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Forest fire risk assessment in Balıkesir using pythagorean fuzzy AHP and pythagorean fuzzy TOPSIS

Pisagor bulanık AHP ve pisagor bulanık TOPSIS kullanılarak Balıkesir'de orman yangını risk değerlendirmesi

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Forest Fire Risk Assessment in Balikesir using Pythagorean Fuzzy AHP and Pythagorean Fuzzy TOPSIS

Highlights

- *Forest fires*
- *Pythagorean Fuzzy Analytic Hierarchy Method*
- *Pythagorean Fuzzy TOPSIS*
- *Sensitivity analysis*

Graphical Abstract

It is aimed to determine the most risky district in terms of forest fire. Pythagorean fuzzy sets were used to evaluate the problem under uncertainty. The results were applied to scenario-based sensitivity analysis.

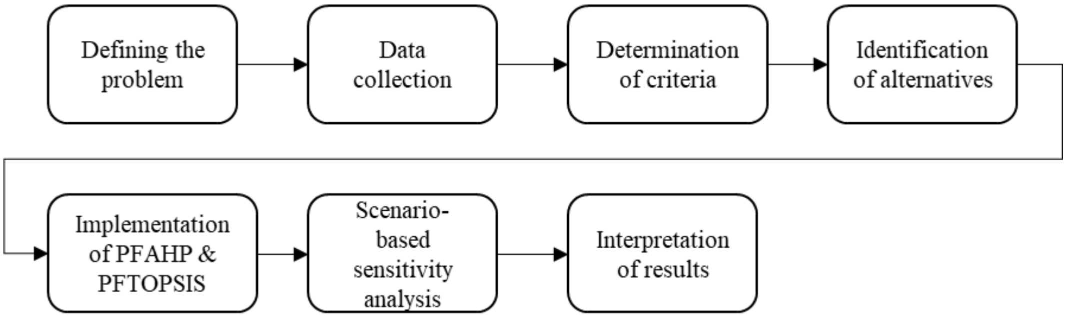

Figure. Application Chart

Aim

In this study, 20 districts of Balıkesir province were evaluated under 9 criteria in terms of forest fire risk.

Design & Methodology

The uncertainty of forest fires was taken into account in solving the problem. Therefore, PFAHP and PFTOPSIS techniques were used as a new perspective. To test the obtained results, 36 different scenarios were applied with sensitivity analysis.

Originality

Forest fire risk assessment of Balıkesir province is important for both biodiversity and animal species living in the region. In this context, real life data were used in this study.

Findings

The 9 criteria that cause forest fires were prioritized by PFAHP method. The first two criteria are air temperature and humidity. Alternative 20 districts were ranked with the PFTOPSIS method. As a result of this ranking, Edremit is the most risky district. When scenario-based sensitivity analysis is applied to the PFTOPSIS method, Edremet is the most risky.

Conclusion

According to the PFAHP method, low humidity and air temperature increase the ignition potential of vegetation by reducing its water content. This situation causes the spread of forest fires to accelerate and intensify. According to the PFTOPSIS method, Edremit district is the most risky in terms of forest fire. Considering that Edremit district has 32 different endemic plants, results consistent with real life were obtained.

Declaration of Ethical Standards

The author(s) of this article declare that the materials and methods used in this study do not require ethical committee permission and/or legal-special permission.

Forest Fire Risk Assessment in Balikesir using Pythagorean Fuzzy AHP and Pythagorean Fuzzy TOPSIS

Araştırma Makalesi / Research Article

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ABSTRACT

Forest fires can occur for a variety of reasons and spread rapidly. Therefore, this is a major environmental problem. In Turkey, especially in the Aegean and Mediterranean regions, 12 million hectares are at risk of forest fires. Risk areas in forest fires are places where fires can easily start and spread rapidly to other areas. Nature is difficult to control. In this context, this study addresses the problem of identifying areas with high fire risk in Turkey. Especially Balıkesir province is a touristic place, has a large forest area, high plant diversity and is an agricultural region. For this reason, 20 districts of Balıkesir were identified as alternatives. These are Bandirma, Edremit, Dursunbey, Susurluk, Manyas, Burhaniye, Ayvalik, Havran, Gönen, Kepsut, Erdek, Marmara Island, Altieylül, Karesi, İvrindi, Savastepe, Bigadic, Sindirgi, Gömec, Balya. Due to the high probability of fire in these districts, proposing a multi-criteria decision-making (MCDM) model is very valuable to obtain convincing results. For this reason, Pythagorean Fuzzy Sets (PFS) have been used in many applications in the literature, which offer a broad evaluation scale to the decision maker, and the combination of AHP-TOPSIS has been applied. In addition, PFS has been used for the first time in order to model uncertainties more effectively in risk assessment and management of forest fires. The weights of the criteria causing forest fires were calculated by Pythagorean Fuzzy AHP method. From this method, air temperature ranks first with a ratio of 0.153. The second rank is humidity. Therefore, low humidity and air temperature significantly affect the frequency and severity of forest fires by reducing the water content of vegetation, increasing the ignition potential and favoring the rate of fire spread. Using these weights, the Pythagorean Fuzzy TOPSIS method was used to rank the districts at risk of forest fires. Edremit is ranked first. The Edremit district is the most sensitive region due to high temperatures and low humidity in summer. In addition, 32 different endemic plant species in the Kaz Mountains increase the area's ecological importance. Therefore, it is of great importance to develop effective strategies to prevent forest fires in the Edremit district. Sensitivity analysis was applied to test the significance of the result.

Keywords: Forest fires, PFAHP, PFTOPSIS, sensitivity analysis, Balikesir.

1. INTRODUCTION

Forest fire is the most risky natural disaster in the world [1]. This risk is more common in the Mediterranean climate during the dry summer months. This situation increases every year [2]. Every year, 1% of Mediterranean forests burn, causing economic and ecological damage [3]. Due to climate change with increasing temperatures and decreasing precipitation [4], there is a change in wildfire severity and fire regime [5], [6]. In the Mediterranean region, vegetation establishment decreases with increasing wildfires [7]. At the same time, flammable plant species and shrub layers cause fire growth [8]. Afforestation of forests with flammable species, especially endemic plants such as red pine, increases forest fire [9]. Forest fires have negative environmental and socioeconomic impacts [10]. Precipitation after a fire causes soil erosion and surface runoff increases by 150% when burned forests are compared to unburned forests [11]–[13].

Most of the forest fires in Turkey are human-caused; negligence and carelessness are among the main causes of fires [14]. According to 2023 data for Balikesir province, 71 forest fires occurred and a total of 98.66 hectares of forest area was damaged [15]. For this reason, entrances and exits to and from forest areas have been controlled in Balikesir province. Considering the probability of occurrence of forest fires, districts in Balikesir province should be prioritized in case of fire. In this context, expert opinions and experiences in fighting forest fires should be evaluated using multi-criteria decision making (MCDM) techniques. This method allows the application of both realistic and fuzzy logic approaches in determining the regions with high fire risk.

In this study, in case of a possible forest fire, the districts of Balikesir province (Bandırma, Edremit, Dursunbey, Susurluk, Manyas, Burhaniye, Ayvalık, Havran, Gönen, Kepsut, Erdek, Marmara Island, Altıeylül, Karesi, İvrindi, Savaştepe, Bigadiç, Sındırgı, Gömeç, In order to prioritize Balya) evaluation criteria (endemic plants, aspect, distance to settlement, slope, humidity, air temperature, biomass density, elevation) Pythagorean Fuzzy Analytic Hierarchy Process (PFAHS) technique was used to weight these criteria. Pythagorean Fuzzy (PFTOPSIS) technique was applied for prioritization of Balikesir districts. Then, a scenario-based sensitivity analysis was conducted to evaluate the situations that may arise under different conditions.

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In the second part of the study, the literature review is described, and the methods are explained step by step in the third part. The application is presented in the fourth section. The fifth section describes the sensitivity analysis. The last section presents the conclusions drawn from the application, the contribution of the study and recommendations for future work.

2. LITERATURE RESEARCH

This study provides a broad perspective on the application of Multi-Criteria Decision Making (MCDM) techniques that assist decision-making processes in the academic literature. In order to ensure comparability of the findings, studies that consider the issue of forest fires are reviewed. Through this research, the main objective and problem framework are defined. It is aimed to identify and prioritize the areas at risk of forest fires in Balikesir province. Since forest fires cause great damage both environmentally and economically, it is of great importance to identify the risky areas. The study covers topics such as the causes of fires, factors affecting the rate of spread and post-fire recovery processes. The data obtained will enable more efficient use of resources and more efficient planning of fire prevention strategies.

Possible characteristics of forest fires are presented in Charts 1. When the charts is examined, it is divided into four as Meteorological Factors, Hydrological Factors, Topographic Factors and Anthropogenic Factors. Temperature and humidity are important factors in the start and spread of forest fires. High temperature and low humidity increase the risk of fire [16]-[19]. Wind is an effective factor in determining the direction and speed of fire. High wind speed can cause fire to spread to larger areas [20], [21]. The amount and distribution of precipitation plays an important role in reducing the risk of wildfire [22], [23]. Many studies in the literature have considered meteorological factors as a critical component

Charts 1. Literature summary of forest fire potential characteristics

Author	Feature	Meteorological	Hydrological	Topographic	Antropogenic
[16]	Probability of forest fire occurrence	X	Rainfall, Distance to rivers, Evapotranspiration	Slope, Plan Curvature, Slope aspect, Altitude	Distance to Road, Distance to Settlements
[22]	Possibility of wildfires	X	X	Aspect, Land type Slope, Elevation	Population density, Distance to road
[27]	Forest fires	X	X	X	Agricultural machinery, railways, electric line, roads, Demographic Changes,
[17]	Possibility of fire	Wind, Temperature	Annual rainfall, Proximity to rivers	Slope, Slope aspect, Altitude	Distance to Settlements, Roads
[26]	Forest fires risk	X	Precipitation	Altitude, Topographic wetness index Forest Type	Population Density, Distance to Urban Area
[19]	Forest fires probability	Land Surface Temperature	X	X	X
[23]	Probability of forest fire	Temperature, Wet Day Frequency	Precipitation	Slope, Land Cover: Land Use Degree, Aspect	X
[18]	Sensitivity to forest fires	Wind, Temperature	Annual rainfall, Distance to stream	Aspect, Altitude, Slope	Distance to Village, Distance to Road
[25]	Forest fires probability	Humidity, Wind, Temperature	X	Elevation, Aspect, Slope	Population Density, Distance to Electric, Distance to Road
[20]	Forest fires probability	Wind, Temperature	Annual rainfall	Slope, Altitude, Aspect	Distance to Road, Distance to settlements
[21]	Sensitivity to forest fires	Wind, Annual temperature, Potential solar radiation	Annual rainfall, Distance to stream	Aspect, Altitude, Slope, Landform	Distance to Village, Distance to Road
[24]	Forest fires probability	X	X	Aspect, Slope	Distance to Village, Distance to Road
Current study	Forest fires risk	Humidity, Air temperature,	X	Aspect, Slope, Elevation, Wind, Biomass Density	Distance to settlement

in fire risk analyses. However, some studies [24] did not include meteorological factors. This is due to regional differences. Rivers and streams can limit or stop the spread of fire. This factor is frequently used in fire risk analyses [16]–[18]. Rainfall acts as a bridge between hydrological and meteorological factors [18], [23]. Sun-drenched slopes are more prone to drought and therefore have a higher fire risk [18], [25]. Elevation can directly affect fire risk as it influences climatic factors such as temperature and humidity [20], [26]. Areas close to settlements are considered to be areas where forest fires occur more frequently [17], [25], [27].

In Charts 1, the criteria considered by different studies on forest fire risk are classified and presented. When the charts is examined, it is divided into four categories: Meteorological criteria, Hydrological criteria, Topographic criteria, and Antropogenic criteria. The source from which each criterion in the charts is taken is shown in the line of the corresponding study. For example, since [16] do not use Meteorological criteria in their study, the cross is omitted.

A summary of the studies using Pythagorean fuzzy sets (PFS) is presented in Charts 2. When the charts is examined, the use of PFS provides significant advantages in the construction industry, especially in project risk management and environmental factors analysis. These methods provide decision makers with a more flexible and uncertainty-sensitive analysis [28], [29]. Studies have been conducted in high-risk areas such as mining and transportation sectors [30], [31]. The manufacturing sector requires complex decisions, especially in terms of environmental impact and risk management. AHP and VIKOR methods offer solutions with high accuracy and the capacity to manage uncertainty when assessing risks in this sector [32], [33]. In the technology sector, better managing uncertainty with PFS provides a significant advantage, especially when it comes to security risks [34]. [35], [36] analyzed risks by combining AHP and TOPSIS methods with PFS when evaluating Natech incidents. [37] proposed a model that combines AHP and TOPSIS methods to make more accurate and reliable decisions in pipeline construction projects. [38] In this study, the literature on forest fire resource planning is reviewed in detail, and a comprehensive analysis is carried out using a systematic approach.

Charts 2. Literature summary on methods

Study	Application area	MCDM metod	Fuzzy set
[28]	Construction	AHP	PFS*
[30]	Mining	AHP, TOPSIS	PFS*
[31]	Transportation	AHP	PFS*, TFS*
[29]	Construction	AHP	PFS*
[37]	Pipeline construction	TOPSIS	PFS*
[34]	Information security	AHP, TOPSIS	PFS*
[32]	Manufacturing	AHP, VIKOR	PFS*
[1]	Forest fires	AHP, VIKOR	PFS*
[39]	Forest fires	AHP	PFS*
[33]	Industrial symbiosis	AHP, TOPSIS	PFS*
[40]	Forest fires	AHP	PFS*
[41]	Energy of pine needles	AHP	PFS*
[35]	Natech	AHP, TOPSIS	PFS*
[36]	Natech	AHP, TOPSIS	PFS*
[42]	Personnel selection	AHP, TOPSIS	PFS*
Current study	Forest fires	AHP, TOPSIS	PFS*

*PFS: Pythagorean fuzzy set, TFS: Triangular fuzzy set

- *Application Area:* The increasing share of forest fires in Turkey in recent years has led to a serious reduction in forest areas. Balikesir province is located in an important location in terms of both agriculture and tourism. Moreover, the fact that this province is located in an earthquake zone is a factor that increases the probability of forest fires. Balıkesir province is a critical region in terms of forest fire risk due to its large forested areas and highly biodiverse ecosystems, such as the Kaz Mountains. High temperatures and low humidity levels in summer pose a significant threat to sensitive vegetation, especially in the Kaz Mountains. In addition, the 32 endemic plant species in the region make the ecological damage of fires even more significant. Therefore, Balikesir province should be prioritized in terms of forest fire risk and necessary measures should be taken. Looking at previous studies, Balikesir province of Turkey has not been selected as an application area for forest fire risk assessment in an uncertain environment.
- *Applicability and Methodology:* There are many criteria for forest fires and some of these criteria are contradictory and uncertain. When prioritizing the districts in Balikesir province in terms of forest fire risk, conflicting and uncertain criteria should be taken into consideration. Therefore, quantitative and qualitative data should be used together when evaluating a decision-making problem. For this purpose, Pythagorean Fuzzy language scale is combined with AHP-TOPSIS techniques, which are widely used in decision-making models.

- *Evaluation:* When the place of forest fires among natural disasters is evaluated from the perspective of society, a perspective on the solution of the problem will be gained. Therefore, it is important to identify the causes of forest fires and risk areas, taking into account academic research. In this context, factors directly affecting the implementation and indirectly expert opinions were used. In this framework, Pythagorean fuzzy set methods were used to support the direct and indirect factors of the proposed approach. For the first time in the literature, PFAHP and PFTOPSIS methods were used to assess forest fire risk in Balıkesir province.

3. MATERIAL and METHOD

It was put forward by Zadeh in 1965 [43]. Fuzzy sets are important for MCDM problems as the complexity and uncertainty of human thought increases. [44], in order to extend Zadeh's fuzzy sets [43] in most fields, determined the membership degree and non-membership degree in 1986 and proposed the theory of intuitive fuzzy sets (IFS). The sum of the membership rating and non-membership rating does not have to be 1.0. Therefore, the distance between 1.0 and the result of the sum is the degree of indecision of the decision maker [44]. IFS is widely used in fields such as image recognition, decision making and medical analysis to make real-world applications [45]. However, there is a possibility of not being a member during the decision-making phase and the sum of membership degrees being more than 1.0. In this case, it is seen that the method is insufficient. To avoid IFS problems, [46] introduced Pythagorean Fuzzy Sets (PFS), which is an extended version of IFS. In other fuzzy sets, the sum of membership and non-membership degrees is obtained as a maximum of 1.0, while in PFSs, the membership and non-membership degrees of the sum of squares are equal to a maximum of 1.0. In this case, this theory eliminates the shortcomings of other fuzzy sets. Different definitions of Pythagorean fuzzy sets are explained below.

3.1. Pythagorean fuzzy sets

The problem was solved using the PFAHP and PFTOPSIS methods. PFAHP provides a more precise determination of criteria weights by better managing the uncertainty and fuzziness of expert opinions in uncertain processes such as forest fire risk. PFTOPSIS, on the other hand, provides a more reliable and objective decision support mechanism by ranking alternatives according to their distance from the best and worst solution using the determined criteria weights. While other fuzzy logic-based methods are effective in uncertainty management, approaches such as triangular and trapezoidal fuzzy numbers may not accurately reflect the uncertainty in expert opinions. Compared to classical fuzzy logic, Pythagorean Fuzzy set theory has a maximum sum of squares of membership and non-membership degrees equal to 1.0. Therefore, it provides flexibility to decision-makers. Thus, uncertainty can be managed well. The stages of the PFAHP and PFTOPSIS methods are explained in detail below.

3.2. Pythagorean Fuzzy Analytic Hierarchy Process

Among MCDM methods, criterion weights are calculated with the AHP method [47], [48]. However, improvement should be made when subjective expressions are used. Fuzzy methods have been developed for this improvement [41], [36]. Pythagorean sets are among these methods. Pythagorean fuzzy sets are evaluated using a linguistic scale. Therefore, it offers a broad evaluation to decision makers. The flowchart of the PFAHP method is given in Figure 2 [35], [49].

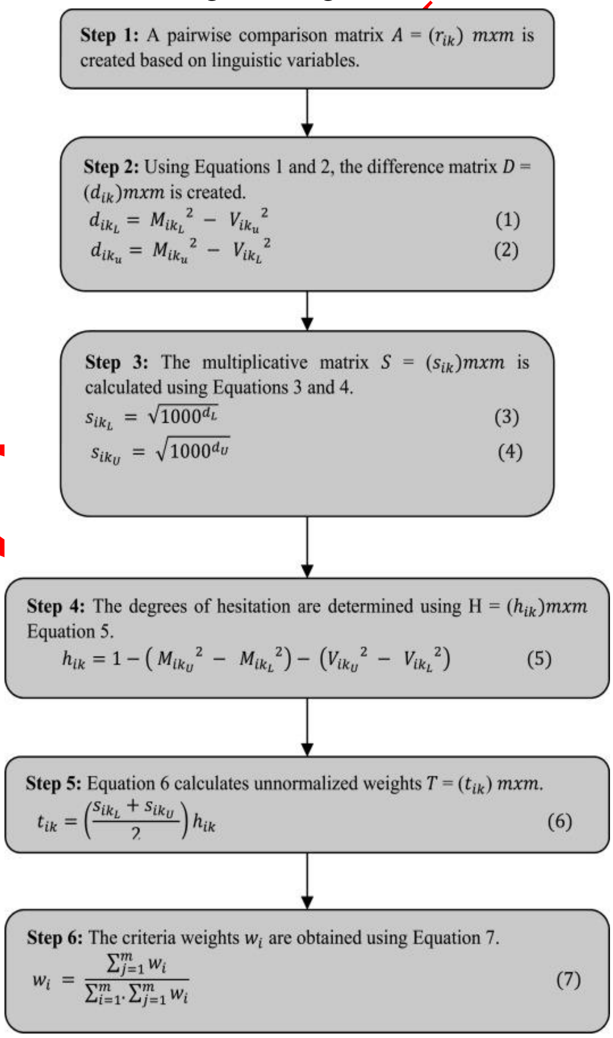

Figure 1. Steps of the PFAHP method

When the figure is analyzed, in the first stage of the method, the decision matrix is constructed using the linguistic scale. In Stage 2, the difference matrix is constructed by applying Equation (1) and Equation (2). After the difference matrix is constructed, Equation (3) and Equation (4) are applied in Stage 3. Stage 4 The degrees of hesitation are created with Equation (5). Then, normalized weights are obtained using Equation (6) in stage 5. In the last stage, Equation (7) is used to find the

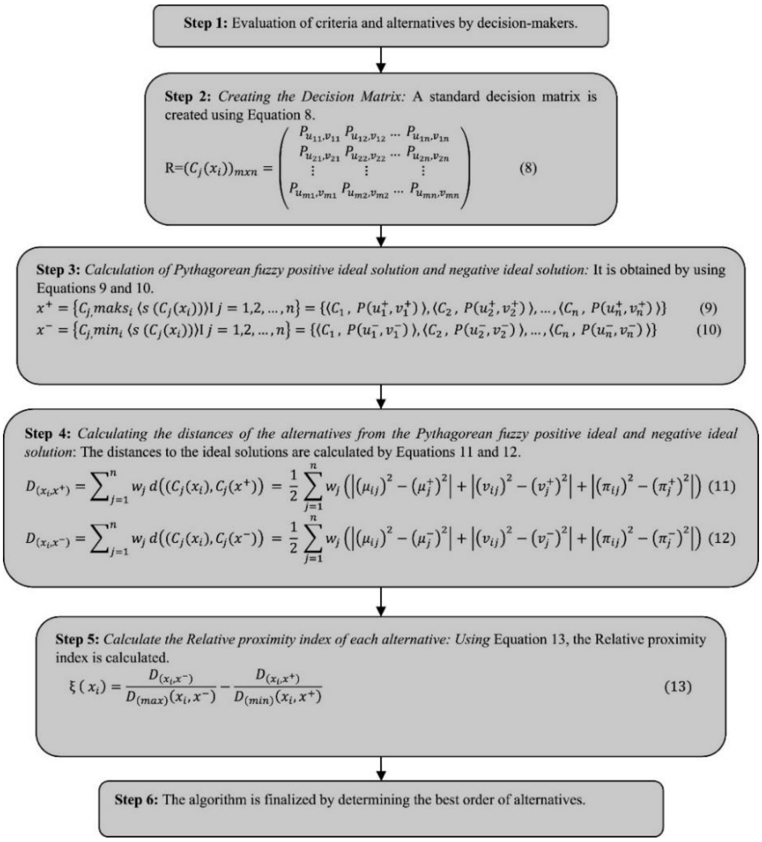

Figure 2. Steps of the TOPSIS method

criteria weights. Thus, the criteria weights and the importance of the criteria are prioritized.

3.3. Pythagorean Fuzzy TOPSIS

MCDM method developed by Hwang and Yoon [50]. In the solution of the problem, alternatives are ranked by considering the positive ideal and negative ideal solution. In this method, the closest solution to the positive ideal solution and the farthest solution to the negative ideal solution are selected in Pythagorean fuzzy sets [51], [52]. Figure 3 shows the stages of the method [46], [53].

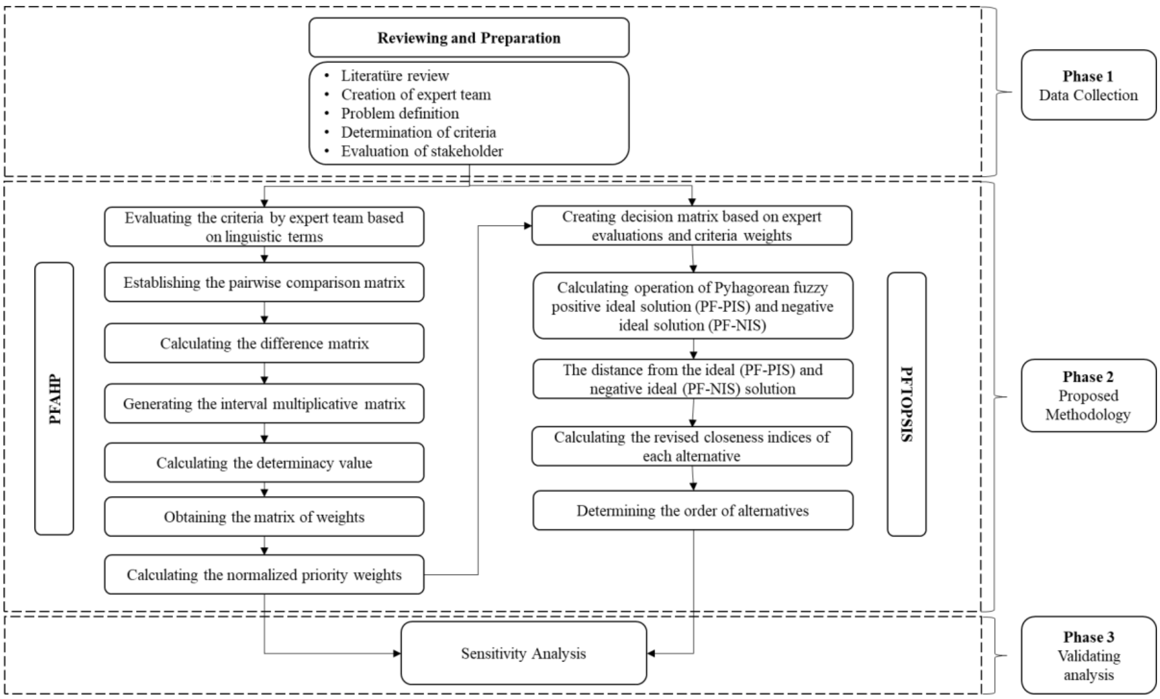

Figure 3. Application flow

Charts 3. Expert knowledge

Expert number	Stakeholder	Directorates	Duration of experience
E1	Afforestation department	Afforestation survey and project management	19
E2		Afforestation branch office	10
E3		Planning and evaluation branch directorate	15
E4		Private tree branch office	6
E5	Department of ecosystem services	Herbal products branch office	21
E6		Ecosystem services branch office	14
E7		Forest biodiversity branch directorate	9
E8		Recreation places branch office	10
E9	Forest administration and planning department	Forest administration branch directorate	13
E10		Follow-up and control branch directorate	18
E11	Department of forest pest control	Forest pest control department branch office	6
E12		Forest Engineer	15

In the first stage, the alternatives are evaluated by the expert considering the criteria. In Stage 2, the decision matrix is constructed in Equation (8), in Stage 3, Pythagorean fuzzy positive-negative ideal solutions are obtained with Equation (9) and Equation (10). In Stage 4, the Pythagorean fuzzy positive-negative ideal solution distances of the alternatives are calculated with Equation (11) and Equation (12). In Stage 5, Equation (13) is used to obtain the relative closeness indices of each alternative. In Stage 6, the algorithm is finalized by finding the best ranking [42].

4. THE CASE STUDY

Balikesir is located between Marmara and Aegean regions of Turkey. It has strategic importance in terms of forest fire risk. Therefore, it was selected as the study province. It is aimed to prioritize 20 districts of Balikesir in terms of forest fires under uncertainty. To realize this objective, the study is divided into 3 phases as shown in Figure 4. Planning is done in the first stage after the research is conducted. The importance of this stage will be determined by considering the forest assets and forest fire risk in the districts of Balikesir.

In Stage 2, PFAHP and PFTOPSIS methods from MCDM approaches are summarized. In step 3, sensitivity analysis is performed to observe the stability of the results obtained. The steps are explained in detail below.

The decision matrices to be used in PFAHP and PFTOPSIS methods were created by experts. Charts 3 shows the information of the experts. Each expert created a decision matrix. A matrix was used by averaging the 12 decision matrices created.

4.1. Defining the Criteria

In the literature review, 9 criteria that constitute forest fire risk were identified. These criteria are given in Charts 4 with explanations.

The 9 criteria selected for forest fire risk assessment cover key factors that have a direct impact on the occurrence, spread and control of fires. Natural factors such as endemic plants, biomass density, slope and elevation determine the probability and rate of spread of fire, while meteorological factors such as humidity, air temperature and wind create environmental conditions that increase fire risk. Proximity to settlements addresses the human-induced fire risk. It also affects the degree of sun exposure of the aspect surface and the drying and flammability of vegetation. These criteria make risk assessment more comprehensive and reliable by understanding the multidimensional nature of fires.

4.2. Announcement of Alternative Districts

The districts of Balikesir are presented in Figure 5 and Charts 5. The reasons for choosing Balikesir as the implementation area are explained below.

- *Geographical location and climate:* It is under the influence of Mediterranean climate and Marmara transition climate. The climate is hot and dry in summer and mild and rainy in winter. High temperatures and low humidity due to the Mediterranean climate increase the risk of forest fires. Especially northeast winds are effective in the coastal areas of Balikesir and may cause fires to spread rapidly.
- *Forest cover:* It is a province with a rich forest cover and forest areas are among the fire-prone areas. Pine trees can easily catch fire due to their resinous nature and cause fires to grow rapidly. Dense forest understorey cover (dry grasses, leaves) facilitates the start and spread of fires.
- *Human activities:* Tourism activities are intense in coastal areas. Carelessly left campfires or cigarette butts can cause fires to start. Agricultural activities such as stubble burning can cause fires in forested areas.
- *Strategic transit point:* It is an important transit point for land and sea transportation. Therefore, thanks to its strategic location, it has the advantage of rapid response from both land and sea. However, this can also lead to logistical challenges in the event of a fire due to heavy traffic.

Charts 4. Explanation of Criteria [40], [54], [55]

Criteria number	Criteria	Definition
O1	Endemic plants	Endemic plants are species that exist only in a specific region and do not naturally grow elsewhere. These plants are often adapted to unique environmental conditions. However, some endemic plant species are more susceptible to fire due to their high resin and oil content. This makes endemic plants a factor that increases the risk of forest fires.
O2	Aspect	Both the east façade receives more sunlight than the west façade and the north façade receives more sunlight than the south façade. Therefore, the east side and the south side are directly heated. The sun dries out both vegetation and soil. Therefore, the probability of fire is high.
O3	Distance to settlement	Proximity to settlements influences the frequency of human-caused fires. Activities like picnics, agricultural practices, or careless behavior such as throwing cigarette butts increase fire risk. Conversely, areas far from settlements are less affected by human activities and thus have lower risk.
O4	Slope	Fires spread faster from higher to lower. Therefore, slope has a linear relationship to forest fire risk. The higher the slope, the higher the risk of forest fire. Therefore, the slope is effective in both fires and fires. These are the direction of the fire and the rate of spread.
O5	Humidity	Moisture in the combustible material can cause a fire to start. By reducing the heat during ignition, the combustible material needs more heat. Moisture content of combustible materials in the top layer reduces convective heat transfer and flame development. For this reason, in the results of the study on coniferous tree needles, it was observed that energy or heat was needed due to the different moisture content of the needles. The moisture content of the leaf has less of an effect on peak fire initiation than sub-peak height. Theoretically, however, leaf moisture content has a strong influence on the peak fire spread rate.
O6	Air temperature	The probability of forest fire is high in weather conditions where the air temperature above 40 °C and the relative humidity fall below 20%. Forest fires that occur under these conditions can spread very quickly with the effect of the wind and it becomes difficult to control. In light of all these, air temperature is an important parameter to be considered.
O7	Biomass Density	Biomass is the total weight of a stand formed by a tree consisting of roots, stems, leaves, bark and branches. Planted wealth, on the other hand, is the sum of the volumes of the trunks above a certain diameter that live and produce at the time the forest is measured. Based on these two explanations, the higher the amount of biomass in the study area, the higher the probability of fire.
O8	Elevation	It is one of the important physiological factors for forest fires. The distance between the cover combustibles and the overhead combustibles is important in the initiation of the overhead fire. Peak height is the distance of a live branch on a tree from the lowest point to the cover surface. Along with dead branches, it also took into account lichen and hanging combustible materials. In the light of all this, the fire starts from the upward slope and progresses rapidly downwards.
O9	Wind	Wind is one of the most significant factors influencing the direction and speed of fire spread. Strong winds can carry flames over a larger area, causing rapid fire expansion. Furthermore, winds can transport sparks over long distances, igniting new fires.

- *Impacts on the ecosystem:* Forested areas have an ecosystem rich in biodiversity. At the same time, potential fires threaten animal species and rare plants in the area. The risk of soil loss and erosion increases after forest fires, which can damage the region's agricultural areas.

Figure 4. Districts of Balikesir

Charts 5. Alternative districts

Alternative no	Alternative	Alternative no	Alternative
I1	Bandirma	I11	Erdek
I2	Edremit	I12	Marmara adasi
I3	Dursunbey	I13	Altieylül
I4	Susurluk	I14	Karesi
I5	Manyas	I15	İvrindi
I6	Burhaniye	I16	Savastepe
I7	Ayvalik	I17	Bigadic
I8	Havran	I18	Sindirgi
I9	Gönen	I19	Gömec
I10	Kepsut	I20	Balya

4.3. Criteria Weights Obtained from the PFAHP Method

The 9 criteria that are effective in the occurrence of forest fire were determined from the literature. In the application phase of this method, a linguistic scale was used to create the decision matrix. The linguistic scale is given in Charts 6 [34].

Charts 6. PFAHP linguistic assessment scale

Linguistic term	Pythagorean fuzzy numbers			
	μ_L	μ_U	v_L	v_U
Definitely Low Significance	0	0	0.9	1
Very Low Significance	0	0	0.8	0.9
Low Significance	0.2	0.35	0.65	0.8
Below Average Significance	0.35	0.45	0.55	0.65
Average Significance	0.45	0.55	0.45	0.55
Above Average Significance	0.55	0.65	0.35	0.45
High Significance	0.65	0.8	0.2	0.35
Very High Significance	0.8	0.9	0.1	0.2
Definitely High Significance	0.9	1	0	0
Exactly Equal	0.1965	0.1965	0.1965	0.1965

(0.124) ranks third with its effect on the direction and speed of fire spread. Biomass density (0.123) and altitude (0.121) are determinants of the amount of combustible material and the way the fire progresses. Slope (0.111) is the sixth most influential factor in fire acceleration, while aspect (0.105) affects sun exposure and thus drying rate. Distance from settlement (0.073) is associated with anthropogenic risks, while endemic plants (0.062) are important for specific fire risk areas. This ranking accurately reflects the impact of each factor to comprehensively analyze fire risk.

Charts 8. Weights of the criteria obtained from the PFAHP method

Criteria no	**Criteria**	**Criteria weights**	**Ranking**
O1	Endemic plants	0.063	9
O2	Aspect	0.101	7
O3	Distance to settlement	0.079	8
O4	Slope	0.109	6
O5	Humidity	0.123	4
O6	Air temperature	0.149	1
O7	Biomass Density	0.122	5
O8	Elevation	0.127	3
O9	Wind	0.128	2

Charts 7. Decision matrix of the PFAHP method

Criteria	Pythagorean fuzzy numbers: $(\mu_L, \mu_U; v_L, v_L)$								
	O1	O2	O3	O4	O5	O6	O7	O8	O9
O1	(0.197,0.197; 0.197,0.197)	(0.200,0.329; 0.671,0.800)	(0.567,0.654; 0.329,0.400)	(0.171,0.288; 0.696,0.829)	(0.192,0.288; 0.688,0.808)	(0.596,0.717; 0.283,0.396)	(0.183,0.271; 0.696,0.817)	(0.258,0.371; 0.629,0.725)	(0.354,0.463; 0.529,0.646)
O2	(0.646,0.767; 0.225,0.354)	(0.197,0.197; 0.197,0.197)	(0.658,0.775; 0.225,0.325)	(0.279,0.392; 0.600,0.721)	(0.408,0.529; 0.471,0.583)	(0.392,0.513; 0.488,0.600)	(0.400,0.513; 0.479,0.600)	(0.250,0.371; 0.629,0.750)	(0.217,0.304; 0.671,0.783)
O3	(0.317,0.379; 0.579,0.667)	(0.229,0.317; 0.658,0.771)	(0.197,0.197; 0.197,0.197)	(0.383,0.479; 0.504,0.617)	(0.450,0.558; 0.442,0.542)	(0.642,0.771; 0.229,0.350)	(0.413,0.513; 0.479,0.588)	(0.342,0.463; 0.538,0.658)	(0.463,0.567; 0.425,0.538)
O4	(0.663,0.788; 0.213,0.321)	(0.392,0.508; 0.492,0.608)	(0.475,0.579; 0.413,0.517)	(0.197,0.197; 0.197,0.197)	(0.500,0.600; 0.392,0.483)	(0.554,0.675; 0.325,0.438)	(0.371,0.471; 0.513,0.629)	(0.475,0.596; 0.404,0.500)	(0.279,0.388; 0.604,0.721)
O5	(0.738,0.867; 0.133,0.238)	(0.446,0.554; 0.438,0.554)	(0.446,0.546; 0.446,0.554)	(0.296,0.379; 0.596,0.704)	(0.197,0.197; 0.197,0.197)	(0.558,0.671; 0.329,0.442)	(0.450,0.554; 0.446,0.550)	(0.379,0.479; 0.513,0.604)	(0.221,0.325; 0.658,0.779)
O6	(0.729,0.854; 0.146,0.246)	(0.504,0.625; 0.375,0.496)	(0.413,0.525; 0.467,0.588)	(0.308,0.396; 0.571,0.692)	(0.279,0.371; 0.613,0.721)	(0.197,0.197; 0.197,0.197)	(0.442,0.550; 0.442,0.550)	(0.691,0.783; 0.166,0.258)	(0.317,0.429; 0.563,0.683)
O7	(0.675,0.796; 0.204,0.292)	(0.454,0.563; 0.438,0.538)	(0.438,0.538; 0.454,0.554)	(0.521,0.642; 0.358,0.479)	(0.417,0.513; 0.479,0.583)	(0.592,0.713; 0.288,0.408)	(0.197,0.197; 0.197,0.197)	(0.463,0.567; 0.425,0.529)	(0.346,0.467; 0.533,0.654)
O8	(0.304,0.417; 0.583,0.696)	(0.558,0.683; 0.317,0.442)	(0.338,0.450; 0.550,0.663)	(0.638,0.746; 0.254,0.354)	(0.604,0.721; 0.279,0.396)	(0.390,0.453; 0.294,0.357)	(0.558,0.671; 0.329,0.442)	(0.197,0.197; 0.197,0.197)	(0.508,0.600; 0.392,0.492)
O9	(0.450,0.563; 0.438,0.550)	(0.592,0.708; 0.292,0.400)	(0.404,0.529; 0.471,0.596)	(0.617,0.733; 0.267,0.383)	(0.533,0.654; 0.346,0.467)	(0.488,0.600; 0.400,0.513)	(0.546,0.663; 0.338,0.454)	(0.533,0.638; 0.363,0.458)	(0.197,0.197; 0.197,0.197)

The decision matrix obtained using the language scale given in Charts 6 is presented in Charts 7.

The ranking of criteria weights in terms of forest fires is given in Charts 8. It was determined according to the importance of the factors affecting the risk of fire outbreak and spread. The highest weight was given to air temperature with 0.153. This is because temperature is the most critical factor that directly affects the origin and speed of fire. Humidity (0.128) ranks second and plays an important role in the flammability of vegetation. Wind

4.4. Ranking of alternatives obtained from the PFTOPSIS method

After calculating the criteria weights using the PFAHP method, the districts of Balikesir are ranked using the PFTOPSIS method. The language scale used in this method is presented in Charts 9.

Tablo 9'daki dil ölçeği kullanılarak Tablo 10'daki karar matrisi oluşturulmuştur.

Charts 9. PFTOPSIS linguistic assessment scale

Linguistic Term	Pythagorean fuzzy numbers	
	u	v
Overly Low	0.1	0.99
Very Little	0.1	0.97
Little	0.25	0.92
Middle Little	0.4	0.87
Middle	0.5	0.8
Middle High	0.6	0.71
High	0.7	0.6
Very High	0.8	0.44
Extremely High	0.1	0

biomass density can increase the fire hazard in certain areas.

Lower down the charts, districts such as Gönen, Manyas and Susurluk have lower fire risk. In these districts, less slope and relatively high humidity levels limit the possibility of fire. However, even in these regions, caution is needed during the dry summer months. Biomass density in particular can affect the likelihood of fires in certain areas.

The districts at the bottom of the list, such as Kepsut, Altıeylül, Karesi, Gömeç and Savaştepe, have a lower fire risk compared to other regions. In these districts, vegetation density and meteorological factors greatly

Charts 10. PFTOPSIS decision matrix

Decision Matrix	**Pythagorean fuzzy numbers: (u;v)**								
	O1	O2	O3	O4	O5	O6	O7	O8	O9
I1	(0.54;0.54)	(0.47;0.73)	(0.30;0.87)	(0.66;0.62)	(0.67;0.63)	(0.58;0.60)	(0.71;0.53)	(0.63;0.58)	(0.43;0.35)
I2	(0.46; 0.50)	(0.51; 0.38)	(0.53; 0.71)	(0.62;0.66)	(0.56; 0.39)	(0.38; 0.40)	(0.52; 0.31)	(0.56; 0.31)	(0.37; 0.30)
I3	(0.46;0.72)	(0.46;0.42)	(0.63;0.66)	(0.45;0.54)	(0.40;0.48)	(0.55;0.63)	(0.57;0.67)	(0.60;0.47)	(0.43;0.72)
I4	(0.46; 0.72)	(0.63; 0.57)	(0.61; 0.63)	(0.48; 0.51)	(0.68; 0.57)	(0.58; 0.60)	(0.61; 0.63)	(0.52; 0.75)	(0.58; 0.71)
I5	(0.46;0.72)	(0.47;0.73)	(0.70;0.52)	(0.73;0.51)	(0.69;0.54)	(0.58;0.60)	(0.66;0.59)	(0.46;0.82)	(0.39;0.68)
I6	(0.55; 0.61)	(0.51; 0.69)	(0.38; 0.80)	(0.71; 0.59)	(0.63; 0.64)	(0.58; 0.60)	(0.71; 0.53)	(0.61; 0.48)	(0.46; 0.43)
I7	(0.29;0.80)	(0.57;0.56)	(0.64;0.62)	(0.65;0.62)	(0.70;0.51)	(0.58;0.60)	(0.66;0.69)	(0.70;0.58)	(0.45;0.67)
I8	(0.29;0.80)	(0.62; 0.58)	(0.67; 0.61)	(0.66;0.62)	(0.73; 0.51)	(0.58; 0.60)	(0.71; 0.53)	(0.63; 0.66)	(0.55; 0.70)
I9	(0.20;0.84)	(0.48;0.72)	(0.74;0.51)	(0.97;0.61)	(0.69;0.54)	(0.58;0.60)	(0.71;0.53)	(0.58;0.73)	(0.61;0.66)
I10	(0.50; 0.67)	(0.37; 0.77)	(0.48; 0.75)	(0.65; 0.63)	(0.68; 0.62)	(0.58; 0.60)	(0.75; 0.49)	(0.43; 0.79)	(0.55; 0.69)
I11	(0.23;0.84)	(0.52;0.68)	(0.34;0.84)	(0.61;0.65)	(0.67;0.63)	(0.58;0.60)	(0.70;0.56)	(0.54;0.73)	(0.72;0.57)
I12	(0.23; 0.91)	(0.47; 0.73)	(0.24; 0.23)	(0.55; 0.53)	(0.69; 0.54)	(0.58; 0.60)	(0.77; 0.48)	(0.43; 0.84)	(0.61; 0.67)
I13	(0.69;0.60)	(0.64;0.50)	(0.69;0.54)	(0.33;0.30)	(0.33;0.25)	(0.58;0.60)	(0.61;0.63)	(0.44;0.79)	(0.41;0.83)
I14	(0.63; 0.66)	(0.47; 0.50)	(0.53; 0.69)	(0.37;0.58)	(0.39;0.48)	(0.53; 0.64)	(0.58; 0.67)	(0.45; 0.52)	(0.50; 0.76)
I15	(0.60;0.67)	(0.56;0.58)	(0.53;0.68)	(0.37;0.58)	(0.45; 0.53)	(0.51;0.66)	(0.57;0.68)	(0.55;0.61)	(0.29;0.65)
I16	(0.66; 0.64)	(0.46; 0.49)	(0.52; 0.68)	(0.40; 0.56)	(0.38;0.57)	(0.50; 0.67)	(0.55; 0.69)	(0.46; 0.60)	(0.41; 0.83)
I17	(0.60;0.68)	(0.59;0.55)	(0.50;0.70)	(0.44;0.41)	(0.44; 0.53)	(0.51;0.67)	(0.58;0.67)	(0.52;0.63)	(0.49;0.74)
I18	(0.57; 0.69)	(0.55; 0.58)	(0.55; 0.57)	(0.50; 0.57)	(0.47;0.51)	(0.45; 0.62)	(0.57; 0.59)	(0.53; 0.62)	(0.39; 0.77)
I19	(0.55;0.72)	(0.55;0.60)	(0.56;0.65)	(0.40;0.56)	(0.35; 0.51)	(0.45;0.62)	(0.63;0.63)	(0.52;0.63)	(0.49;0.77)
I20	(0.59; 0.68)	(0.58; 0.56)	(0.53; 0.68)	(0.38;0.58)	(0.44; 0.53)	(0.50; 0.58)	(0.58; 0.67)	(0.51; 0.65)	(0.48; 0.74)

Charts 11 presents the forest fire risk of Balikesir districts. The data in this charts are evaluated according to the geographical, biological and meteorological characteristics of the districts. Edremit, which ranks first, has the highest fire risk due to the influence of Kazdağları. This region is highly prone to fires due to critical factors such as endemic plant diversity, dense biomass, low humidity and high temperature. The rapid spread of fires in this wind-prone district poses a significant risk.

Burhaniye and Ayvalık rank second and third respectively. These districts are located on the Aegean coast and are similarly affected by temperature, low humidity and wind. In particular, dense vegetation increases the likelihood of fires in these districts. Havran ranks fourth, with its southern slopes more exposed to sunlight and sloping terrain increasing the risk of fire. Bandırma has a relatively lower risk, but wind and

reduce the risk of fire. However, the risk does not completely disappear but remains at low levels. In general, fire risk distribution in the districts of Balikesir varies depending on geographical and ecological characteristics.

Charts 11. Ranking of alternatives with PFTOPSIS method

No	**$\xi(X_i)$**	**Ranking**	**No**	**$\xi(X_i)$**	**Ranking**
I1	-0.406	5	I11	-0.678	12
I2	-0.031	1	I12	-0.667	11
I3	-0.564	9	I13	-0.754	17
I4	-0.559	8	I14	-0.753	16
I5	-0.539	7	I15	-0.732	15
I6	-0.242	2	I16	-0.870	20
I7	-0.294	3	I17	-0.786	18
I8	-0.339	4	I18	-0.618	10
I9	-0.463	6	I19	-0.815	19
I10	-0.706	13	I20	-0.732	14

Charts 12. Sensitivity analysis

Scenarios		Criteria weights									
		O1	**O2**	**O3**	**O4**	**O5**	**O6**	**O7**	**O8**	**O9**	**Ranking of alternatives**
Current		0.063	0.101	0.079	0.109	0.123	0.149	0.122	0.127	0.128	I2-I6-I7-I8-I1-I9-I5-I4-I3-I18-I12-I11-I10-I20-I15-I14-I13-I17-I19-I16
1	O1-O2	**0.101**	**0.063**	0.079	0.109	0.123	0.149	0.122	0.127	0.128	I2-I6-I1-I7-I8-I9-I5-I4-I3-I18-I12-I11-I10-I20-I15-I14-I13-I17-I19-I16
2	O1-O3	**0.079**	0.101	**0.063**	0.109	0.123	0.149	0.122	0.127	0.128	I2-I6-I7-I8-I1-I9-I5-I4-I3-I18-I11-I10-I12-I15-I20-I14-I13-I17-I19-I16
3	O1-O4	**0.109**	0.101	0.079	**0.063**	0.123	0.149	0.122	0.127	0.128	I2-I6-I7-I1-I8-I9-I3-I4-I5-I18-I15-I20-I14-I13-I10-I11-I17-I12-I19-I16
4	O1-O5	**0.123**	0.101	0.079	0.109	**0.063**	0.149	0.122	0.127	0.128	I2-I6-I1-I7-I8-I3-I18-I5-I9-I4-I13-I14-I20-I15-I10-I17-I19-I11-I16-I12
5	O1-O6	**0.149**	0.101	0.079	0.109	0.123	**0.063**	0.122	0.127	0.128	I2-I6-I1-I7-I8-I5-I3-I18-I4-I9-I15-I13-I14-I10-I20-I17-I16-I19-I11-I12
6	O1-O7	**0.122**	0.101	0.079	0.109	0.123	0.149	**0.063**	0.127	0.128	I2-I6-I7-I1-I8-I3-I5-I4-I9-I18-I15-I20-I13-I14-I17-I10-I11-I16-I19-I12
7	O1-O8	**0.127**	0.101	0.079	0.109	0.123	0.149	0.122	**0.063**	0.128	I2-I6-I7-I8-I1-I5-I9-I4-I10-I18-I13-I3-I12-I11-I20-I15-I14-I17-I19-I16
8	O1-O9	**0.128**	0.101	0.079	0.109	0.123	0.149	0.122	0.127	**0.063**	I2-I6-I7-I8-I1-I5-I3-I18-I9-I4-I13-I20-I14-I10-I15-I17-I16-I19-I12-I11
9	O2-O3	0.063	**0.079**	**0.101**	0.109	0.123	0.149	0.122	0.127	0.128	I2-I6-I7-I8-I9-I1-I5-I4-I3-I18-I12-I10-I11-I15-I13-I20-I14-I17-I19-I16
10	O2-O4	0.063	**0.109**	0.079	**0.101**	0.123	0.149	0.122	0.127	0.128	I2-I6-I7-I8-I1-I9-I5-I4-I3-I18-I12-I11-I10-I20-I15-I14-I13-I17-I19-I16
11	O2-O5	0.063	**0.123**	0.079	0.109	**0.101**	0.149	0.122	0.127	0.128	I2-I6-I7-I8-I1-I9-I3-I4-I5-I18-I11-I12-I20-I15-I13-I14-I10-I17-I19-I16
12	O2-O6	0.063	**0.149**	0.079	0.109	0.123	**0.101**	0.122	0.127	0.128	I2-I6-I7-I8-I1-I9-I3-I4-I5-I18-I15-I11-I20-I14-I12-I13-I17-I10-I19-I16
13	O2-O7	0.063	**0.122**	0.079	0.109	0.123	0.149	**0.101**	0.127	0.128	I2-I6-I7-I8-I1-I9-I3-I4-I5-I18-I11-I12-I20-I15-I14-I13-I10-I17-I19-I16
14	O2-O8	0.063	**0.127**	0.079	0.109	0.123	0.149	0.122	**0.101**	0.128	I2-I6-I7-I8-I1-I9-I5-I4-I3-I18-I12-I11-I10-I13-I20-I15-I14-I17-I19-I16
15	O2-O9	0.063	**0.128**	0.079	0.109	0.123	0.149	0.122	0.127	**0.101**	I2-I6-I7-I8-I1-I9-I3-I4-I5-I18-I12-I11-I20-I13-I15-I14-I10-I17-I19-I16
16	O3-O4	0.063	0.101	**0.109**	**0.079**	0.123	0.149	0.122	0.127	0.128	I2-I7-I6-I8-I9-I1-I5-I4-I3-I18-I12-I13-I15-I20-I14-I11-I10-I17-I19-I16
17	O3-O5	0.063	0.101	**0.123**	0.109	**0.079**	0.149	0.122	0.127	0.128	I2-I6-I7-I8-I9-I1-I5-I3-I18-I4-I13-I12-I20-I15-I14-I10-I19-I11-I17-I16
18	O3-O6	0.063	0.101	**0.149**	0.109	0.123	**0.079**	0.122	0.127	0.128	I2-I7-I8-I6-I9-I5-I4-I18-I1-I3-I12-I13-I15-I20-I10-I14-I17-I19-I11-I16
19	O3-O7	0.063	0.101	**0.122**	0.109	0.123	0.149	**0.079**	0.127	0.128	I2-I7-I6-I8-I9-I5-I1-I4-I3-I18-I12-I13-I15-I20-I14-I17-I11-I10-I19-I16
20	O3-O8	0.063	0.101	**0.127**	0.109	0.123	0.149	0.122	**0.079**	0.128	I2-I7-I8-I6-I9-I5-I4-I1-I12-I18-I3-I13-I10-I11-I20-I15-I14-I17-I19-I16
21	O3-O9	0.063	0.101	**0.128**	0.109	0.123	0.149	0.122	0.127	**0.079**	I2-I7-I8-I6-I9-I5-I4-I18-I3-I1-I13-I12-I20-I14-I15-I10-I19-I17-I11-I16
22	O4-O5	0.063	0.101	0.079	**0.123**	**0.109**	0.149	0.122	0.127	0.128	I2-I6-I7-I8-I1-I9-I5-I3-I4-I18-I12-I11-I10-I20-I15-I13-I14-I17-I19-I16
23	O4-O6	0.063	0.101	0.079	**0.149**	0.123	**0.109**	0.122	0.127	0.128	I2-I6-I7-I8-I1-I9-I5-I4-I3-I18-I12-I11-I10-I15-I20-I13-I14-I17-I19-I16
24	O4-O7	0.063	0.101	0.079	**0.122**	0.123	0.149	**0.109**	0.127	0.128	I2-I6-I7-I8-I1-I9-I5-I4-I3-I18-I12-I11-I10-I15-I20-I13-I14-I17-I19-I16
25	O4-O8	0.063	0.101	0.079	**0.127**	0.123	0.149	0.122	**0.109**	0.128	I2-I6-I7-I8-I1-I9-I5-I4-I3-I18-I12-I11-I10-I20-I13-I15-I14-I17-I19-I16
26	O4-O9	0.063	0.101	0.079	**0.128**	0.123	0.149	0.122	0.127	**0.109**	I2-I6-I7-I8-I1-I9-I5-I4-I3-I18-I12-I11-I10-I20-I13-I15-I14-I17-I19-I16
27	O5-O6	0.063	0.101	0.079	0.109	**0.149**	**0.123**	0.122	0.127	0.128	I2-I6-I7-I8-I1-I9-I5-I4-I3-I18-I12-I11-I10-I15-I20-I14-I13-I17-I19-I16
28	O5-O7	0.063	0.101	0.079	0.109	**0.122**	0.149	**0.123**	0.127	0.128	I2-I6-I7-I8-I1-I9-I5-I4-I3-I18-I12-I11-I10-I20-I15-I13-I14-I17-I19-I16
29	O5-O8	0.063	0.101	0.079	0.109	**0.127**	0.149	0.122	**0.123**	0.128	I2-I6-I7-I8-I1-I9-I5-I3-I4-I18-I12-I11-I10-I15-I20-I14-I13-I17-I19-I16
30	O5-O9	0.063	0.101	0.079	0.109	**0.128**	0.149	0.122	0.127	**0.123**	I2-I6-I7-I8-I1-I9-I5-I4-I3-I18-I12-I11-I10-I15-I20-I14-I13-I17-I19-I16
31	O6-O7	0.063	0.101	0.079	0.109	0.123	**0.122**	**0.149**	0.127	0.128	I2-I6-I7-I8-I1-I9-I5-I4-I3-I18-I12-I11-I10-I15-I20-I14-I13-I17-I19-I16
32	O6-O8	0.063	0.101	0.079	0.109	0.123	**0.127**	0.122	**0.149**	0.128	I2-I6-I7-I8-I1-I9-I3-I4-I5-I18-I11-I15-I12-I14-I20-I10-I17-I13-I19-I16
33	O6-O9	0.063	0.101	0.079	0.109	0.123	**0.128**	0.122	0.127	**0.149**	I2-I6-I7-I8-I1-I9-I5-I4-I3-I18-I11-I12-I10-I15-I20-I14-I17-I13-I19-I16
34	O7-O8	0.063	0.101	0.079	0.109	0.123	0.149	**0.127**	**0.122**	0.128	I2-I6-I7-I8-I1-I9-I5-I4-I3-I18-I12-I11-I10-I15-I20-I14-I13-I17-I19-I16
35	O7-O9	0.063	0.101	0.079	0.109	0.123	0.149	**0.128**	0.127	**0.122**	I2-I6-I7-I8-I1-I9-I5-I4-I3-I18-I12-I11-I10-I20-I15-I13-I14-I17-I19-I16
36	O8-O9	0.063	0.101	0.079	0.109	0.123	0.149	0.122	**0.128**	**0.127**	I2-I6-I7-I8-I1-I9-I5-I3-I4-I18-I12-I11-I10-I20-I15-I14-I13-I17-I19-I16

5. SENSITIVITY ANALYSIS

Through sensitivity analysis, the validity and accuracy of the proposed approach can be questioned, as well as confirming whether the model is good or not [56]. 36 scenarios were obtained from the binary combination of 9 criteria. A summary of these scenarios is presented in Charts 12.

When the charts is examined, it is seen that Edremit, Burhaniye, Ayvalık, Havran and Bandırma districts are included regardless of the ranking of the criteria. This shows that these districts are risky in terms of forest fires. Thus, Altıeylül, Bigadiç, Gömeç and Savaştepe districts are determined as the districts with the lowest probability of forest fires. There is a change in some rankings due to the binary change of the criteria ranking.

A significant change was observed when the weights of air temperature with the highest criterion weight and endemic plants with the lowest criterion weight were swapped. Especially when endemic plants are high, districts such as I2, I6, I7 and I8 are ranked higher in the ranking, indicating that these regions have a higher fire risk and more precautions should be taken. In addition, in districts where the air temperature is low, the fire can spread rapidly, so the fact that districts such as I1 and I5 rise in the ranking emphasizes the risk of areas where the fire can be more controlled. Overall, the sensitivity analysis allows for a more precise identification of areas at risk of fire and helps to effectively shape the measures to be taken in these areas.

The summary of the results of the proposed model shows that in an uncertain and complex decision environment, logical and robust results are obtained, as well as wildfire risk assessment from a comprehensive perspective. The advantages of PFSs have been proven in this study and it has been revealed that they offer a strong decision-making advantage over ordinary fuzzy sets. The implications of the results and suggestions for future work are described in the conclusion.

6. CONCLUSIONS

Forest fires destroy a large part of forests. According to forest fire data, between 2004 and 2024, 9161 hectares of land burned in Balikesir province [15]. Considering all these data, it is important to identify the areas at risk of forest fires. Therefore, the assessment of districts in terms of forest fires is a complex and uncertain decision-making problem. This problem should be evaluated and solved so that necessary measures can be taken before forest fires occur. In the model proposed in this study, forest fire risk assessment is examined: taking expert opinions that have direct and indirect influence on forest fires, evaluating alternative districts in a fuzzy environment by considering fire risk status, conflicting and uncertain criteria, climatic conditions and topographical features, and creating a strong and consistent case by comparing the results obtained. In this study, Edremit was found to be the most risky district in case of a forest fire in Balikesir province. According to the data obtained from Balikesir Regional Directorate of Forestry, there are 632,405 hectares of forest. In addition, the forest fire risk of Balikesir province was evaluated based on the climatic characteristics of the region and human activities. Being located at the junction of Mediterranean and Marmara climates creates conditions that can trigger forest fires with high temperatures and low humidity in summer. In the coastal areas, especially with the effect of northeast winds, an environment where fires can spread rapidly is created. Forests in the region, where pine trees are dense, are susceptible to fire due to their resinous nature, and the richness of the forest understorey also causes fires to grow rapidly. Human activities also increase this risk; factors such as carelessly left campfires and cigarette butts during tourism activities in coastal areas can start forest fires. Moreover, agricultural activities such as stubble burning also increase the risk of fire. Although Balikesir's strategic location allows for rapid response, heavy traffic and logistical challenges can create significant obstacles in the event of a fire.

First of all, the criteria were determined by the expert team working in the General Directorate of Forestry. There are nine criteria: Endemic plants (O1), Aspect (O2), Distance to settlement (O3), Slope (O4), Humidity (O5), Air temperature (O6), Biomass Density (O7), Elevation (O8), Wind (O9). Criteria weights were calculated by the experts using the language scale with the PFAHP method. According to the results obtained, the Air temperature (O6) criterion is the most risky, with a ratio of 0.149. This criterion weight is followed by 0.128 Wind (O9), 0.127 Elevation (O8), 0.123 Humidity (O5), 0.122 Biomass Density (O5), 0.109 Slope (O4), 0.101 Aspect (O2), 0.079 Distance to Settlement (O3) and 0.063 Endemic plants (O1). It is rational that the Air Temperature criterion ranks first and Endemic plants (O1) rank last in forest fire. This shows that air temperature is a determining factor in the start and spread of fires. In addition, the limited direct impact of endemic plants on fire risk makes it logical that they have the lowest weight. These results show that factors such as temperature, wind, and height should be prioritized in forest fire risk management.

In the second stage, 20 districts of Balıkesir were ranked by PFTOPSIS with the weights obtained from the PFAHP method. The districts were selected as alternatives due to the risk of forest fires in Balıkesir province. Experts scored using a language scale. According to the results obtained from the PFTOPSIS method, the Edremit district is the most risky. Considering that 10 different decision matrices were created and ranked by the experts, the consistency and reliability of the results were increased. Thus, a more robust and objective decision support mechanism has been made in fire risk assessment. The vegetation cover of the Edremit district increases the risk of fire, mainly due to the highly flammable Mediterranean maquis flora and resinous tree species. In addition, endemic plant species in the region play a critical role in determining the rate of fire spread and post-fire effects on the ecosystem. Sensitivity analysis was performed with 36 different scenarios to assess the reliability of the results and the robustness of the model. In all scenarios, it was consistently confirmed that the Edremit district has the highest risk of wildfire, thus strengthening the robustness of the findings and their contribution to decision-making.

Practical recommendations are given below.

- Early warning systems that continuously monitor temperature, humidity, and wind data should be established in high-risk areas.
- Local emergency response teams should be strengthened in districts with high fire risk
- Resource allocation planning of fire fighting equipment should be made.
- The public should be educated and raised awareness, especially in areas at risk of fire due to agricultural and tourism activities.

All academic question marks have been removed, and critical suggestions for future work have been made. In this context, it can model the uncertainty level of Spherical, Neutrosophic, and Unstable fuzzy sets. In future studies, the economic and socioeconomic impacts of forest fires can be evaluated more comprehensively by using these methods. In addition, comparative analyses with different MCDM methods, such as Interval Type-2 Fuzzy Logic, Hesitant Fuzzy Set, DEMATEL, or VIKOR, can be performed to determine the most appropriate fuzzy framework for fire risk assessments.

Thus, the advantages and disadvantages of different methods can be better revealed.

DECLARATION OF ETHICAL STANDARDS

The author(s) of this article declare that the materials and methods they used in their work do not require ethics committee approval and/or legal-special permission.

AUTHORS' CONTRIBUTIONS

Burcu TEZCAN: Writing - review & editing, Data curation, Conceptualization, Methodology.

Tamer EREN: Supervision, Validation - original draft, Software, Data curation.

CONFLICT OF INTEREST

There is no conflict of interest in this study.

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