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Forest Fire Risk Mapping Using GIS Based Analytical Hierarchy Process Approach

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Abstract

Turkiye is located in a region sensitive to forest fires due to its climate, vegetation characteristics, and topography. Every year, forest fires, for various reasons, cause burning of thousands of hectares of forest area. Fires damage the ecosystem and have economic consequences. The Mediterranean, Aegean and Marmara coasts, where the Mediterranean climate and fire-sensitive tree species dominate, are at primary risk against forest fires. For an effective fight against forest fires, it is crucial to identify zones with fire risk based on various parameters such as forest structures (tree species, crown closure, stand development class), topographic features (slope, aspect), climate, and proximity to certain points (such as roads, settlements, agricultural areas). Fire risk data will shed light on the measures that can be taken against fire. In this study, GIS (Geographic Information Systems) based Analytical Hierarchy Process (AHP) method, one of the well know Multi-Criteria Decision Making Analysis (MCDA) methods, was used to develop the fire risk map of Mersin Forestry Regional Directorate (FRD) within the Mediterranean region of Turkiye. Then, the accuracy of the fire risk map was evaluated by taking into account the previous fires in the regional directorate. As a result, the findings showed that 13.87% of the study area was classified as very high, 25.87% as high, 24.68% as medium, 22.44% a low, and 13.14% as very low risk areas. The results also indicated that tree species are the most influential risk factor in forest fires, and followed by stand development class factor. The accuracy of the fire risk map was evaluated by using the location information of a total of 562 forest fires in Mersin FRD between 2003-2022. In order to determine the accuracy of the fire risk map, the Receiver Operating Characteristic (ROC) curve method was used in the ArcGIS environment. As a result, the Area Under Curve (AUC) value was approximately 74%, which showed that the fire risk map developed for Mersin FRD was moderately reliable. With this study, it has been demonstrated that it is possible to produce reliable fire risk maps in a short time using the GIS-based AHP method.

Keywords: Forest fire, GIS, Fire risk map, AHP, ROC, Mediterranean region.

1. Introduction

Forests are renewable natural resources that have effects on climate, provide raw wood materials and non-wood forest products, carry out recreational activities, provide rich services in terms of visual and health, and most importantly, host thousands of living creatures by ensuring the atmospheric cycle for the continuation of life (Baysal, 2014). To continuously fulfill these duties, forested areas should be well protected and managed by evaluating social, environmental, economic, health, and sociocultural elements to transfer them to future generations (Wilkie, 2003). Recently, the demands of the rapidly increasing population have increased the pressure on renewable forests. Cutting down trees for economic gain and heating purposes and forest fires can be given as examples of the pressure on forest resources (Ertuğrul, 2005). The most important of these effects are forest fires, which greatly destroy forests and affect the continuity of forest resources (Bilici, 2009).

In Turkey, approximately 12 million hectares of forest area along the coastline, starting from Kahramanmaraş in the east of the Mediterranean Region and continuing to the Marmara Region, are sensitive areas in terms of forest fires. About 140,000 hectares of forest area were burned due to big wildfires in 2021. According to the statistical results of forest fires between 2004 and 2021, Forestry Regional Directorates (FRD) of Antalya, Muğla, İzmir, Mersin, and Kahramanmaraş are in the top five rankings according to annual averages on an area basis (GDF, 2022).

In order to effectively combat forest fires, it is necessary to determine areas with varying fire risks depending on risk factors such as forest structures, topographic conditions, proximity to certain points, and

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climate (Carmel et al., 2009). Forest structures determining fire risk are tree species, crown closure, and stand development class (Gao et al., 2011). One of the most important factors affecting fire risk is tree species. Coniferous trees can quickly catch fire and burn due to their high resin and low moisture content. Deciduous species are more fire-resistant due to their high moisture content (Gazzard, 2012). As the cover of the stand increases, the density of flammable materials also increases, and any fire that may break out can easily turn into a hill fire and spread quickly. For this reason, stands with high crown closure are riskier in terms of fire (Küçük et al., 2009). Another forest structure is stand development class. While young stands are at high risk in terms of forest fires, old forests are at lower risk (Bilgili, 2003; Sağlam et al., 2008).

Topographic structure is one of the important factors affecting forest fires. Knowing the characteristics of the topographic structure, such as land shape, slope, aspect, and elevation provides information on the outbreak of fire, its spread rate, and fire direction (Şakar, 2010). Areas with high slopes are at high fire risk, and the fire spreads faster uphill on steep slopes (Bonora et al., 2013). Since the aspect factor affects the temperature and humidity rate, it reflects the risk of fire as well. Since the humidity is low in southern aspects, the risk of fire is higher (Lin and Rinaldi, 2009).

Another factor highly affecting forest fires is climate conditions. Climate factors such as temperature values, rainfall amount, and wind direction and intensity affect forest fire risk. As the air temperature increases, flammable substances heat up and reach the ignition temperature fast. In this case, forest fires tend to spread rapidly (Çanakçıoğlu, 1993). Since precipitation affects the moisture content of flammable materials, the summer season, when precipitation is low, is very risky in terms of forest fires. Winds, which quickly transport the heat and gases generated during a fire to flammable materials (Küçük et al., 2009), are another climate parameter that affects the fire risk. High wind intensity causes the fire to spread over a wide area quickly by carrying the flames over long distances, increasing the area affected by the fire (Çanakçıoğlu, 1993). Additionally, since human activities are high in areas close to road networks, settlements, and agricultural areas, these forest areas are more risky in terms of fire (Jaiswal et al., 2002).

In order to minimize the ecological and economic negativities caused by forest fires, fire risk areas should be determined spatially, and precautions should be taken to intervene in these areas before a fire breaks out or grows (Akay and Erdoğan, 2017). It is essential to use advanced technologies commonly used in every field today, in forest fires. Remote sensing, artificial intelligence, geographic information systems, and decision support systems are used by fire organizations around the world (Bilgili and Küçük, 2002). The use of these systems enables data to be obtained in order to fight most effectively before and during a fire. The GIS techniques enable us to generate fire risk maps of large areas evaluating various data layers in a short time (Erten et al., 2005). GIS techniques have been integrated with MCDA to make fire risk maps fast and effective over time (Carmel et al., 2009). There are previously conducted studies where various GIS-based MCDA methods such as AHP, fuzzy logic, fuzzy AHP, and artificial neural network (ANN) were used to generate fire risk maps (Ateşoğlu, 2014; Sati et al., 2016; Eskandari, 2017; Silva et al., 2020). Among others, AHP is one of the most commonly used MCDA methods to analyze complex spatial information in forest areas. Sivrikaya and Küçük (2022) conducted a study in which GIS-based MCDA method utilizing the AHP was used to generate forest fire risk map. The AUC score of their risk map was 77.5%, which indicated that the fire risk map produced a reliable result.

In this study, the AHP method was used together with GIS techniques to produce a forest fire risk map, taking into account factors such as tree species, crown closure, stand development class, slope, aspect, and proximity to roads, settlements, and agricultural areas. The study was carried out within the borders of Mersin FRD, where forests are mostly sensitive to forest fires.

2. Material and Methods

2.1. Study Area

The study was conducted within the borders of Mersin FRD, which covers the city of Mersin, located in the Mediterranean region of Turkiye (Figure 1). In terms of forest conditions in the Mersin FRD, about 56% of the forest area (468.129 ha) was classified as productive forest, while 44% (367.405 ha) was degraded. The dominant tree species in the region is *Pinus brutia*, and there are also *Pinus nigra*, *Juniperus* L., and some of the broadleaves in maquis formation. About 87% of Mersin FRD is hilly, with a high elevation of 3524 m. In Mersin, summers are hot and humid, and winters are warm and rainy. The average annual precipitation and the temperature is 1095 mm and 22 °C, respectively.

2.2. GIS Database

The forest fire risk map was generated using a GIS database based on spatial data layers of specified fire risk factors. Forest fire risk factors used in the study were tree species, crown closure, stand development class, slope, aspect, and proximity to roads, settlements, and agricultural areas. Climate parameters were not directly used in fire risk assessments, and the climate effect was represented by some factors (i.e., aspect, tree type) in the study. ArcGIS 10.8 program was used to perform GIS analyses.

2.2.1. Forest Structures

Tree species, crown closure and stand development class data were evaluated as forest structures affecting forest fire risk. Digital data layers for factors related to forest structures were generated based on the digital stand map (1:25000) obtained from Mersin FRD. Since there are many tree species and stand types, a tree species map was produced by categorizing the tree species according to their risk levels. Stand crown closure map was generated based on four classes, including bare-land (degraded forests) (0-10%), sparse (11-40%), moderate (41-70%) and dense (>70%) areas. Stand development classes were categorized into six classes, including young (A), middle-aged (B), maturing (C), mature (D), over-mature (E), and degraded areas that were not included in the stand development classes.

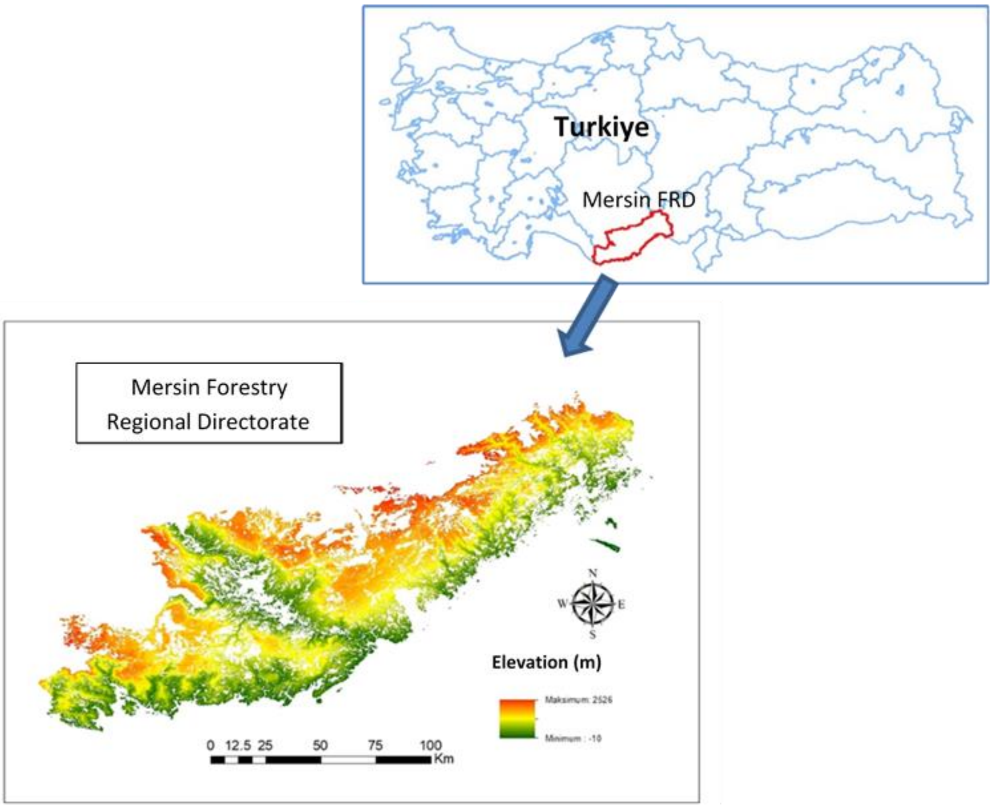

Figure 1. Study area.

2.2.2. Topographic factors

A Digital Elevation Model (DEM) was produced using the contour line map (10 m) obtained from Mersin FRD. Then, the slope and aspect maps of the study area were produced based on the DEM. The slope map was evaluated in five classes: gentle (0-5%), low (5-15%), medium (15-25%), high (25-35%), and steep (>35%). The aspect map was divided into nine classes as flat: N, NW, W, SW, S, SE, E, and NE.

2.2.3 Proximity to certain points

In order to determine the fire risk levels of forests, their proximity to roads, settlements, and agricultural areas adjacent to the forest was taken into account. The data layer of road networks was obtained from Mersin FRD. The stand-type map of the regional directorate was used to obtain digital data layers of settlements and agricultural areas. Then, with the "Buffer" command in the ArcGIS 10.8 program, five buffer zones of 100 m, 200 m, 300 m, 400 m, and > 400 m were generated around roads, settlements, and agricultural areas bordering the forest (Sivrikaya et al., 2011).

2.2.4. Fire points data layer

In order to evaluate the accuracy of the fire risk map developed within the scope of the study, coordinate information regarding fires that occurred in areas of 0.5 ha and larger within the study area between 2003 and 2022 was obtained from Mersin FRD. Then, in light of this information, a digital data layer showing fire points was produced.

2.3. Analytical Hierarchy Process Method

In the study, a forest fire risk map was developed using the AHP method. Each cluster of elements forming the phased structure defines a hierarchy level in the AHP method (Saaty, 1977). In this structure, there is the main goal at the top level, the upper and lower criteria necessary to ensure the realization of this goal at the bottom layer, and the alternatives at the bottom level.

In the AHP application, criteria such as tree species, crown closure, stand development class, slope, aspect, proximity to roads, settlements, and agricultural areas were evaluated as the main criteria. In the hierarchical system, the degree of influence of the components on each other is determined by pairwise comparisons within the criteria. In pairwise comparison, the relative importance scale is used to indicate numerically the importance levels of the factors. In this study, the 1-9 relative importance scale, which is the most preferred and gives good results, was used (Saaty, 1977) (Table 1).

Table 1. Relative importance scale in the AHP method

Importance level	
1	Equal importance
3	Weak importance of one over another
5	Essential or strong importance
7	Demonstrated importance
9	Absolute importance
2, 4, 6, 8	Intermediate values between the two adjacent judgments

Pairwise comparisons are made with the decision of the expert or experts who conduct research on the subject. Decision makers can be one or more people (Özden, 2008). Since there may be some drawbacks in terms of consistency when many people are decision makers, having a single person as a decision maker ensures that decisions are made more consistently and gives more positive results. In this study, therefore, pairwise comparisons were made by a single person. The consistency of pairwise comparisons made by decision-makers is evaluated by calculating the consistency ratio (*CR*) (Equation 1). The consistency ratio was obtained by dividing the consistency index (*CI*) by the correction value, which is called the random index (*RI*). The consistency index is defined as a function from the set of the judgmental matrices to the set of the real numbers (Pant et al., 2022). Table 2 indicates the *RI* values given depending on the number of criteria as suggested by Saaty (1980). If the *CR* value is less than 0.10, it shows that the decision maker is consistent, and if it is greater than 0.10, it shows that the decision maker is inconsistent.

$$CR = \frac{CI}{RI} \quad (1)$$

In the final stage of AHP, the relative importance values of the alternatives are determined in terms of the general purpose. At the decision stage, the forest fire risk level was determined by comparing the relative importance values of the alternatives. Risk levels evaluated in the study were very low risk, low risk, medium risk, high risk and very high risk. For this purpose, the “extAhp 2.0” extension, which allows AHP application in the ArcGIS 10.8 environment, was used.

Table 2. The random index *(RI)*

n	*RI*	n	*RI*
1	0.00	8	1.41
2	0.00	9	1.45
3	0.58	10	1.49
4	0.90	11	1.51
5	1.12	12	1.54
6	1.24	13	1.56
7	1.32	14	1.57

2.4. Accuracy of the Fire Risk Map

The accuracy of the fire risk map generated with AHP was evaluated with the ROC (Receiver Operating Characteristic) curve method. The ROC curve method was first used in studies on electronic signal identification and radar problems in the 1950s. The ROC curve method, which has been used effectively in many different disciplines in the following years, has also been applied to evaluate the accuracy of various risk maps (Satir et al., 2016; Silva et al., 2020; Sivrikaya and Küçük, 2022). In the ROC curve method, is a graphical approach, the x-axis shows the false positive rate (1-specificity) and the y-axis shows the true positive rate (sensitivity). The ROC curve is a graphical technique to interpret the relationship between specificity and sensitivity. A large area under the ROC curve (Area Under Curve - AUC) indicates the statistical success of the prediction ability. An AUC value of one indicates a perfect prediction. In interpreting the areas under the curve, the AUC value is divided into five categories: weak (0.5–0.6); medium (0.6–0.7); good (0.7–0.8); very good (0.8–0.9); and excellent (0.9–1.0) (Yeşilnacar, 2005; Gheshlaghi et al., 2020). Within the scope of the study, to test the accuracy of the developed fire risk map, the "ROC_ArcSDM" extension, which allows ROC curve application in the ArcGIS 10.8 environment, was used, considering the digital data layer of forest fires occurring within the borders of Mersin FRD.

3. Results

Land use types map and forest areas map within the border of the study area were produced from the Mersin FDR stand map in ArcGIS 10.8. The largest land use type in Mersin FRD was forest areas (53.5%), followed by agricultural areas (27.90%) and forest soil-stony areas (12.39%). In terms of tree species, Mersin FRD has a very wide species number and composition. These species mostly include Red pine, Black pine, Cedar, Fir, Juniper, Oak, Stone pine, Eucalyptus, Maquis, Cypress and Coast pine, and there are other deciduous species such as Laurel, Carob, Walnut, Plane tree, False acacia and Almond. There are also mixed stands of tree species. Considering the ratio of tree species in the total forest area, Red pine took the first place with 35.25%, Cedar took the second place with 4.45% and Juniper took the third place with 4.31%.

In the study, tree species were divided into eight classes according to fire risk degree, and a tree species map was generated using the stand type map (Figure 2). The class with the largest area in the study area, with 48.7%, consists of pure Red pine and a mixture of Red and Stone pine. It is followed by the third and fourth classes, with 19.4% and 12.9%, respectively (Table 2).

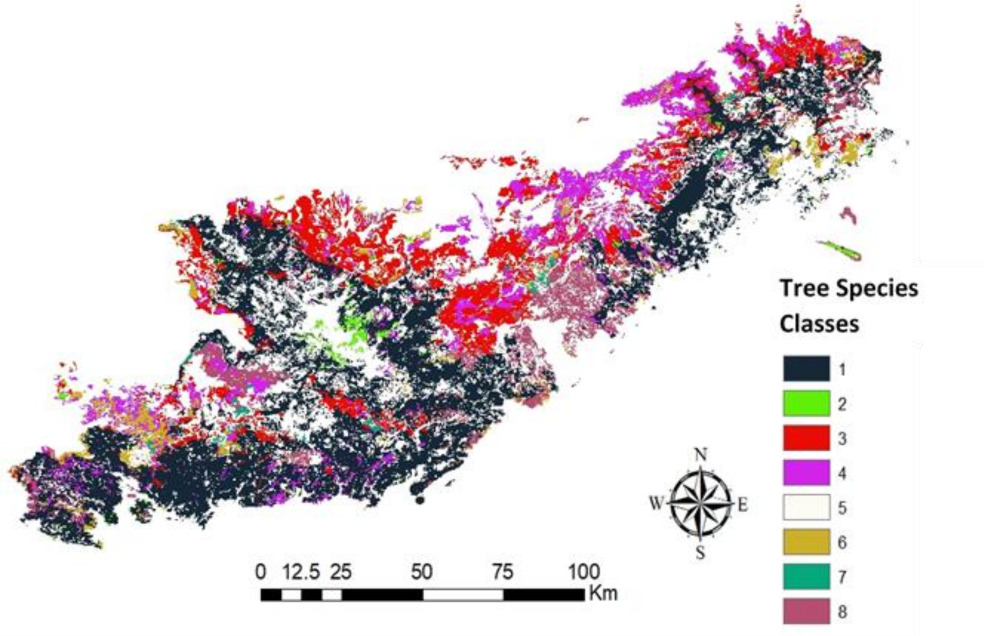

Figure 2. Tree species classes map

Table 2. Tree species and species compositions

Tree species classes	Tree species compositions	Area (%)
1	Red pine, Red pine-Stone pine	48.7
2	Stone pine, Red pine-Black pine, Red pine-Juniper	1.5
3	Black pine, Black pine-Cedar, Red pine-Cedar, Juniper, Black pine-Juniper	19.4
4	Cedar, Cedar-Black pine, Cedar-Juniper, Red pine-Fir, Red pine-Oak, Black pine-Oak, Red pine-Other deciduous, Red pine-Other coniferous	12.9
5	Juniper-Fir, Black pine-Fir, Juniper-Oak, Oak-Red pine, Oak-Black pine, Carob-Red pine	3.6
6	Fir-Cedar, Oak-Juniper, Laurel, Carob, Laurel-Carob	4.3
7	Fir, Carob-Fir, Carob-Other deciduous, Cedar-Oak, Cedar-Other deciduous, Cypress	0.9
8	Oak, Other deciduous, Maquis, Eucalyptus, Private afforestation	8.7

A digital data layer of crown closure was produced from stand features. When the closure values of the stands in the study area are examined, it was found that 44.21% of the forest area was bare-lands, 26.26% was sparse, 15.67% was moderate, and 13.86% was dense stands (Figure 3). When the stand development classes map was examined, it was seen that 12.82% of the forest area was young, 19.57% was middle-aged, 10.79% was maturing, 12.52% was mature, and 0.10% was over-mature (Figure 4).

According to the slope map developed using the DEM of the study area, 3.42% of the forest area consisted of slope class of 0-5%, 18.32% was 5-15%, 19.11% was 15-25%, 15.71% was 25-35%, and 43.44% consists of slope classes above 35%. It was determined that the slope in the area was relatively high, and the average slope was 36.53% (Figure 5). According to the aspect map developed using the DEM of the study area, it was seen that 20.20% of the forest area was in the southern aspect, and 15.68% was in the eastern aspect. Fire risk is considered high since the humidity rate decreases in the southern and southeastern aspects (Lin and Rinaldi, 2009). It was also found that 18.91% of the area was in flat areas (Figure 6).

Buffer zones were generated in forest areas to determine forest fire risk according to the proximity to roads, settlements, and agricultural areas bordering the forest. The buffer zones were located sides along the forest roads on both sides using the road network map obtained from Mersin FRD. According to the results, 19.38% of the forest area was 0-100 m away from roads, while 18.70% was 100-200 m, 13.34% was 200-300 m, 9.74% was 300-400 m, and 32.99% of them was found to be more than 400 m away from roads (Figure 7).

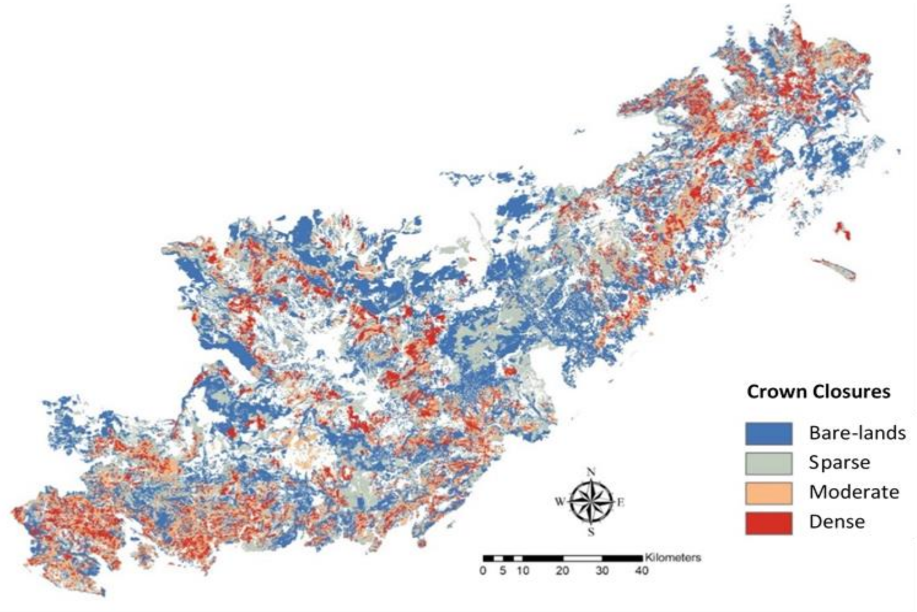

Figure 3: Crown closure map

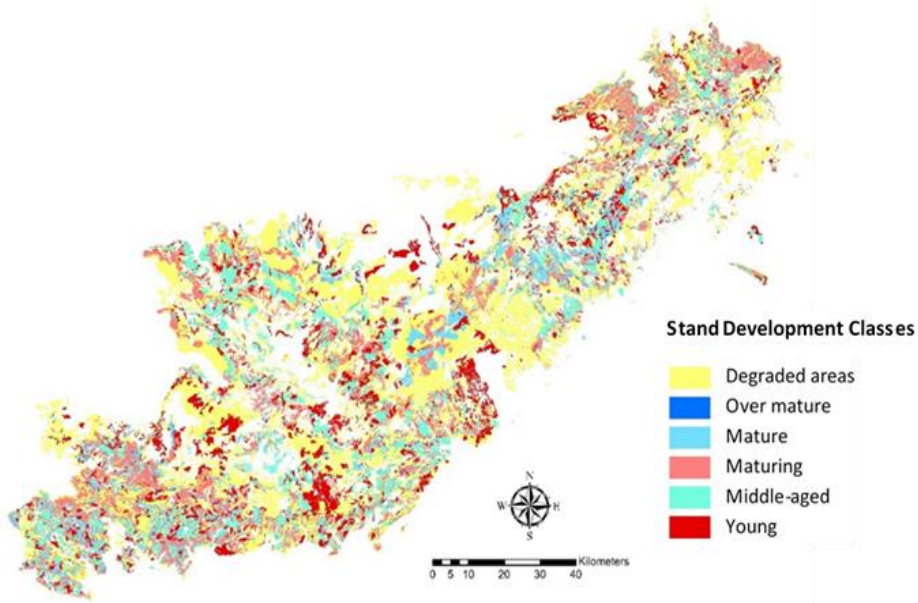

Figure 4. Stand development class map

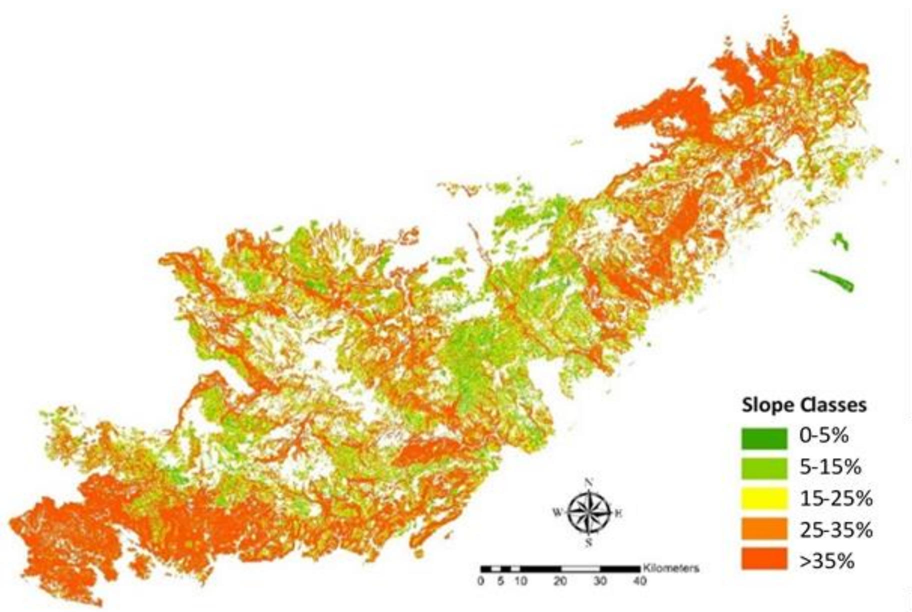

Figure 5. Slope classes map

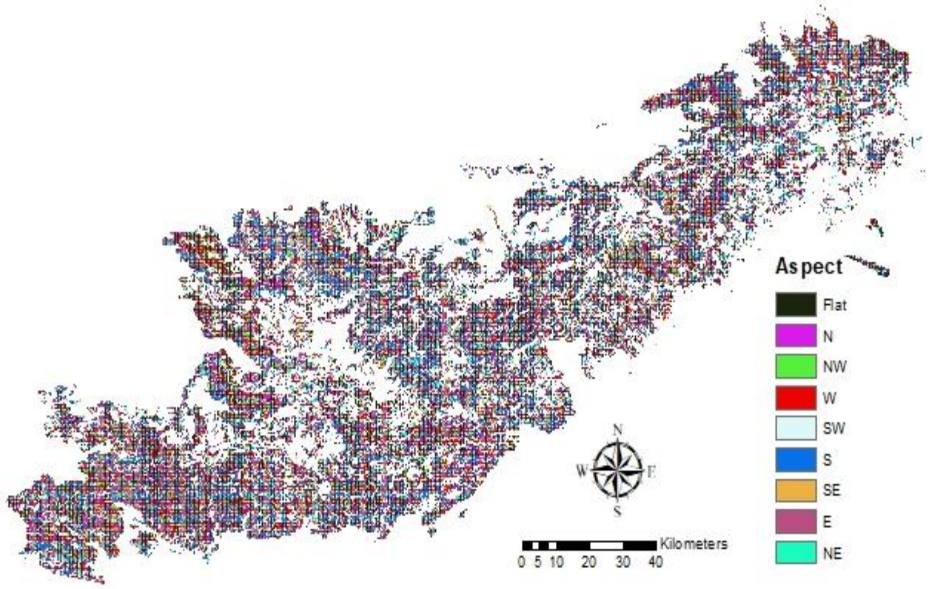

Figure 6. Aspect map

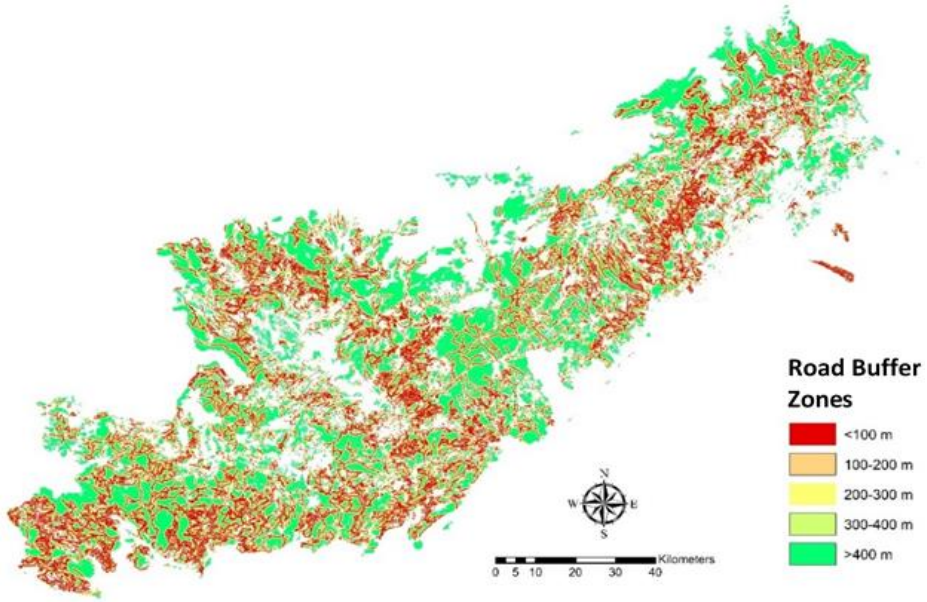

Figure 7. Road buffer zone map

According to the data layer developed for the proximity factor to settlements, it was seen that 95.25% of the forest areas in the study area were more than 400 m away from settlements (Figure 8). According to this data, it has been determined that forest areas were generally far from settlements.

After determining the agricultural areas on the stand type map, the data layer of the agricultural areas bordering the forest areas was produced in ArcGIS 10.8 (Figure 9). The results showed that 27.39% of forest areas were within 100 m of agricultural areas, 15.51% were within 100-200 m, 10.76% were within 200-300 m, 8.03% were within 300-400 m, and 38.31% of them were determined to be more than 400 m away from agricultural areas. Considering that human interaction is high in agricultural areas, and most of the fires are human-caused, it has been determined that the fire risk is high in the study area close to agricultural areas (Jaiswal et al., 2002).

A total area of 21,682.83 ha was affected by 562 forest fires (≥0.5 hectares) between 2003 and 2022 in Mersin FRD. Table 3 shows the distribution of fires according to Forest Enterprise Directorates in Mersin FRD. The data layer showing fire locations is given in Figure 10.

4. Discussion

4.1. Fire Risk Factors

For the tree species factor, AHP results indicated that the potential forest fire risk value was highest in Red pine and Red pine-Stone pine stands, followed by mixed stands of Red pine with Stone pine, Black pine, and Juniper species (Table 4). Stands containing Maquis and other deciduous species had the lowest risk value. A similar study by Akay and Erdoğan (2017) reported that the highest fire risk values were seen in coniferous forests, while oak and other deciduous species had a low fire risk.

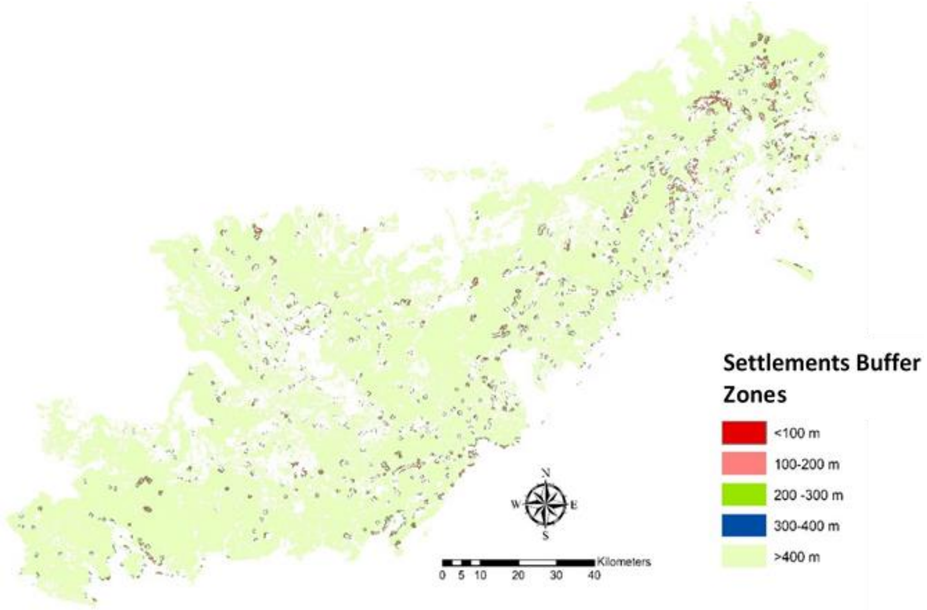

Figure 8. Settlements buffer zone map

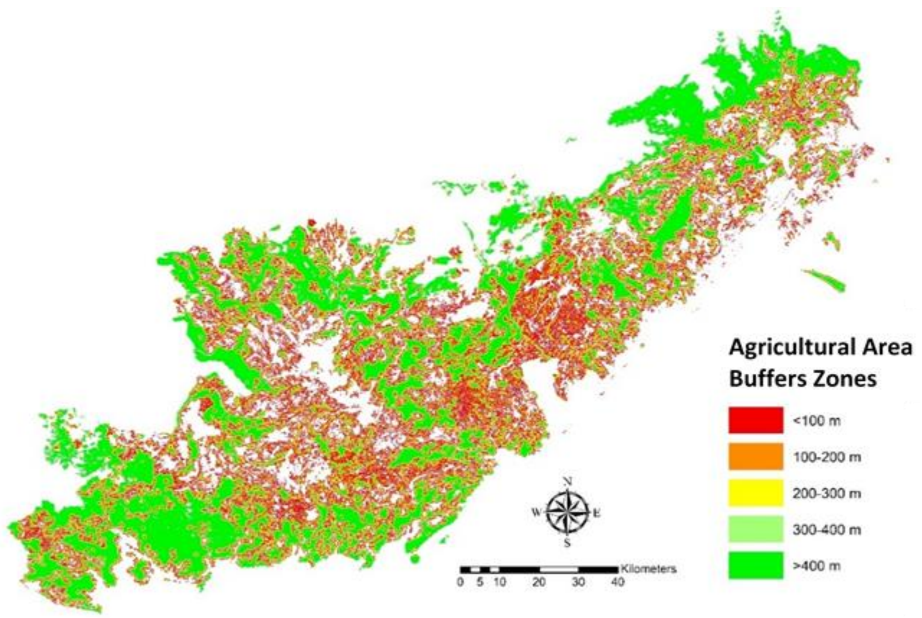

Figure 9. Agricultural areas buffer zone map

Table 3. Fire data according to Forest Enterprise Directorates (2023-2022)

Forest Enterprise Directorates	Number of fires	Burned areas (ha)
Anamur	64	1,715.07
Bozyazı	60	401.90
Erdemli	37	153.45
Gülnar	92	14,402.97
Mersin	48	100.38
Mut	62	156.11
Silifke	113	4,468.56
Tarsus	86	284.39
Total	562	21,682.83

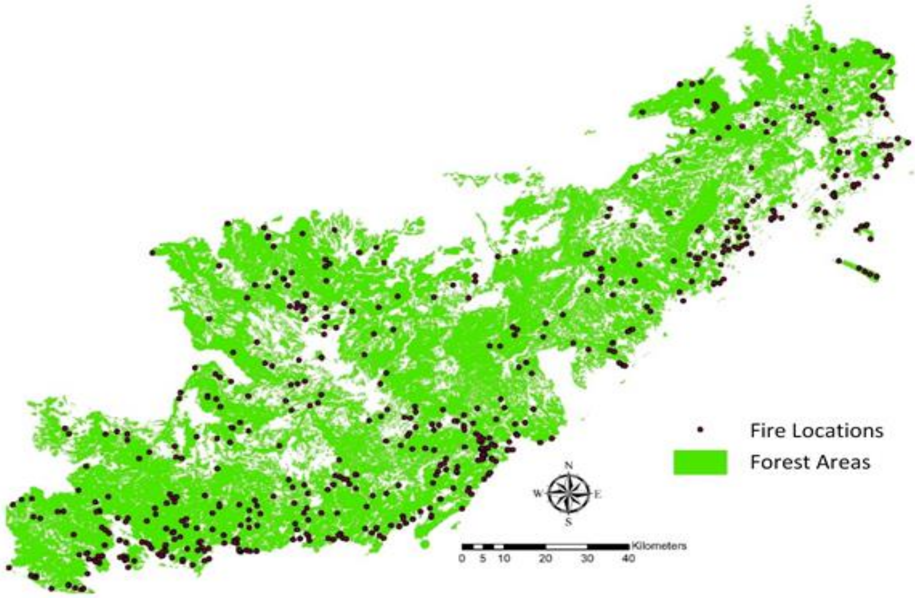

Figure 10. Locations of forest fires in the study area

Table 4. Importance values for potential fire risk by tree species

Tree species compositions	Importance values
Red pine, Rep pine-Stone pine	0.33
Stone pine, Red pine-Black pine, Red pine-Juniper	0.23
Black pine, Black pine-Cedar, Red pine-Cedar, Juniper, Black pine-Juniper	0.16
Cedar, Cedar-Black pine, Cedar-Juniper, Red pine-Fir, Red pine-Oak, Black pine-Oak, Red pine-Other deciduous, Red pine-Other coniferous	0.11
Juniper-Fir, Black pine-Fir, Juniper-Oak, Oak-Red pine, Oak-Black pine, Carob-Red pine	0.07
Fir-Cedar, Oak-Juniper, Laurel, Carob, Laurel-Carob	0.05
Fir, Carob-Fir, Carob-Other deciduous, Cedar-Oak, Cedar-Other deciduous, Cypress	0.03
Oak, Other deciduous, Maquis, Eucalyptus, Private afforestation	0.02

For the crown closure factor, it was observed that dense forests had the highest risk value, while the risk was at the lowest level in bare-lands (Table 5). Previous studies also stated that forest fire risk increases in areas with a high percentage of crown closure (Küçük et al., 2009). Besides, the dense stands can have relatively more dead organic material than younger stands, which increases the potential for transforming surface fire into crown fires. In terms of stand development classes, it was determined that the middle and the young stand development classes had high importance levels. The importance values were very low in the mature and over-mature stand development classes (Table 6). Forest fire risks are higher in early stand development classes, while risks tend to decrease in mature classes (Sağlam et al., 2008).

When looking at the importance values for slope, it was seen that forest areas with a slope above 35% had the highest risk value (Table 7). Previous studies also suggested that slope has an important effect on fire risk, and the risk increases as the slope increases (Bentekhici et al., 2020).

In terms of aspect, it was determined that the south and southwest aspects had the highest values, while the north and northeast aspects and flat areas had the lowest values (Table 8). Aspect is one of the key topographic factors that plays a significant role in forest fires as it next to roads, humidity and temperature (Sari, 2021).

Forest fire risk increases in forest areas near settlements and agricultural areas. The importance level of buffer zones produced for roads, settlements, and agricultural areas according to fire risk are given in Tables 9, 10, and 11. For these three areas, it was observed that the risk of fire in buffer zones increased as the distances to forests decreased.

Table 5. Importance values for potential fire risk by crown closure

Crown closure	Importance values
Bare-land	0.05
Sparse	0.10
Moderate	0.28
Dense	0.57

Table 6. Importance values for potential fire risk by stand development classes

Stand development classes	Importance values
Young	0.27
Middle	0.40
Maturing	0.19
Mature	0.07
Over mature	0.03

Table 7. Importance values for potential fire risk by slope classes

Slope classes	Importance values
0-5%	0.03
5-15%	0.07
15-25%	0.13
25-35%	0.26
>35%	0.50

Table 8. Importance values for potential fire risk by aspect

Aspect	Importance values
Flat	0.03
N	0.03
NE	0.03
E	0.06
SE	0.10
S	0.31
SW	0.31
W	0.06
NW	0.06

Table 9. Importance values for potential fire risk by proximity to roads

Proximity to roads	Importance values
<100 m	0.51
100 – 200 m	0.28
200 – 300 m	0.12
300 – 400 m	0.06
>400 m	0.04

Table 10. Importance values for potential fire risk by proximity to settlements

Proximity to settlements	Importance values
<100 m	0.50
100 – 200 m	0.26
200 – 300 m	0.13
300 – 400 m	0.07
>400 m	0.03

Table 11. Importance values for potential fire risk by proximity agricultural areas bordering forests

Proximity agricultural areas	Importance values
<100 m	0.45
100 – 200 m	0.30
200 – 300 m	0.15
300 – 400 m	0.07
>400 m	0.04

4.2. Fire Risk Map and its Validation

In the final stage, the fire risk map was generated by combining the weighted averages of the criteria using the "extAhp 2.0" plug-in in the ArcGIS 10.8 program (Figure 11, Table 12). It has been determined that the most effective criterion for forest fire was tree species, and followed by the stand development class. A similar study conducted by Sivrikaya and Küçük (2022) stated that tree species was the first significant criterion to affect forest fire risk. The criteria of crown closure, slope, proximity to settlements, and agricultural areas bordering the forest had similar importance values on the risk of forest fire risk. In contrast, proximity to roads and the aspect had a relatively lower effect on the fire risk. When the average importance values of three main criteria were considered, it was revealed that the main factor affecting forest fire risk was forest structures (0.194), followed by proximity to certain points (0.091) and topographical factors (0.073). In previous studies, forest structures were the most important parameters (Suryabhagavan et al., 2016), while topographical factors were the least important (Eskandari, 2017).

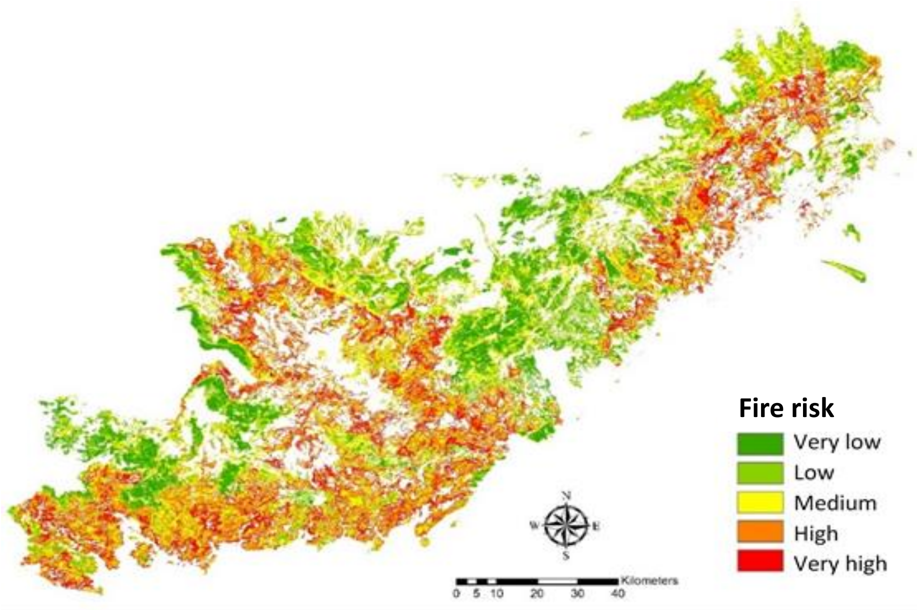

Figure 11. Fire risk map

Table 12. Importance values for potential fire risk by the main criteria

Main criteria	Importance values
Tree species	0.291
Crown closure	0.106
Stand development class	0.186
Slope	0.106
Aspect	0.039
Proximity to roads	0.060
Proximity to settlements	0.106
Proximity agricultural areas	0.106

When the results of the GIS-based AHP method were examined, it was seen that approximately 40% of the forests in the study area had a very high and high forest fire risk, and 35.5% had a very low and low fire risk (Table 13). During the validation phase of the fire risk map, the accuracy of the map was evaluated using the ROC curve method based on the locations of the previous forest fires in Mersin FRD. The results showed that the AUC value was 74%. According to these results, the fire risk map developed for the Mersin Regional Directorate of Forestry was moderately reliable (Figure 12). In previous studies where fire risk map was generated based on similar fire risk factors, the AUC values ranged from 76% to 80% (Adab, 2017; Ghorbanzadeh et al., 2019; Sivrikaya and Küçük, 2022). In the final stage, the fire data of the study area, which occurred in areas of 0.5 hectares and larger between 2003 and 2022, overlapped with the fire risk map. In the risk map of a total of 562 forest fires, 36.65% of the fires were very high, and 35.05% were high fire risk zones (Table 14).

Table 13. Areal distribution of fire risk levels

Fire risks	Area (%)
Very low	13.14
Low	22.44
Medium	24.68
High	25.87
Very high	13.87

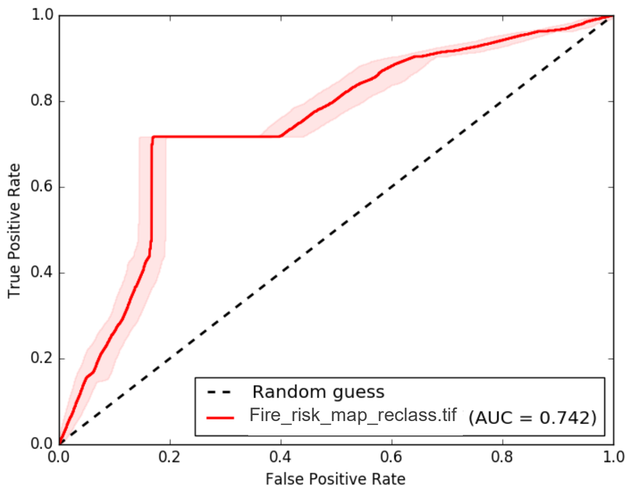

Figure 12. ROC curve of fire risk map

Table 14. The number of forest fires between 2003-2022 according to risk levels

Fire risks	Number of fires
Very low	21
Low	33
Medium	105
High	197
Very high	206

5. Conclusions

A risk map was generated using the GIS-based AHP method for Mersin FRD, which is located in a risky area in terms of forest fires in the Mediterranean region of Turkiye. Fire risk factors, including forest structures (i.e., tree species, crown closure, stand development class), topographic factors (i.e., slope and aspect), and proximity to certain points (i.e., roads, settlements and agricultural areas adjacent to the forest) were evaluated in implementation of AHP method. Five alternative risk levels were taken into account to determine the fire risk level of forest areas in the study area: very low, low, medium, high, and very high risk areas. According to the risk map produced as a result of the study, it was determined that approximately half of the forests in the study area remained in very high and high areas in terms of forest fire.

ROC curve was developed in ArcGIS 10.8 environment to determine the accuracy of the fire risk map. As a result of the analysis, the AUC value was found to be 74%. In addition, the numerical data of the previous fires that occurred in Mersin FRD between 2003 and 2022 were superimposed with the fire risk map of the study area. The results showed that approximately 71.71% of the previous fires were located in high and very high areas. The results indicated that the AHP method provided accurate and reliable results for the study area according to the ROC curve analysis and spatial analysis of fires.

Predetermination of the risk values of forest fires guides decision-makers about what course of action to follow before, during and after the fire. With this study in Mersin FRD, in which forests are primarily sensitive to fires, forest fires can be fought in the most effectively by taking the necessary precautions according to the risk levels determined. Fire action plans should be reviewed, and fire organization should be formed, considering risk levels to combat forest fires. The fire risk maps should be used in many fire prevention activities, such as deploying firefighting teams and determining the number of teams according to risk areas. Besides, they can be used to evaluate the efficiency of road networks and the adequacy and proximity of water resources in risky areas. The optimum location of fire-watch towers with a wide view of especially risky areas can be determined based on fire risk maps. Furthermore, locating a buffer zone between forest areas, residential areas, and agricultural areas in risky areas can be carried out using the fire risk map.

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References

Adab, H. 2017. Landfire hazard assessment in the Caspian Hyrcanian forest ecoregion with the long-term MODIS active fire data. *Natural Hazards*, 87(3):1807–1825.

Akay, A.E., Erdoğan, A. 2017. GIS-based multi-criteria decision analysis for forest fire risk mapping. In 4th International Geoadvances Workshop-Geoadvances 2017: ISPRS Workshop on Multi-Dimensional & Multi-Scale Spatial Data Modeling. October 14-15. Safranbolu, Turkiye.

Ateşoğlu, A. 2014. Forest hazard identifying, mapping using satellite imagery-geographic information system and analytic hierarchy process: Bartin-Turkey. *J. Environ. Prot. Ecol.* 15(2):715–725.

Baysal, İ. 2014. Integration of forest fires into forest management planning. PhD. Thesis, Karadeniz Technical University, Trabzon. 128 p.

Bentekhici, N., Bellal, S., Zegrar, A. 2020. Contribution of remote sensing and GIS to mapping the firerisk of Mediterranean forest case of the forest massif of Tlemcen (North-West Algeria). *Nat. Hazards*, 104:811–831.

Bilgili, E. 2003. Stand development and fire behavior. *Forest Ecology and Management,* 179(1-3), 333-339.

Bilgili, E., Küçük, Ö. 2002. Determination of forest fires with remote sensing technique. GAP IV. Engineering Congress 06-08 June, Şanlıurfa, Turkiye.

Bilici, E. 2009. A Study on the Integration of Firebreaks and Fireline with Forest Roads Networks and It's Planning and Construction (A Case Study of Gallipoly National Park), *Istanbul University. Faculty of Forestry Journal* Series: A 59(2):86-102.

Bonora, L., Conese, C., Marchi, E. 2013. Wildfire occurrence: integrated model for risk analysis and operative suppression aspects management. *Am. J. Plant Sci.* 4:705–710.

Carmel, Y., Paz, S., Jahashan, F., Shoshany, M. 2009. Assessing fire risk using Monte Carlo simulations of fire spread. *Forest Ecology and Management*, 257(1):370-377.

Çanakçıoğlu, H. 1993. Forest Conservation. Istanbul University, Faculty of Forestry Press. Istanbul, Turkiye.

Erten, E., Kurgun, V., Musaoğlu, N. 2005. Forest fire risk zone mapping by using satellite imagery and GIS. TMMO Chamber of Surveying and Cadastre Engineers. 10th Turkish Mapping Scientific and Technical Congress. 28 March - 1 April. Ankara, Turkiye.

Ertuğrul, M. (2005). The Situation of Forest Fires in the World and in Turkey. *ZKÜ Bartın Faculty of Forestry Journal*. 7(7):43-50.

Eskandari, S. 2017. A new approach for forest fire risk modeling using fuzzy AHP and GIS in Hyrcanian forests of Iran. *Arab. J. Geosci.* 10, 190.

Gao, X., Fei, X., Xie, H. 2011. Forest fire risk zone evaluation based on high spatial resolution RS image in Liangyungang Huaguo Mountain Scenic Spot. International Conference on Spatial Data Mining and Geographical Knowledge Service, pp. 593-596. China: Fuzhou.

Gazzard, R. 2012. Risk management control measure: Toolkit for practitioners and advisors. UK Vegetation Fire Risk Management*,* 24.

GDF, 2022. General Directorate of Forestry, Forestry Statistics 2022, https://www.ogm.gov.tr/tr/e-kutuphane/resmi-istatistikler. Last visit: 29-10-2023.

Gheshlaghi, H.A., Feizizadeh, B., Blaschke, B. 2020. GIS-based forest fire risk mapping using the analytical network process and fuzzy logic. Journal of Environmental Planning and Management*, 63*(3):481-499.

Ghorbanzadeh, O., Blaschke, T., Gholamnia, K., Aryal, J. 2019. Forest fire susceptibility and risk mapping using social/infrastructural vulnerability and environmental variables. *Fire*, 2(3):1–27.

Jaiswal, R. K., Mukherjee, S., Raju, K. D., Saxena, R. 2002. Forest fire risk zone mapping from satellite imagery and GIS. *International Journal of Applied Earth Observation and Geoinformation, 4*(1):1-10.

Küçük Ö., Bilgili, E., Durmaz, B.D., Sağlam, B., Baysal, İ. 2009. The Effect Factors on Transition from Surface Fire to Crown Fire. *Kastamonu Univ., Journal of Forestry Faculty*, 9(2):80-85.

Lin, J., Rinaldi, S. 2009. A derivation of the statistical characteristics of forest fires. *Ecological Modelling,* 220(7):898-903.

Özden, Ü.H. 2008. Choosing primary school with analytic hierarchy process, Marmara University, *İ.İ.B.F. Journal,* 24(1):299-320.

Pant, S., Kumar, A., Ram, M., Klochkov, Y., Sharma, H.K. 2022. Consistency Indices in Analytic Hierarchy Process: A Review. *Mathematics,* 10(8):1206.

Saaty, T.L. 1977. A scaling method for priorities in hierarchical structures. *J Math Psychol*. 15:234-281.

Saaty, T.L. 1980. The Analytic hierarchy process. ISBN 0-07-054371-2, USA.

Sağlam, B., Bilgili, E., Durmaz, B.D., Kadıoğulları, A. İ., Küçük, Ö. 2008. Spatio-temporal analysis of forest fire risk and danger using LANDSAT imagery. *Sensors,* 8(6):3970-3987.

Sari, F. 2021. Forest fire susceptibility mapping via multi-criteria decision analysis techniques for Mugla, Turkey: a comparative analysis of VIKOR and TOPSIS. *For. Ecol. Manag*. 480(2021): 118644.

Satir, O., Berberoğlu, S., Dönmez, C. 2016. Mapping regional forest fire probability using artificial neural network model in a Mediterranean forest ecosystem. *Geomatics Nat. Hazards Risk,* 7(5):1645-1658.

Silva, I.D.B., Valle, M.E., Barros, L.C., Meyer, J.F.C.A. 2020. A wildfire warning system applied to the state of Acre in the Brazilian Amazon. *Appl. Soft Comput. J.* 89:106075.

Sivrikaya, F., Akay, A.E., Oğuz, H., Yenilmez, N. 2011. Mapping Forest Fire Danger Zones Using GIS: A Case Study from Kahramanmaraş. 6th International Symposium on Ecology and Environmental Problems. 17-20 November, Antalya.

Sivrikaya, F., Küçük, Ö. 2022. Modeling forest fire risk based on GIS-based analytical hierarchy process and statistical analysis in Mediterranean region. *Ecological Informatics,* 68(2022):101537.

Suryabhagavan, K.V., Misrak, A., Balakrishnan, M. 2016. GIS-based multi-criteria decision analysis for forest fire susceptibility mapping: a case study in Harenna forest, southwestern Ethiopia. *Trop. Ecol.* 57(1):33–43.

Şakar, D. 2010. Determining the optimum route providing the fastest transportation to the fire areas by using GIS based decision support system. MSc Thesis. KSU, Faculty of Forestry, Kahramanmaraş. Turkiye. 81 p.

Wilkie., V.A. 2003. Sustainable Forest Management and The Ecosystem Approach: Two Concepts, One Goal. FAO, Rome: Forestry Department.

Yeşilnacar, E.K. 2005. The Application of Computational Intelligence to Landslide Susceptibility Mapping in Turkey. PhD. Dissertation, Department of Geomatics, The University of Melbourne. 709 p.