local Weights	Global Weights
Human behaviors	0.5054	Proximity to the settlement	0.2375	0.1200
		Proximity to the road network	0.6010	0.3037
		Proximity to agricultural fields	0.1036	0.0523
		Proximity to energy transmission lines	0.0577	0.0291
Structural Properties of Forests	0.3173	Vegetation type	0.5580	0.1770
		The age of stand development	0.3422	0.1085
		Stand closure	0.0990	0.0314
Topographic Structure	0.1161	Elevation	0.5781	0.0670
		Slope	0.1058	0.0123
		Aspect	0.3161	0.0366
Climate	0.0612	Average temperature	0.5629	0.0344
		Average precipitation	0.3255	0.0199
		Average wind speed	0.1115	0.0068

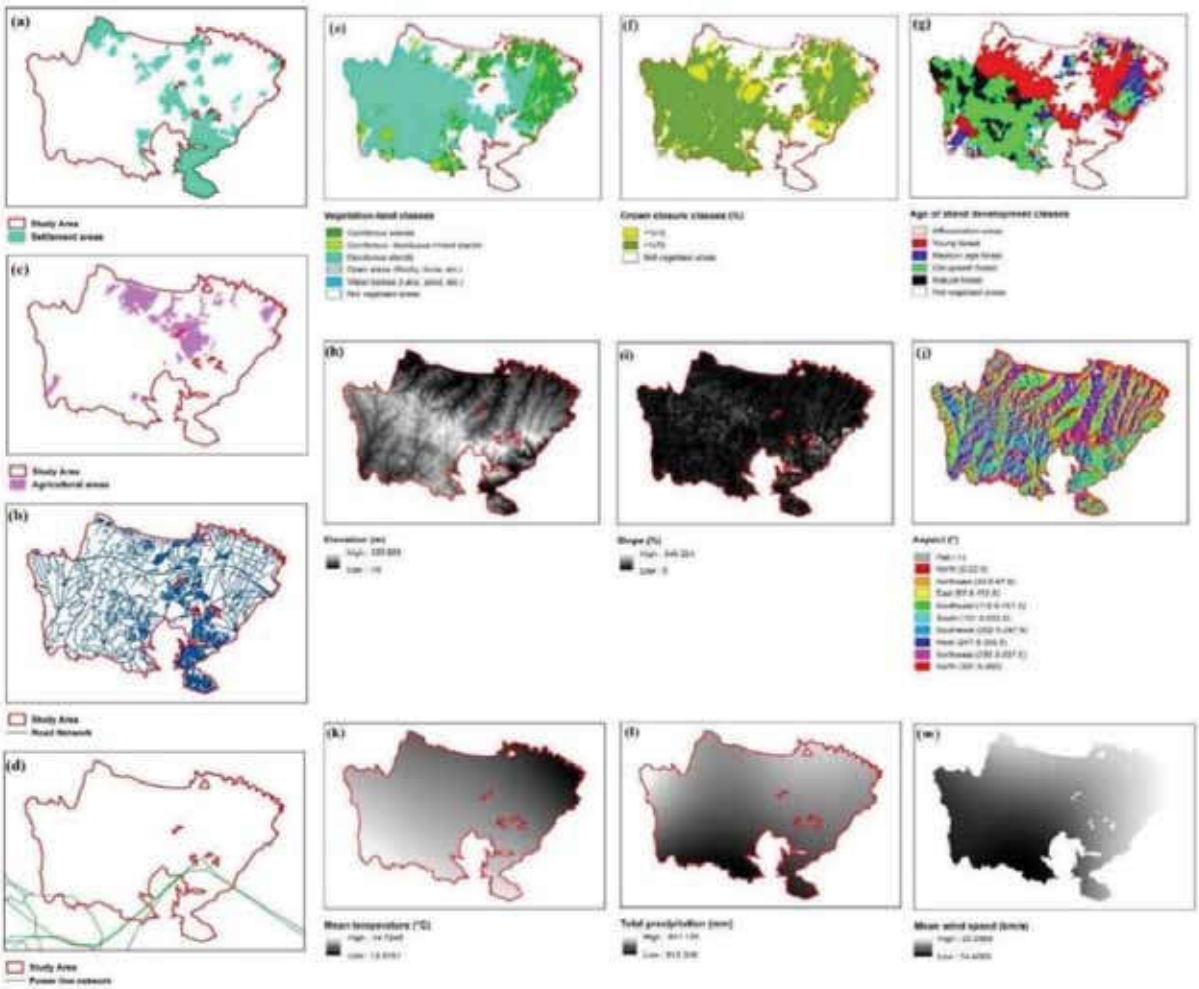
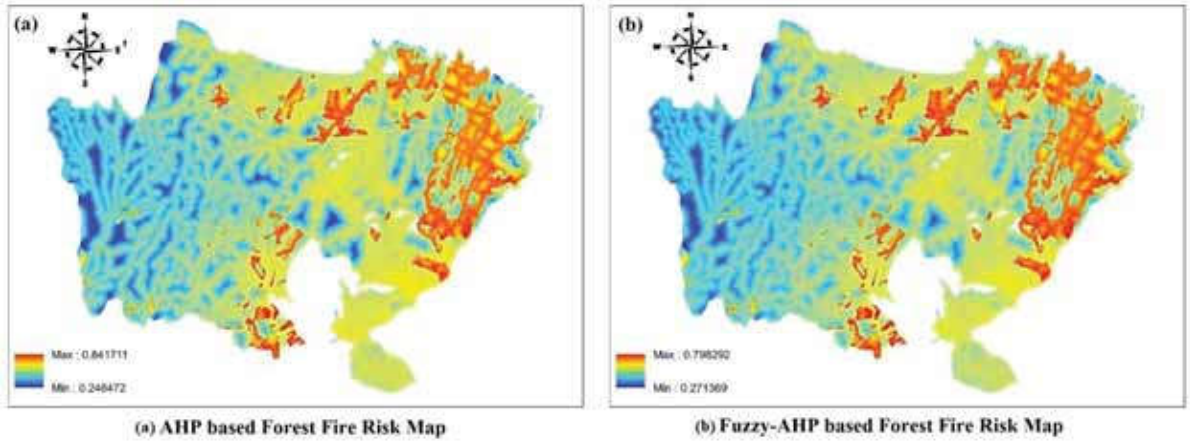


FIGURE 3
Layer creation of the study area according to the criteria
(a) Proximity to the settlement, (b) Proximity to the road network, (c) Proximity to agricultural fields, (d) Proximity to energy transmission lines. (e) Vegetation type, (f) The age of stand development, (g) Stand closure, (h) Elevation, (i) Slope, (j) Aspect, (k) Average temperature, (l) Average precipitation, (m) Average wind speed



(a) AHP based Forest Fire Risk Map (b) Fuzzy-AHP based Forest Fire Risk Map

FIGURE 4
Forest Fire risk maps determined by applying the AHP and Fuzzy-AHP

Finally, the normalized weights of the criteria are found as:

$$Normalized\ W = (0.5054, 0.3173, 0.1161, 0.0612)$$

After the criteria weights are calculated, a consistency ratio is required to be calculated to see if the calculated weights are valid. The first step to do this

is to clarify the fuzzy numbers in the pairwise comparison matrices. However, there was no need for a consistency check here, since the clarified values of these matrices were used in calculations with the AHP and consistency check was made. All calculations for the main criteria were also repeated for the sub-criteria. The weights of all criteria and sub-criteria calculated using the Fuzzy AHP method are shown in Table 3.

GIS-based Mapping. The GIS-based evaluation of the study was carried out using the ESRI - ArcGIS 10.7 software. The structural properties and the topographic structure of the areas were associated with the region's temperature and precipitation data. Before forest fire risk mapping the layers were created according to the determined criteria. Layer creation is done in GIS environment. The layers of the study area are given in Figure 3.

GIS-based Forest Fire Risk Assessment and Mapping. In the GIS-based mapping stage firstly each criterion was evaluated as a layer and the obtained results were indicated with the minimum and maximum limit values in terms of fire risk. All layers of the study area were recorded in the GIS database as raster data. In the second step, each criterion was multiplied by the significance weights calculated with the AHP and the Fuzzy-AHP methods, and final evaluations were reached. The data related to each criterion and criteria weights determined by the AHP and Fuzzy-AHP were formulated with the help of ArcGIS software's spatial analysis tool. This calculation was applied to the related layers. In the third step, all layers were overlapped, and results were obtained according to the AHP and Fuzzy-AHP evaluations. In the mapping stage first the AHP and Fuzzy-AHP results are used separately. AHP and Fuzzy-AHP based forest fire risk maps are given in Figure 4.

When evaluating forest fire risk maps in Figure 4, despite having some differences, fire risk limit values calculated using the AHP and Fuzzy-AHP methods overlap to a large extent. This forest area constitutes 60 % of Istanbul with 280 thousand hectares and it is highly sensitive to forest fires [42, 43]. As can be seen from the forest fire risk maps, forest fire risk of the northeast part of this area is very high. Western part of the region has lower forest fire risk compared to the other parts of the region. Generally, the forest fire risk in this region increases from west to northeast. According to the forest fire risk maps, forest fire prevention and response plans should be concentrated mainly in the northeast of the area. Since northeast of the area has higher forest fire risk, this part must be prioritized for forest fire prevention plans to reduce damages that might be occurred by possible fires. Forest fire risk mapping is crucial for preserving this area and ensuring sustainable development of the province. To prevent possible forest fires, the created forest fire risk maps could be very useful.

It is observed that forest fire risk limits differ by the methods. Forest fire risk limits are given in Table 4.

TABLE 4
Forest fire risk limits by the method used

	AHP	Fuzzy AHP
Maximum risk	0.841711	0.798292
Minimum risk	0.248472	0.271369

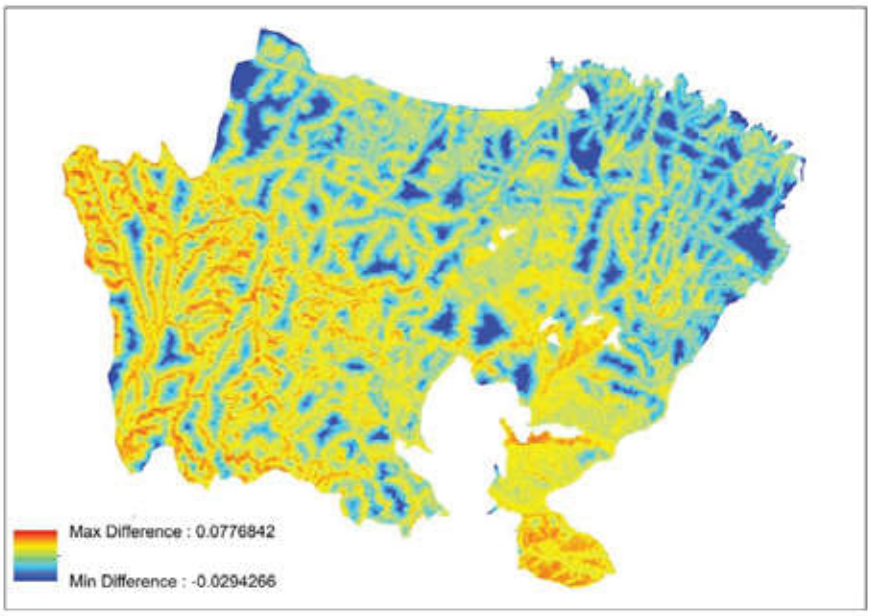


FIGURE 5
Forest Fire risk differences of the AHP and Fuzzy-AHP results

According to the AHP results, forest fire risk limits of the study area are ranging from 0.25 to 0.84. On the other hand, according to the Fuzzy-AHP results, forest fire risk limits are ranging from 0.27 to 0.80. While the maximum forest fire risk of the AHP results is higher, the Fuzzy AHP risk areas are observed to be high in a limited area. As seen in Figure 4 the forest areas with high fire risks determined using the AHP and Fuzzy-AHP are very similar to each other. In order to see the similarities and differences, a combined map is created using the AHP and Fuzzy-AHP results. The differences of these results are shown in Figure 5.

Forest fire risk differences of the AHP and Fuzzy-AHP results are ranging from -0.09 to 0.08. The difference risk scores are lower in east and northeast of the region. Especially northeast of the region has higher forest fire risk according to the fire risk maps (Figure 4). The results of the both methods provides very similar risk scores for this region of the area. Forest fire risk maps show that the evaluation results based on the AHP and Fuzzy-AHP largely overlap. These two methods substantially give similar results. The fire risk limit values calculated using the both methods provide significant and practical guide for decision-makers.

CONCLUSIONS

This study aims to assess forest fire risk of the largest forest area of Istanbul, Turkey. In this study MCDM methods were integrated with the GIS for forest fire risk assessment and mapping. 4 main criteria and 13 related sub-criteria determined. Criteria weights were calculated using the AHP and Fuzzy AHP methods. Calculated criteria weights were used to map forest fire risk in GIS environment. The results show that although the fire risk limit values differed in some areas, the evaluation results based on the AHP and Fuzzy AHP overlapped to a large extent. Both of the methods provide valid, reliable and useful results in the forest fire risk assessment. The created forest fire risk maps present insightful guidance in designing forest fire risk prevention and response plans and strategies. The regions with high forest fire risks should be prioritized for fire prevention action by considering the forest fire risk maps.

This study shows that integrating Multi-Criteria Decision-Making methods with Geographical Information Systems for forest fire risk assessment provides very important results in making the necessary planning and taking measures for forest fires. These approaches could be very useful for ensuring sustainability of forests and environment. Forest fire risk mapping using MCDM techniques and GIS would make a great contribution to preventing forest fires.

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