ASSESSMENT OF THE MONTHLY FOREST FIRE DANGER POTENTIAL USING GIS-BASED ANALYTIC HIERARCHY PROCESS IN SOUTHWEST TÜRKİYE

PROCJENA MJESEČNOG POTENCIJALA OPASNOSTI OD ŠUMSKIH POŽARA POMOĆU ANALITIČKOG HIJERARHIJSKOG PROCESA ZASNOVANOG NA GIS-u U JUGOZAPADNOM DIJELU TURSKE

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SUMMARY

Every year, more than ten thousand hectares of forest in Türkiye are affected by fires. The majority of forest fires occurs in the southern part of Türkiye, where conifer forests and maquis prone to fire are abundant. Forest fires can lead to the loss of human lives, properties and natural resources. Knowledge of Forest Fire Danger Potential (FFDP) is critical to protect lives, property, and natural resources from fire damage. We modeled and mapped FFDP with a GIS-based Analytic Hierarchy Process. The FFDP model was developed based on nine environmental factors that affect fire behavior, including maximum temperature, precipitation, wind speed, species composition, development stage, canopy cover, slope, aspect, and elevation. FFDP was mapped and thoroughly assessed. The results showed that FFDP was significantly correlated with maximum temperature, precipitation, and species composition. We found that the FFDP differed considerably on a monthly basis. Forest lands in the study area of 2% in May, 50% in June, 65% in July, 61% in August, 25% in September, and 0% in October belonged to the extreme danger class. For model evaluation, we compared fire locations from 2008 to 2018 with those on the FFDP maps and then controlled the actual number of fires in each category and its fire danger class. The dominant danger classes of the study area according to the months were: extreme class in June, July, and August (50%, 65% and 61%, respectively), high class in May and September (74% and 68%, respectively) and moderate class in October (82%). This danger classes were more affected by fires. We observed that FFDP changed significantly by month. The amount of burned area per fire was the highest in the extreme danger class in August and July (3.39 ha and 2.14 ha, respectively). The amount of burned area was higher in areas with extreme or high fire danger class. This study can guide fire organizations in pre-fire management planning, firefighting, and post-fire studies.

KEY WORDS: fire hazard, fire model, MCDA, Türkiye, wildfires

INTRODUCTION
UVOD

Forests are ecologically and economically one of the most important parts of the terrestrial ecosystem. Forests, a carbon sink and an energy source in nature, play a critical role in maintaining the ecological balance. However, forests are endangered by fires, which not only destroy vegetation and reduce carbon storage but also forest structure. Forest fires are ecologically responsible for carbon emissions, global warming, deforestation, and desertification (Sivrikaya and Kucuk 2022) but also contribute to global warming due to

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carbon emissions (Bustillo Sánchez et al. 2021). Forest fires cause loss of life as well as economic and natural resource losses every year (Rosavec et al. 2013).

Forest fires are a disaster in the dry season in conifer forest regions such as in the south of Türkiye (Goltas et al 2017). According to past fire records (from 1988 to 2020) in Türkiye, the annual average number of hectares burned was 10806, but in 2021, 139503 ha of forest area was burned (i.e., 13 times the annual average) (GDF 2022). The damage caused by fires in extreme meteorological conditions is greater due to climate change (Kucuk and Sevinc 2023). Therefore, the importance of modeling and mapping the potential of forest fires is obvious. This will allow for effective planning of firefighting efforts, making quick and focused decisions, and allow the implementation of emergency measures.

Forest fire danger has increased in Mediterranean countries such as Türkiye, Greece, Spain, Italy, Portugal, and France (Quintano et al. 2011, Bilgili et al. 2021). The term *fire danger* refers to the growth of the fire, the difficulty of its control, and the potential damages (NWCG 1996, Saglam et al. 2008). In countries whose forests are threatened by fire, fire danger potential models are developed using environmental factors (Cipriani et al. 2011, Pereira et al. 2012, Kucuk et al. 2015). Models estimating Forest Fire Danger Potential (FFDP) have been developed in various regions that have different fuel and climatic conditions around the world (Kucuk and Bilgili 2007, Bilgili et al. 2019a, Baysal 2021).

Modeling and mapping of FFDP requires complex temporal and spatial analyses (Saglam et al. 2008). Because FFDP is affected by complex temporal and spatial processes in combination with fixed and changeable environmental factors, such as fuel characteristics, topography, and weather conditions (Kucuk and Bilgili 2008; Yavuz et al. 2018; Bilgili et al. 2019b, Sevinc et al. 2020, Kucuk et al. 2021).

Estimation of FFDP is a complex problem because there are many main and sub-criteria to be considered in the decision process. FFDP is estimated with different tools and methodologies to reach the most reliable results. Some researchers have used regression analysis and logistic models (Andrews et al. 2003, Wang et al. 2018), Maxent models (Goltas 2022), Bayesian network model (Sevinc et al. 2020), and Neural Network Model (Liang et al. 2019). Researchers have used multi-criteria decision-making approaches in most of the studies of fire risk and danger estimation in recent years since this approach (MCDM) is a flexible and easily applicable method. Also, combining MCDM with GIS is an effective method for modeling and mapping FFDP (Gheshlaghi et al. 2020, Sivrikaya and Küçük 2022). The use of Geographic Information Systems (GIS) allows the effective and economic distribution of resources.

Although there are some studies estimating FFDP (Saglam et al. 2008, Gungoroglu 2017), there have not been enough studies on FFDP modeling and mapping in the Mediterranean basin, which is dominated by *Pinus brutia* and maquis species vulnerable to fire.

Saglam et al. (2008) conducted a study in the Korudag forest planning unit in northwestern Türkiye; they estimated the Fire Danger Potential by using variables such as species composition, stand development age, canopy cover, slope, and aspect. Laneve et al. (2020) developed the Fire Danger Potential Index in Sardinia, Italy, using variables of wind speed, topography, and local solar radiation (aspect). Sharples et al. (2009) used only meteorological parameters to create the Fire Danger Index in the central USA.

The use of meteorological parameters in addition to fuel properties and topography variables in the prediction of FFDP will increase the accuracy, because there is a close relationship between forest fires and meteorological factors. The factors affect fire ignition, fire severity, spreading rate, and the difficulty of fire control (Deeming 1972, Kucuk and Sağlam 2004). Therefore, it is critical to use meteorological factors in fire danger models. In this paper spatial and temporal (i.e., monthly) evaluations were used because forest FFDP changes as meteorological factors change. Also, we preferred to evaluate FFDP on a monthly basis using field verification, as we think it may be more useful to fire managers.

The objectives of this paper were (i) to model and map the monthly forest fire danger potential using GIS-based AHP that is one of the most common MCDM techniques, (ii) to make field verification of model results, and (iii) to assess (reveal) the FFDP change on a monthly basis. This study can be used for effective fire prevention and suppression, rapid decision making and implementation of emergency measures.

MATERIALS AND METHODS
MATERIJALI I METODE

Study area – *Područje istraživanja*

The study was conducted within the Muğla Regional Directorate of Forestry (RDF) in southwestern Türkiye (Figure 1). Fifty-six percent (1,158,925 ha) of the Muğla RDF, which has a total of 2,051,212 ha, is covered with forests. The vegetation is composed of Calabrian pine (*Pinus brutia* Ten.), Anatolian black pine (*Pinus nigra* Arnold), cedar (*Cedrus libani* A. Rich.), stone pine (*Pinus pinea* L.), oak (*Quercus* spp.), Turkish sweetgum (*Liquidambar orientalis* Mill.) and eucalyptus (*Eucalyptus camaldulensis* Dehn.) trees, and the shrubs that form the maquis. Different tree species have varying levels of vulnerability or resistance to fire. Forests in Türkiye, especially consisting of Calabrian pine and Anatolian black pine, as well as of some maquis species, have a high fire risk and danger potential.
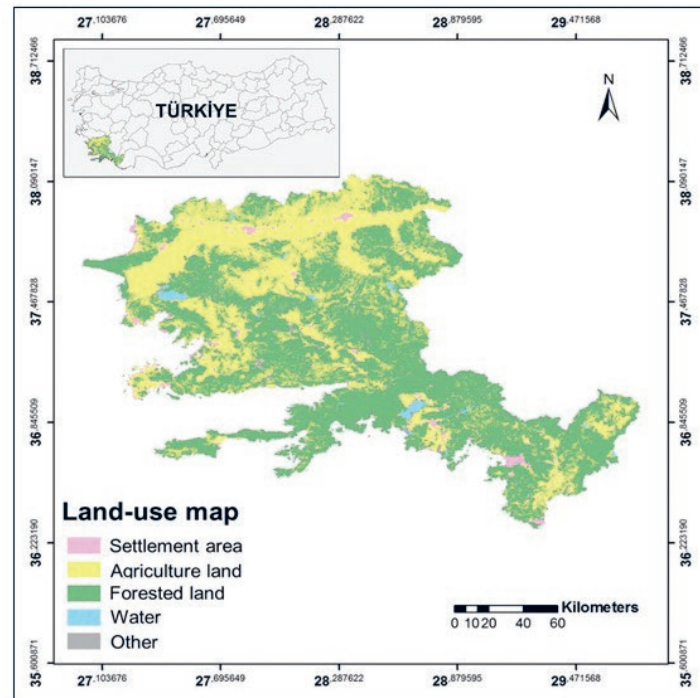
Figure 1. Land-use map of the study area
Slika 1. Karta područja istraživanja

(Mutch and Quigley 1993, Kucuk et al. 2005). In addition, sixty-seven percent of the forests of the study area are below 500 meters altitude. Therefore, there is dense dead and living cover, and this situation increases the fire risk and danger potential. Human activities in and near these forests are common because agricultural areas are intertwined with the forests; the area is one of the most popular tourist destinations in Türkiye and has many facilities for tourists. There are many mining sites nearby, construction takes place near the forests, and the number of wind turbines in the area is increasing day by day. The increase in human activities has increased the risk of anthropogenic forest fires. In 2021, 369 fires broke out in the study area and a forest area of 52,219 ha was damaged by fire (GDF 2022).

Variables and data collecting – *Varijable i prikupljanje podataka*

Topography – *Topografija*

Topography is one of the constant factors affecting fire behavior. There are differences in fuel characteristics depending on the aspect. Southern aspects of the northern hemisphere have more sunlight, higher temperatures, strong winds, and low humidity. Accordingly, the lower fuel humidity on south-facing slopes increases the fire risk by making the fuel more suitable for ignition. Elevation is one of the topographic factors affecting the fire in terms of weather conditions and changes in fuel characteristics. Slope is

effective on the spread direction and spread rate of the fire (Attri et al. 2020). Slope, aspect, and elevation variables representing topographic features were derived from the digital elevation model (DEM) using ArcGIS 10.5. (Esri 2017).

Meteorological parameters – *Meteorološki parametri*

High temperatures not only cause fuel to dry but also cause fuel to need less heat to reach its ignition temperature. The highest temperatures and lowest levels of relative humidity occur at noon, and therefore, the fire risk and danger are highest at this time of day. Therefore, we used the monthly maximum temperature instead of the monthly average temperature as the independent variable. We downloaded the monthly maximum temperature maps from the open source website (URL-1) and then we cut these maps according to the study area using ArcGIS 10.5. (Esri 2017).

As it is known, precipitation increases the moisture content of fuel and therefore reduces the fire probability. We obtained monthly precipitation maps from the open-source website (URL-1) and extracted the necessary data to produce maps of monthly precipitation in the study region using ArcGIS 10.5 (Esri 2017). Wind highly affects the direction and spread of fire (Kucuk and Sağlam 2004). There is a very close relationship between wind speed and the rate of fire spread. As the wind speed increases, the rate of fire spread also increases. We used maximum temperature, precipitation, and wind speed variables representing meteorological parameters for modeling FFDP.
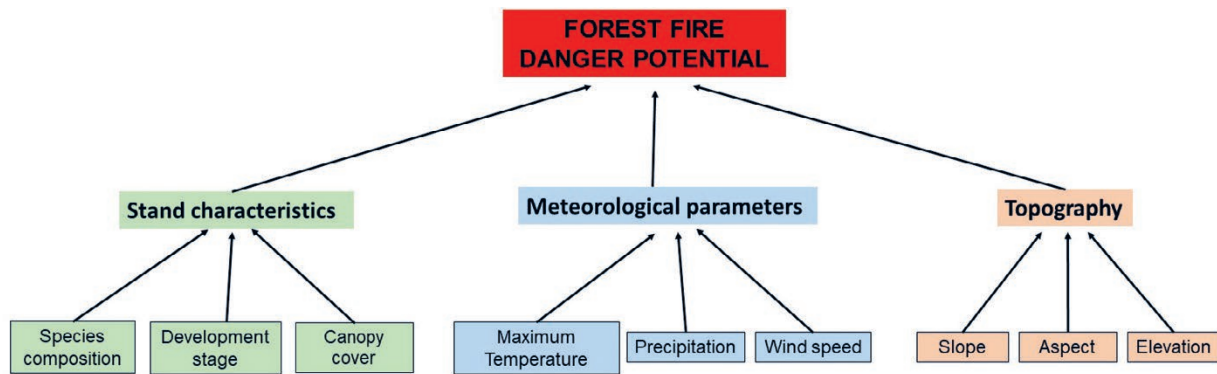
Figure 2. Hierarchy construction of forest fire danger potential (FFDP)
Slika 2. Hijerarhijska konstrukcija potencijala opasnosti od šumskog požara (POSP)

Stand characteristics – *Karakteristike šumskih sastojina*

Fuel is defined as organic material that can ignite and burn, living or dead, on the cover or top. Fuel characteristics such as the fuel type, its continuity, amount and size affect fire behavior (Kucuk et al. 2015). Fuel type affects the flammability of fuel, while fuel continuity affects fire intensity, direction, and the rate of spread. The amount of fuel also affects the burning rate (Küçük et al. 2005). In this study, species composition representing the fuel type, stand canopy cover representing the continuity and the amount of fuel, and the development stage representing fuel size were used as the explanatory variables. Stand maps in the forest management database obtained from GDF were reclassified according to tree species composition, development stage, and canopy cover, and stand characteristics variables representing fuel characteristics were prepared using the ArgGIS 10.5. Maps of stand characteristics prepared in vector format were converted to raster format.

Modeling of forest fire danger potential using AHP method – *Modeliranje potencijala opasnosti od šumskog požara AHP metodom*

Analytical Hierarchy Process (AHP) is a tool that can be used in various study topics to simplify and synthesize complexity. AHP is a multi-criteria decision-making method in which the relative weights of possible decision alternatives or outcomes are given a functional value based on a mathematical representation of pairwise comparisons (Saaty 1990). AHP includes five steps: hierarchy construction, pairwise comparisons, calculating weights, checking for consistency, and generating results (Saaty 2001).

To begin AHP, it is necessary to identify the parts of the decision that contribute to the overall outcome and construct the hierarchy. We have established a hierarchic order for FFDP in line with the classical AHP technique (Figure 2). In order to model the FFDP, the main criteria affecting the fire behavior are topography, meteorological parameters,

and stand characteristics (forest fuel properties). Nine sub-criteria related to the main criteria were determined, and a hierarchy was constructed (Figure 2).

To determine the importance of the main criteria and sub-criteria using the AHP method, the opinions of 5 fire specialists were taken and each fire specialist presented her/his own opinion according to a pairwise comparison scale (Table 1). In order to obtain the values representing the group, a pairwise comparison matrix was formed by averaging the expert opinions.

Table 1. Pairwise comparison scale (Saaty, 1990)
Tablica 1. Skala matrica uspoređivanja (Saaty, 1990)

Importance Scale Vrijednost skale	Definition of importance scale Definicija vrijednosti skale
1	Equally important – *Jednako važni*
3	Moderately important – *Umjereno važni*
5	Strongly important – *Jako važni*
7	Very strongly important – *Vrlo važni*
9	Extremely important – *Iznimno važni*
2, 4, 6, 8	Intermediate values – *Srednje vrijednosti*

We calculated the normalized weight coefficients with a total value of 1 (Table 3). After that, we calculated the consistency ratios (CR) of the matrix to determine whether the experts' answers were consistent. If the Consistency Ratio (CR) value is less than 0.1, the matrix is sufficiently consistent and can be used to calculate results. If the Consistency Ratio (CR) value is greater than 0.1, pairwise comparisons should be made again by experts to increase the consistency of the final decision.

Furthermore, the variable classes are given a fire danger level of extreme, high, medium, low, and very low according to the danger potential of each class (Jaiswal et al. 2002). Then each fire danger parameter in itself is created in ArcMap 10.5 (Esri 2017). Six maps were derived by grading from 1 to 5 by reclassification using the GIS program (Table

Table 2. Classification of relative effects of criteria.
Tablica 2. Klasifikacija relativnih učinaka kriterija.

Main criteria *Glavni kriteriji*	Sub-criteria *Podkriteriji*	Classes *Klasa*	FFDP Score *POSP vrijednost*	FFDP *POSP*
Stand characteristics *Karakteristike šumske sastojine*	**Species composition** *Vrsta drveća*	Pinus brutia	5	Extreme – *Ekstreman*
		Pinus brutia and *Pinus nigra*	5	Extreme – *Ekstreman*
		Pinus nigra, Pinus halepensis and Eucalyptus spp.	4	High – *Visok*
		Pinus brutia and *Quercus* spp	4	High – *Visok*
		Maquis – *Makija*	4	High – *Visok*
		Pinus pinea	3	Medium – *Srednji*
		Quercus spp. and *Pinus brutia*	3	Medium – *Srednji*
		Plantation fields – *Plantaže*	2	Low – *Nizak*
		Other conifers – *Ostala crnogorica*	2	Low – *Nizak*
		Angiosperms – *Kritosjemenjače*	1	Very low – *Vrlo nizak*
	Development stage *Razvojna faza sastojine*	Newly planted – *Novo posađeno* (Dbh* <8 cm)	3	Medium – *Srednji*
		Young – *Mlada* (Dbh: 8–19.9 cm)	5	Extreme – *Ekstreman*
		Mature – *Zrela* (Dbh: 20–35.9 cm)	4	High – *Visok*
		Overmature – *Prezrela* (Dbh > 36 cm)	2	Low – *Nizak*
	Canopy cover *Sklop krošanja*	< 10%	1	Very low – *Vrlo nizak*
		11 – 40%	2	Low – *Nizak*
		41 – 70%	4	High – *Visok*
		41 – 100%	5	Extreme – *Ekstreman*
	Slope *Nagib*	≤ 5%	1	Very low – *Vrlo nizak*
		5 – 10%	2	Low – *Nizak*
		10 – 20%	3	Medium – *Srednji*
		20 – 35 %	4	High – *Visok*
		> 35%	5	Extreme – *Ekstreman*
Topography *Topografija*	**Aspect** *Izloženost*	0 – 23° and 339 – 360° (North– *Sjeverna*)	1	Very low – *Vrlo nizak*
		24 – 68° (Northeast – *Sjeveroistočna*)	2	Low – *Nizak*
		69 – 113° (East – *Istočna*)	2	Low – *Nizak*
		114 – 158° (Southeast – *Jugoistočna*)	4	High – *Visok*
		159 – 203° (South – *Južna*)	5	Extreme – *Ekstreman*
		204 – 248° (Southwest – *Jugozapadna*)	5	Extreme – *Ekstreman*
		249 – 293° (West – *Zapadna*)	3	Medium – *Srednji*
		294 – 338° (Northwest – *Sjeverozapadna*)	3	Medium – *Srednji*
	Elevation *Nadmorska visina*	0–200 m	5	Extreme – *Ekstreman*
		201–400 m	4	High – *Visok*
		401–600 m	3	Medium – *Srednji*
		601–800 m	2	Low – *Nizak*
		>800 m	1	Very low – *Vrlo nizak*
Meteorological parameters *Meteorološki parametri*	**Maximum Temperature** *Maksimalna temperatura*	≥ 29 °C	5	Extreme – *Ekstreman*
		25.1 – 29 °C	4	High – *Visok*
		21.1 – 25 °C	3	Medium – *Srednji*
		17.1 – 21 °C	2	Low – *Nizak*
		≤ 17 °C	1	Very low – *Vrlo nizak*
	Precipitation *Oborine*	≤ 25 mm	5	Extreme – *Ekstreman*
		25 – 50 mm	4	High – *Visok*
		50 – 75 mm	3	Medium – *Srednji*
		75 – 125 mm	2	Low – *Nizak*
		≥ 400 mm	1	Very low – *Vrlo nizak*
	Wind speed *Brzina vjetra*	≤ 10 km/h	2	Low – *Nizak*
		10–20 km/h	3	Medium – *Srednji*
		21 km/h	5	Extreme – *Ekstreman*

*Dbh = Diameter at breast height – *Prsni promjer*

2). In the values assigned to the parameters, the value "1" indicates that the fire danger is very low, and the value of "5" means that the fire danger is extreme. FFDP maps were produced monthly using Equation 1.

To test the model accuracy, we compared the FFDP maps with fires in the period 2008–2018 (Figure 3, Table 4). After that, we did a monthly assessment for each of the fire danger classes (Table 4). We then looked at the distribution of fires that occurred between 2008 and 2018, by fire danger class, on a monthly basis.

RESULTS AND DISCUSSION
REZULTATI I RASPRAVA

In this study, we assessed the forest fire danger potential monthly during the fire season by using the AHP method as the environmental variable (i.e., meteorological parameters, topography, stand characteristics). It is necessary to determine the importance of each criterion to estimate the weights in preparing fire danger potential maps using AHP. In this study, the AHP pairwise comparison matrix was created by taking expert opinions to determine the weights of the criteria and sub-criteria. Consistency ratios (CR) of meteorological parameters, stand characteristics, and topography criteria were calculated (Table 3). According to the findings, the CR value of all criteria and sub-criteria values is less than 0.1; that is, all pairwise comparison matrices have sufficient and acceptable consistency.

While meteorological parameters were the most important main criteria affecting the FFDP with a weight of 66%, they were followed by stand characteristics with a weight of 21%. Considering the sub-criteria, the four most important factors affecting the FFDP were maximum temperature (40%), precipitation (18%), species composition (%13) and wind speed (8%) (Table 3, Equitation 1).

$$FFDP = 0.4 \times MaxTemp + 0.18 \times P + 0.08 \times WS + 0.13 \times SC + 0.04 \times CC + 0.04 \times DS + 0.04 \times S + 0.05 \times A + 0.03 \times E \qquad \text{(Eq. 1)}$$

Where:

FFDP = Forest fire danger potential

MaxTemp = Maximum temperature

P   = Precipitation,

WS = Wind speed,

SC   = Species composition,

CC = Canopy cover,

D   = Development stage,

S   = Slope,

A   = Aspect, and

E   = Elevation.

We mapped the monthly FFDP using Equation 1 by GIS. In the monthly FFDP representation on the map, we used red color for extreme fire danger, orange for high, yellow for medium, green for low, and blue for very low (Figure 3). The results showed that the fire danger potential changes significantly on a monthly basis. Forest lands in the study area of 2% in May, 50% in June, 65% in July, 61% in August, 25% in September, and 0% in October belong to the extreme danger class (Figure 3).

We performed the accuracy assessment of the model on a monthly basis. For model evaluation, we compared the fire locations from 2008 to 2018 with those on the FFDP maps and then compared the actual number of fires in each category and the fire danger class (Table 4). The results showed that the potential fire danger class of the study area was extreme (50%, 65%, and 61%, in June, July, and August, respectively). It was high in May and September (74% and 68%, respectively). In October, it was observed that the areas belonging to the medium (83%) danger class were in the majority and were more affected by the fire (Table 4). The

Table 3. Normalized weights of main criteria and sub-criteria
Tablica 3. Normalizirani ponderi glavnih kriterija i podkriterija

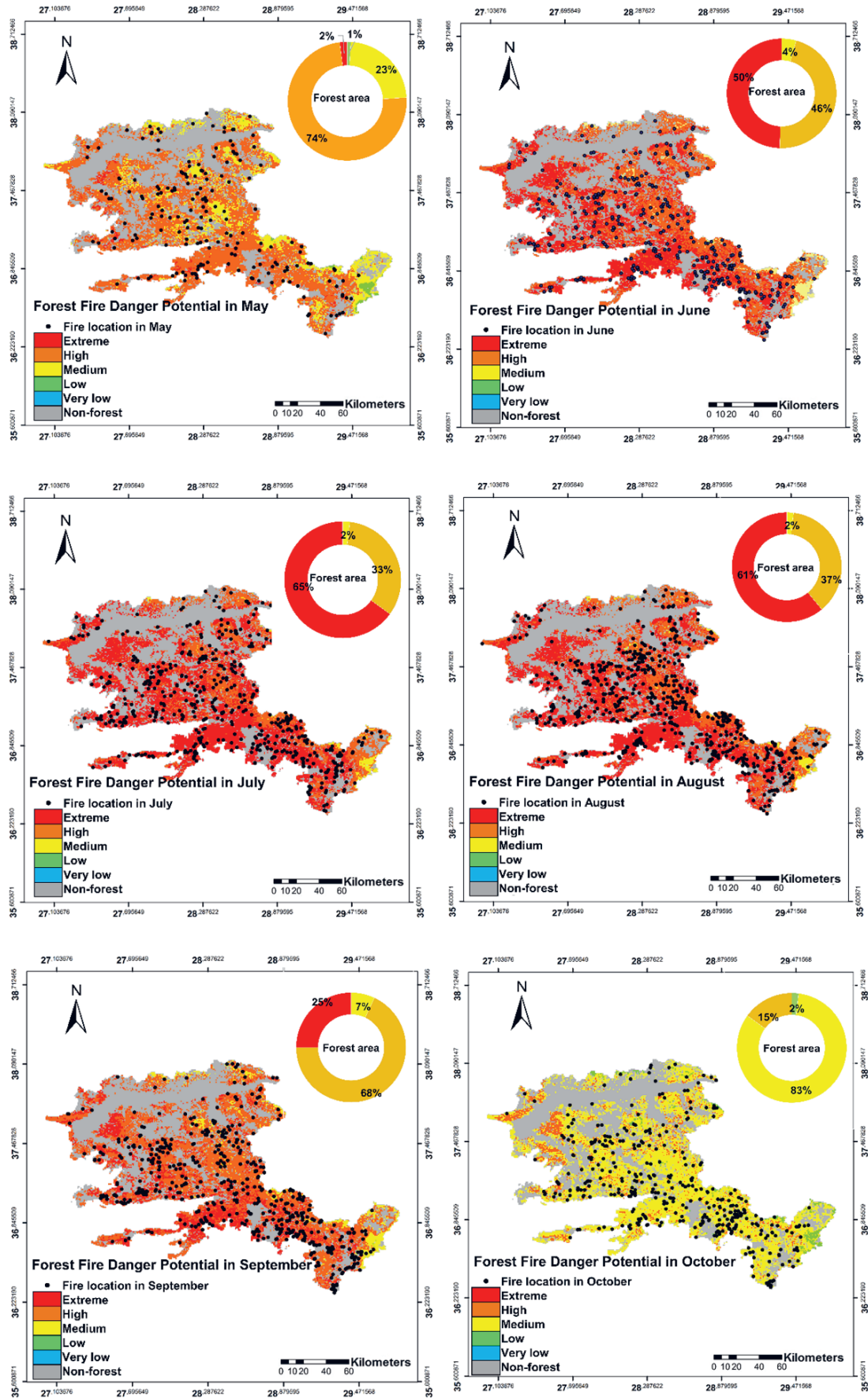| Main criteria *Glavni kriteriji*	Main criteria weight *Vrijednost glavnih kriterija*	Consistency ratio (CR) *Omjer konzistencije*	Sub-criteria *Podkriteriji*	Sub-criteria weight *Vrijednost podkriterija*	Final weight *Konačne težine*
Meteorological parameters *Meteorološki parametri*	0.66	0.064	Maximum temperature – *Maksimalna temperatura*	0.61	0.40
			Precipitation – *Oborine*	0.27	0.18
			Wind speed – *Brzina vjetra*	0.12	0.08
Stand characteristics *Karakteristike šumske sastojine*	0.21	0.008	Species composition – *Smjesa vrsta drveća*	0.63	0.13
			Canopy cover – *Sklop krošanja*	0.17	0.04
			Development stage – *Razvojna faza sastojine*	0.19	0.04
Topography *Topografija*	0.13	0.046	Slope – *Nagib*	0.33	0.04
			Aspect – *Izloženost*	0.41	0.05
			Elevation – *Nadmorska visina*	0.26	0.03

Figure 3. FFDP maps and fire location in the period 2008-2018.
Slika 3. FFDP karte i lokacija požara u razdoblju 2008.-2018.

Table 4. Potential fire danger categories of forest areas and monthly comparison of estimated FFDP maps and fires that occurred between 2008 and 2018

Tablica 4. Potencijalne kategorije ugroženosti šumskih površina od požara i mjesečna usporedba procijenjenih FFDP karata i požara koji su se dogodili u razdoblju od 2008. do 2018.

Month / Mjesec	FFDP / POSP	Total forest area / Ukupna šumska površina		Number of fires / Broj požara		Burned area / Opožarena površina		Burned area per fire – Opožarena površina po požaru
		ha	%	Number – Broj	%	ha	%	ha
May / Svibanj	Very low – Vrlo nizak	–	–	–	–	–	–	–
	Low – Nizak	12516.8	1.1	–	–	–	–	–
	Medium – Srednji	265291	22.9	27	14.3	6.3	9.4	0.23
	High – Visok	856018	73.8	149	78.8	56.7	84.3	0.38
	Extreme – Ekstreman	25099.5	2.2	13	6.9	4.2	6.3	0.32
June / Lipanj	Very low – Vrlo nizak	–	–	–	–	–	–	–
	Low – Nizak	–	–	–	–	–	–	–
	Medium – Srednji	49672	4.3	4	1.1	0.121	0.1	0.03
	High – Visok	536444.2	46.3	139	37.3	66.962	43	0.48
	Extreme – Ekstreman	572808.8	49.4	230	61.6	88.421	56.9	0.38
July / Srpanj	Very low – Vrlo nizak	–	–	–	–	–	–	–
	Low – Nizak	131.8	0.1	–	–	–	–	–
	Medium – Srednji	20817.4	1.8	4	0.7	0.75	0.1	0.19
	High – Visok	387164.7	33.3	163	28.1	213.03	19.4	1.31
	Extreme – Ekstreman	750811.1	64.8	413	71.2	883.88	80.5	2.14
August / Kolovoz	Very low – Vrlo nizak	–	–	–	–	–	–	–
	Low – Nizak	–	–	–	–	–	–	–
	Medium – Srednji	24836	2.1	8	1.2	0.63	0.1	0.08
	High – Visok	430776	37.2	216	32.4	472.535	23.9	2.19
	Extreme – Ekstreman	703313.1	60.7	443	66.4	1501.694	76	3.39
September / Rujan	Very low – Vrlo nizak	–	–	–	–	–	–	–
	Low – Nizak	461.1	0.1	–	–	–	–	–
	Medium – Srednji	75298.5	6.5	19	3.5	8.993	1.7	0.47
	High – Visok	788822.6	68.0	341	62.1	170.515	31.2	0.50
	Extreme – Ekstreman	294342.7	25.4	189	34.4	367	67.1	1.94
October / Listopad	Very low – Vrlo nizak	–	–	–	–	–	–	–
	Low – Nizak	26812.3	2.3	5	1.3	0.52	0.2	0.1
	Medium – Srednji	957338.5	82.6	308	80	151.042	70.7	0.49
	High – Visok	174774.2	15.1	72	18.7	62.055	29.1	0.86
	Extreme – Ekstreman	–	–	–	–	–	–	–

amount of burned area per fire has the highest value in the extreme danger class in August and July (3.39 ha and 2.14 ha, respectively) (Table 4). The amount of burned area was higher in areas with high and extreme fire danger classes (Table 4).

In a similar study, Saglam et al. (2008) evaluated FFDP on a spatial and temporal scale. According to the Fire Danger Potential results, 3,068 ha of the study area represented medium, 4,729 ha high, and 4,728 ha extreme danger class in 1987. By the year 2000, 597 ha of the study area represented low, 208 ha medium, 4448 ha high, 6569 ha extreme danger class. In the study area, it was emphasized that together with fire extinguishing and afforestation activities, it caused the growth and development of the forest, the accumulation of vegetation and combustible material, more continuity in the vertical and horizontal stand structure, and thus contributed to the increase of the fire danger potential between 1987-2000. Although their results are similar to our study in terms of the influence of stand characteristics and topography on fire danger potential, meteorological parameters

were also taken into account in addition to these variables in our study. The most important variable was meteorological parameters, followed by stand characteristics and topography factors, respectively.

Laneve et al. (2020) developed the Daily Dynamic Fire Danger Potential Index in Sardinia, Italy, using variables of wind speed, topography, and local solar radiation (aspect). The results showed that 17% of the study area was classified as very low, 39% as low, 26% as moderate, 13% as high, and 54% as representing extreme danger. 12% of the fires occurred in very low, 21% in low, 31% in medium, 13% in high, and 23% in extreme danger class areas. Fuel properties, topography, wind, and temperature variables used in estimating the fire danger potential are similar to those used in this study.

Sharples et al. (2009) combined meteorological information with fuel moisture content estimates to create a fire danger index. The meteorological variables used to estimate the fire danger potential are similar to this study. Unlike their study, topography and fuel characteristics were also used as variables in the modeling of fire danger potential, and it was revealed that especially fuel characteristics were among the main variables affecting fire danger.

CONCLUSION
ZAKLJUČCI

In recent years, the forests in the Mediterranean basin, including Türkiye, have been seriously affected by forest fires. Despite the increasing fire prevention efforts of the fire department, the annual number of fires and the resulting damage is increasing significantly. It has become increasingly important to reveal the danger potential of a possible fire on a spatial and temporal scale. For this reason, modeling and mapping of FFDP can help fire organizations in pre-fire management planning, firefighting efforts, and post-fire studies. FDDP can also guide the application of silvicultural treatments. Modeling and mapping of the fire danger potential was conducted using the multi-criteria decision-making method (AHP) technique by fixed and variable environmental factors such as fast and easily accessible stand characteristics, topography, and meteorological parameters as variables.

The points where the FFDP model and maps can be used are given below:

– FFDP can be predicted for a particular area based on fixed and changeable environmental factors.

– FFDP maps may help to decide to warn the public against a forest fire and restrict human activity in the forest when the fire danger is high.

– Considering FFDP can contribute to the spatial planning of forest roads and firebreaks as a preventive measure.

– FFDP can contribute to determining areas with high fire danger potential and planning silvicultural treatments such as thinning and pruning in these areas.

– The FFDP of a possible fire can be predicted, and thus, it will help to prepare an effective and successful fire suppression plan.

– Considering FFDP can contribute to the temporal and spatial planning of controlled burning treatments.

– FFDP maps that are updated in each plan period depending on the environmental factors and included in the forest management plan will be very useful to mitigate fire and damage by fire.

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SAŽETAK

Svake godine više od deset tisuća hektara šuma u Turskoj zahvati požar. Većina šumskih požara događa se u južnom dijelu Turske, gdje su rasprostranjene crnogorične šume i makija koji su skloni požarima. Šumski požari mogu dovesti do gubitka ljudskih života, imovine i prirodnih resursa. Poznavanje potencijala opasnosti od šumskog požara (POSP) ključno je za zaštitu života, imovine i prirodnih resursa od štete od požara. U radu su modelirani i mapirani POSP pomoću analitičkog hijerarhijskog procesa temeljenog na GIS-u. POSP model razvijen je na osnovi devet čimbenika okoliša za koje je poznato da utječu na ponašanje požara, uključujući maksimalnu temperaturu, oborine, brzinu vjetra,

zastupljenost drvenastih vrsta, starosnu strukturu, sklop krošanja, nagib, ekspoziciju i nadmorsku visinu. Kako bi se utvrdila važnost kriterija metodom AHP, uzeta su mišljenja protupožarnog vještaka. Nakon što su ponderi kriterija određeni na temelju mišljenja stručnjaka, POSP je izračunat i mapiran. POSP je temeljito procijenjen. Rezultati su pokazali da je POSP bio u značajnoj korelaciji s maksimalnom temperaturom, oborinama i zastupljenošću drvenastih vrsta. Osim toga, POSP se uvelike razlikuje na mjesečnoj razini. Rezultati su pokazali da je POSP bio u značajnoj korelaciji s maksimalnom temperaturom, oborinama i sastavom vrsta. Otkrili smo da se POSP uvelike razlikuje na mjesečnoj bazi. Šumsko zemljište na istraživanom području 2% u svibnju, 50% u lipnju, 65% u srpnju, 61% u kolovozu, 25% u rujnu, 0% u listopadu spada u kategoriju ekstremne opasnosti. Za procjenu modela usporedili smo lokacije požara od 2008. do 2018. s onima na kartama POSP-a i zatim kontrolirali stvarni broj požara u svakoj kategoriji i klasi opasnosti od požara. Dominantne klase opasnosti istraživanog područja prema mjesecima su: ekstremna klasa u lipnju, srpnju i kolovozu (50%, 65%, odnosno 61%), visoka klasa u svibnju i rujnu (74%, odnosno 68%) i umjerena klasa u listopadu (82%); ova je klasa opasnosti bila više pogođena požarom. Utvrđeno je da se POSP značajno mijenjao mjesečno. Opožarena površina po jednom požaru imala je najveću vrijednost u kolovozu i u srpnju (3,39 ha, odnosno 2,14 ha). Ova studija može pomoći vatrogasnim organizacijama u planiranju upravljanja prije požara, gašenju požara i studijama nakon požara.

KLJUČNE RIJEČI: opasnost od požara, model požara, Turska, šumski požari