FOREST FIRE RISK ASSESSMENT USING GIS AND AHP INTEGRATION IN BUCAK FOREST ENTERPRISE, TURKEY

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Abstract. Forest fires create an increasingly severe and negative impact on ecosystem services such as carbon storage, climate balancing and water supply as a result of global warming threatening our planet. One of the steps to fight forest fires is to perform a risk assessment. Forest fire risk assessment allows the identification of locations at high risk of forest fire and estimate its sphere of influence. In this way, it provides decision-making support to the fire-fighting organization. The purpose of this study was to conduct a forest fire risk assessment in forests located in Bucak Forest Enterprise in Turkey that is vulnerable to fire at the first degree. In the study, the weights of the criteria that lead to fire risk were computed with Analytic Hierarchy Process (AHP). The risk classes of the criteria were exported to the raster layer of the Geographical Information System (GIS). The results showed that 25% of forests in Bucak region were at high risk, while 32% were at medium fire risk. We believe that the approach adopted in this study may contribute to forest fire risk assessments and risk mapping of Mediterranean forest ecosystems that have similar climate, topographic structure and vegetation.
Keywords: *Mediterranean forests, fire risk factors, fire risk mapping, spatial analysis, fire sensitivity*

Introduction

Fire is an incident that leads to very severe changes in forest ecosystems (Naderpour et al., 2019). Forest fire poses a great danger to human life and environment (McKenzie et al., 2014; Garbolino et al., 2017). The European statistics demonstrate that 500 thousand hectares of forests are destroyed on average every year due to fire (EC, 2017). It is argued that the number of forest fires will increase in the future owing to climate change, changes in land use and forestry policies (González-De Vega et al., 2016; García-Llamas et al, 2019).

The Mediterranean forest ecosystems are resistant to fire (Pausas and Vallejo, 1999; Calvo et al., 2008); nevertheless, it is important to prevent fire before it reaches a dramatic point and fight against fire for social life and economy. We hope that forest fire risk assessments and organization of the efforts according to the risk levels identified will provide positive inputs for success in anti-forest fire efforts.

The forests located in the Mediterranean Region in the south of Turkey are vulnerable to fire; therefore, fire occurs very frequently in the forest ecosystems in this region. The statistics of the General Directorate for Forestry (GDF, 2019) reveal that on average more than 500 forest fire on average occur every year as a result of which more than 10000 hectares of forests are destroyed (*Figure 1*). As regards the causes of these fires, almost 90% of them are manmade (*Figure 2*).

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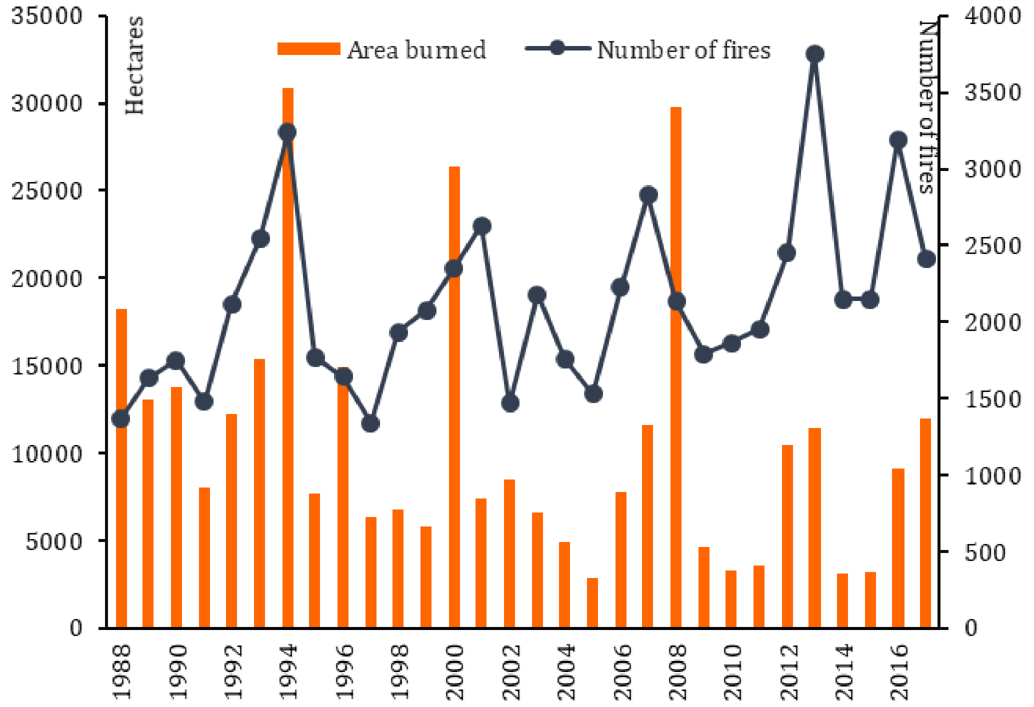

Figure 1. *The number of forest fires in Turkey between years 1988-2017 and the area of forests burned (GDF, 2019)*

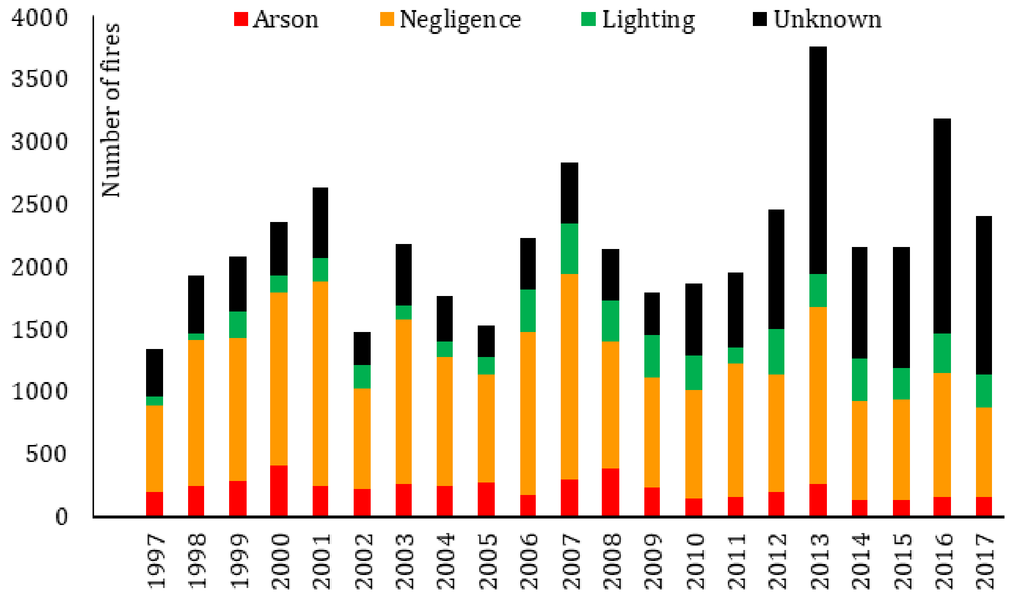

Figure 2. *The causes of forest fires in Turkey between years 1997-2017 (GDF, 2019)*

Forest lands are managed according to the decisions based on multiple criteria decision making (MCDM) methods. Particularly, decisions taken to prevent, fight and monitor forest fires are the most important ones. The location of fire lookout towers as well as

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deployment area and number of first response teams are also decided with MCDM methods alone or MCDM in combination with GIS (Fisher and Keida, 1990; Korkmaz, 2004; Akay and Şakar, 2009; Akay and Şahin, 2019).

The objective of this study was to determine and map the fire risk zones of a forest ecosystem in Bucak Forest Enterprise in Turkey that is vulnerable to fire at the first degree. We are of the opinion that the best method to fight forest fires is to use the experts' knowledge, experience and predictions. In this context, the weights of the criteria for forest risk were determined with Analytic Hierarchy Process (AHP). GIS was also used as a support to determine the fire risk zones in the study area because one of the main goals of GIS is to support spatial decision making process (Simon, 1960). In this way, the spatial analysis of the criteria related to human behaviours, climate, vegetation and topography was conducted in GIS by using the risks computed for the study area with AHP. As a result, the "forest fire risk zones" of the forests in Bucak region were determined and mapped.

Multi-criteria decision making and AHP

Multi-criteria decision analysis is defined as a matrix to choose the best alternative from several potential candidates and in case of conflicting criteria to solve problems, which is called decision matrix. Various MCDM methods have been developed since 1960 for solving decision making problems (Malczewski and Rinner, 2015). What is important at this point is to determine which multiple-criteria decision-making method is the best to solve a certain multiple-criteria decision making problem (Guarini et al., 2018).

AHP is one of the most comprehensive methods of multi-criteria decision analysis, which is a digital approach (Kumar and Garg, 2017). It is a powerful and flexible decision-making theory to rank different features (Belhadi et al., 2017). AHP is a measurement theory based on pairwise comparison. In its comparisons, it uses absolute judgment scale to represent the measurement of a scale for a feature whereas the linguistic judgments related to the assessment of people are usually uncertain in real life and it is not realistic to represent them with exact values (Ishizaka and Nguyen, 2013). This method developed by Saaty (1980) is widely used to solve multiple-criteria decision making problems. It allows modelling in a hierarchical structure that describes the relationship between the main target of the criterion, sub-criteria and alternatives in solving a complex decision making problem. In another word, AHP is a method that synthesizes knowledge, experience, views and feelings of an individual (Kuruüzüm and Altan, 2001).

A priority vector is obtained in the pairwise comparison matrix. The priority vector is the "eigenvector" of the matrix. The decision priorities called as weights attributed to the qualitative features are determined in the form of eigenvector of the pairwise comparison matrix (Jain and Naq, 1996). The "relative importance" of the criteria is determined from the lowest ranking criteria to the highest criteria using the eigenvector. The stages of solving a multi-criteria decision making problem with AHP include the identification of the problem, observation of the system, creation of the hierarchical structure, control of consistency, determination of the priority values and conclusion (Saaty and Vargas, 2012).

GIS-based approach

GIS is a valuable tool that collects, processes and analyses spatial data with its structural and functional components and offers support to the decision-making process

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(Chang, 2016). While it is commonly used in disciplines examining spatial data, many users in forestry sector also prefer it. The GIS-based studies regarding the identification of forest fire risk zones showed that the interactive structure of GIS was a powerful source (Jaiswal et al., 2002; Yomralıoğlu, 2015). A formulation was developed to calculate the fire risk index values using vegetation type, proximity to settlements, proximity to roads and gradient variables. The variables were categorized according to their vulnerability to fire and every category was given a specific value (You et al., 2017). To determine the fire risk zones, the factors and sub-factors were determined using AHP, while spatial distribution of the risk categories were produced using GIS computation in proportion to the weights of these factors.

In Turkey, there are studies that have determined fire risk categories based on GIS (Sağlam et al., 2008; Küçük et al., 2017) and combined use of GIS and AHP (Güngöroğlu, 2017; Akbulak et al., 2018). AHP appears to be a method used for determining factors and their weights as regards fire risk. The determination of weights of main factors and sub-factors, determination of risk categories of the sub factors and setting values for those categories are all done by consulting an expert opinion. Besides using multi-criteria decision-making methods when determining these factors, the fire statistics observed for many years are also relevant. It is therefore possible to adapt the information from the relevant literature to the special characteristics of the field.

Materials and Methods

Study area

This study was conducted in Bucak Department of Forestry located in Western Mediterranean Region of Turkey with coordinates of 37°12'08" - 37°34'20" North latitude and 30°14'02" - 30°50'53" East longitude (*Figure 3*). As for the topographic structure of the region; the minimum, maximum and average altitudes are 72 m, 2317 m and 900 m, respectively. Average slope is 26%. In addition to the Mediterranean climate, continental climate can also be observed. In this region, the mean temperature was 15°C, the average maximum temperature was 21°C and the average minimum temperature was 9°C from 1932 to 2018. Summer is arid and warm (maximum temperature 43°C) and winter is cold and rainy (minimum temperature -14°C). The annual mean precipitation is 450 mm whereas it is 15 mm on average in summer. The relative mean humidity in summer is 40% and while the dominant wind direction is south (GDF, 2019; Worldclim, 2019).

The size of the field is 141,057 ha, and 71% is forestland. 38.64% of the forestland is unproductive with crown closure under 10%. In the region’s forests, 73013 ha of land consist of coniferous species, while 19621 ha consist of deciduous species. Approximately 72% of the coniferous species consists of *Pinus brutia* Ten. and *Pinus nigra* Arnold which are relatively sensitive to fire.

Bucak Department of Forestry under Isparta Regional Directorate of Forestry is highly sensitive regarding forest fires. From 2008 to 2018 when the forest fires were investigated in the region, the highest number of fires was observed in this region with 0.9×10^{-3} per hectare. According to the same statistics, 85% of the forest fires in the region started during daytime, from 7:00 to 19:00 (IRDF, 2019). Within the fire-fighting organization, there are 4 lookout towers, 5 fire first response teams, 11 water trucks, 1 grader, 1 dozer and 10 fire pools.

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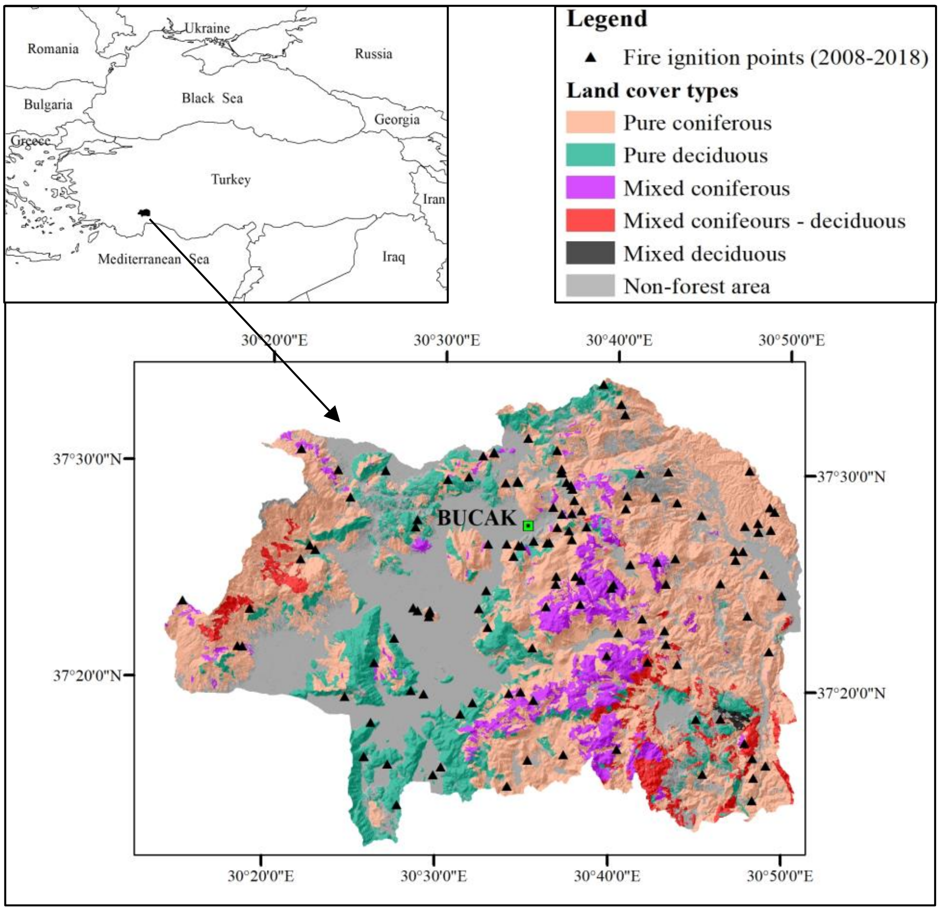

Figure 3. *Spatial location of the study area*

Dataset

Shuttle Radar Topography Mission (SRTM; version 3) data was used to create digital elevation model of the study field. This data was downloaded from https://gdex.cr.usgs.gov/gdex/ at a resolution of 1 arc-second (30 meters) from a global dataset (USGS, 2019). Altitude, slope and aspect maps were produced from the digital elevation data. Forest management plan maps for the years 2007 to 2017 of Bucak Forest State Enterprise were geographically categorized in ArcGIS environment into vegetation type, stand development period, crown closure, cultivated areas and settlements. Digital vector data of power lines and roads were provided by GIS department of Isparta Regional Directorate of Forestry. Climate data from 1970 to 2000 was obtained from http://worldclim.org/. In this platform where global climate data are presented, raster data with a resolution of approximately 1 km × 1 km was used. ArcGIS (version 10.2.2) software was used for GIS applications.

Methods

Computing the criteria weights using AHP

In the first stage of AHP, the decision problem was structured hierarchically. In the second step of AHP, pairwise comparisons and the option matrix were established. The pairwise comparison is an innate human ability and focuses on the relationship between

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pairwise data groups, thereby significantly reducing the complexity of decision-making (Saaty and Saaty, 2019). Pairwise comparison method consists of three steps: a) Forming the pairwise comparison matrix in all steps of the hierarchy, b) Computing the weights for each hierarchy, c) Determining the consistency index.

Hierarchically structuring the decision problem:

- Determining the criteria: Criteria are determined by expert opinion, relevant data sources and experiences of forest fire experts (Criteria and their definitions are shown in *Table 1*).
- The hierarchical structure of the decision problem was created (Saaty and Vargas, 2012).
- For pairwise comparisons to be evaluated by decision-makers to determine the criteria weights, pairwise comparison tables were formed (Saaty and Saaty, 2019).
- In pairwise comparisons, experts perform comparisons using the fundamental scale (Saaty, 1990).

Decisions are made by agreement based on two comparison scales or the geometric mean method can be used in the event of three different scales (Van den Honert and Lootsma, 1996; Bolloju, 2001).

Table 1. *Criteria and definitions*

Criteria	Sub-criteria	Definition
K_1: Human behaviour	K_{11}: Proximity to settlements K_{12}: Proximity to the road network K_{13}: Proximity to the cultivated areas K_{14}: Proximity to the power lines	Settlements in and around the forest Roads in and around the forest Cultivated areas in and around the forest Power lines in and around the forest
K_2: Structural characteristics of forests	K_{21}: Vegetation type K_{22}: Age of stand development K_{23}: Crown closure	Fire sensitivity of tree species Forest texture which is sensitive to fire Shading rate of forest trees
K_3: Topographic structure of forests	K_{31}: Altitude K_{32}: Slope K_{33}: Aspect	Elevations of the forest Forest slope Dominant aspect of forest areas
K_4: Climate data	K_{41}: Mean temperature of warmest quarter K_{42}: Precipitation of warmest quarter K_{43}: Mean wind speed of warmest quarter	Mean temperature during fire season Precipitation during fire season Mean wind speed during fire season

After determining the criteria and completing pairwise comparisons, the comparison matrices of criteria and sub criteria are formed. By evaluating the comparison matrices, weights of criteria are computed. Consistency tests were applied to check the reliability of the matrices. In order to check the consistency of the matrix, consistency index and consistency rate are calculated (Saaty, 1980). The consistency index (CI) of the comparison matrix is calculated with the following formulation:

$$CI = \frac{\lambda_{max} - n}{n - 1} \quad \text{(Eq.1)}$$

where CI is consistency index, λ_{max} is the largest eigenvalue, n is the number of criteria compare.

The consistency rate (CR) is calculated with the following formulation:

$$CR = \frac{\mathrm{CI}}{RI} \quad \text{(Eq.2)}$$

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where, CI is consistency index, RI is random index which depends on the number of criteria being compared. For example, for n = 2, 3, 4, and 5, RI = 0.00, 0.52, 0.89 and 1.11, respectively. CR <0.10 indicates a reasonable consistency level for pairwise comparisons. CR ≥0.10, however, indicates that the values in the pairwise comparison matrix should be reviewed and revise (Saaty, 1980).

GIS-based evaluation and mapping

The relevant literature for determining the risk categories of the sub criteria used to identify the fire risk zones was reviewed (Jaiswal et al., 2002; Sağlam et al., 2008; You et al., 2017). Jaiswal et al. (2002) developed a formulation for fire risk index, which is also suitable for the field's conditions. The special conditions of the field require customisation of the variables related to the fire risk values. For example, variables of latitude and vegetation differ considerably. The risk values of vegetation cover were listed by examining the fire sensitivity status of the target stands, which were distributed in the region. After defining the risk values for all stand types in the geographic database, the stands with the same risk values were combined and clustered.

The most fire sensitive tree species in the region were red pine and black pine stands (Neyişçi et al., 1996). The highest risk values were assigned to these stands. The variables of the distance between the road and the power lines and the distance between the settlements and the cultivated areas were determined according to the approach described by You et al. (2017) and values proposed by Şentürk (2018). Additionally, the distribution of 130 fire exit points in the zones which were produced at intervals of 0-25 m, 25-50 m, 50-100 m and 100 m farther from the road, power lines, settlements and cultivated areas were also evaluated. The climate data was calculated according to the approach proposed by You et al. (2017).

Raster layers were prepared and categorized according to the classes in *Table 2*. These raster layers were multiplied by their own criteria weight using the "raster calculator" available at ArcGIS software and fire risk values were achieved. These values were categorized (Jenks and Caspall, 1971) and fire risk zones were mapped.

Results and Discussion

Forming of the comparison matrices of criteria and sub criteria in AHP

The criteria indicated in *Table 1* were evaluated by the experts according to the AHP comparison scale specified in *Table 3* and the comparison scheme in *Table 2*. Comparison matrix of the criteria was formed (*Table 3*).

Similarly, the same steps were applied for the sub criteria and as a result, the comparison matrices of the sub criteria of the K_1, K_2, K_3, K_4 criteria were calculated (*Tables 4-7*).

Evaluation of comparison matrices

To normalize the pairwise comparisons of the criteria,

- All columns are summed up (*Table 3*).
- Each column element in *Table 3* is divided into column sum (*Table 8*).
- Total rows are calculated (*Table 8*).
- Average of row sum (w) is found (*Table 8*).

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Table 2. *Variables and risk values to be used in the calculation and mapping of fire risk*

Structural characteristics of forests

Criterion	Class	Risk	Value
Vegetation type	*Pinus brutia* and *P. nigra* stands	Very high	1.0
	Pinus brutia / *P. nigra* – coniferous mixed stands	High	0.7
	Other pure coniferous stands	Moderate	0.5
	Coniferous- deciduous mixed stands	Low	0.3
	Deciduous stands	Very low	0.1
Age of stand development	Young forest	Very high	1.0
	Medium age forest	High	0.7
	Old-growth forest	Moderate	0.5
	Mature forest	Low	0.3
Crown closure	%10-%40	Very high	1.0
	%40-%70	High	0.7
	>%70	Moderate	0.5
	<%10 coniferous –deciduous mixed stands	Low	0.3
	<%10 deciduous mixed stands	Very low	0.1

Human behavior

Criterion	Class	Risk	Value
Proximity to settlements (meter)	0-25	Very high	1.0
	25-50	High	0.7
	50-75	Moderate	0.5
	75-100	Low	0.3
	>100	Very low	0.1
Proximity to the road network (meter)	0-25	Very high	1.0
	25-50	High	0.7
	50-75	Moderate	0.5
	75-100	Low	0.3
	>100	Very low	0.1
Proximity to the cultivated areas (meter)	0-25	Very high	1.0
	25-50	High	0.7
	50-75	Moderate	0.5
	75-100	Low	0.3
	>100	Very low	0.1
Proximity to the power lines (meter)	0-25	Very high	1.0
	25-50	High	0.7
	50-75	Moderate	0.5
	75-100	Low	0.3
	>100	Very low	0.1

Topographic structure of forests

Criterion	Class	Risk	Value
Altitude (meter)	<700	Moderate	0.5
	700-1000	Very high	1.0
	1000-1300	High	0.7
	1300-1600	Low	0.3
	>1600	Very low	0.1
Slope (%)	1-15	Moderate Very	0.5
	15-30	high	1.0
	30-40	High	0.7
	40-50	Low	0.3
	>50	Very low	0.1
Aspect	Sunny (S,SW)	Very high	1.0
	Semi sunny (W,SE)	High	0.7
	Flat	Moderate	0.5
	Semi shady (NW,E)	Low	0.3
	Shady (N,NE)	Very low	0.1

Climate data

Criterion	Class	Risk	Value
Mean temperature of warmest quarter (°C)	>24	Very high	1.0
	22-24	High	0.7
	21-22	Moderate	0.5
	20-21	Low	0.3
	>20	Very low	0.1
Mean wind speed of warmest quarter (meter second^{-1})	>2.1	Very high	1.0
	2.0-2.1	High	0.7
	1.95-2.0	Moderate	0.5
	1.90-1.95	Low	0.3
	>1.90	Very low	0.1
Precipitation of warmest quarter (millimeter)	<40	Very high	1.0
	40-50	High	0.7
	50-60	Moderate	0.5
	60-70	Low	0.3
	>70	Very low	0.1

Table 3. *Comparison matrix of the criteria*

	K_1	**K_2**	**K_3**	**K_4**
K_1	1	3	5	7
K_2	0.333	1	3	5
K_3	0.200	0.333	1	1
K_4	0.143	0.200	1	1
Total	1.676	4.533	10	14

K_1: Human behaviour, K_2: Structural characteristics of forests, K_3: Topographic structure of forests, K_4: Climate data

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Table 4. *Comparison matrix of the sub-criteria of K_1*

	K_{11}	**K_{12}**	**K_{13}**	**K_{14}**
K_{11}	1	0.2	3	4
K_{12}	5	1	9	7
K_{13}	0.333	0.111	1	2
K_{14}	0.25	0.143	0.5	1

K_{11}: Proximity of settlement, K_{12}: Proximity of road network, K_{13}: Proximity of cultivated areas, K_{14}: Proximity of power lines

Table 5. *Comparison matrix of the sub-criteria of K_2*

	K_{21}	**K_{22}**	**K_{23}**
K_{21}	1	3	5
K_{22}	0.333	1	4
K_{23}	0.2	0.25	1

K_{21}: Vegetation type, K_{22}: Age of stand development, K_{23}: Crown closure

Table 6. *Comparison matrix of the sub-criteria of K_3*

	K_{31}	**K_{32}**	**K_{33}**
K_{31}	1	5	3
K_{32}	0.2	1	0.333
K_{33}	0.333	3	1

K_{31}: Altitude, K_{32}: Slope, K_{33}: Aspect

Table 7. *Comparison matrix of the sub-criteria of K_4*

	K_{41}	**K_{42}**	**K_{43}**
K_{41}	1	3	4
K_{42}	0.333	1	2
K_{43}	0.25	0.5	1

K_{41}: Mean temperature, K_{42}: Precipitation, K_{43}: Mean wind speed

Table 8. *Calculation of criterion weights*

	K_1	**K_2**	**K_3**	**K_4**	**Row total**	**w**
K_1	0.596659	0.661813	0.5	0.5	2.258472	0.564618
K_2	0.198687	0.220604	0.3	0.357143	1.076436	0.269109
K_3	0.119332	0.073461	0.1	0.071429	0.364220	0.091055
K_4	0.085322	0.044121	0.1	0.091055	0.300872	0.075218

w: the matrix's eigenvector

"w" in the last column of *Table 8* is the matrix's eigenvector and gives the weight of the criteria by percentage (%). It is necessary to calculate the consistency of the comparison matrix of the criteria. For a comparison matrix to be consistent, the maximum eigenvalue (λ max) must be equal to the dimensions of the matrix (*Table 9*). Consistency rate greater than 10% shows that some evaluations are contradictory in the comparisons (Partovi and Hopton, 1994).

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Table 9. *Calculation of the consistency of the comparison matrix of criteria*

	K_1	K_2	K_3	K_4	w	v	v/w
K_1	1	3	5	7	0.564618	2.353746	4.168741
K_2	0.333	1	3	5	0.269109	1.106382	4.111278
K_3	0.200	0.333	1	1	0.091055	0.368810	4.050408
K_4	0.143	0.200	1	1	0.075218	0.300835	3.999510

w: the matrix's eigenvector, v: column vector

The previously calculated column vector (eigenvector/priority vector) is obtained by multiplying each row of the comparison criterion. The calculated column vector (v) is divided by the corresponding elements of the column vector (w) to obtain v/w values. The arithmetic mean of the v/w column vector gives the largest eigenvalue (ƛ max = 4.082484).

Consistency Indicator = (ƛ max-n)/n-1 = (4.082484-4)/4-1 = 0.27495

Consistency Ratio = Consistency Indicator / Random index

Random Index for matrices with sizes of 1 to 15, in the table of random index, n = 4 is 0.89 (Saaty, 1990). According to this;

Consistency Ratio = 0.027495 / 0.9 = 0.03055

Since the consistency ratio is <0.1, the matrix can be considered consistent. For the other comparison matrices, the same steps were taken, and the criteria weights and consistency of the criteria were calculated and shown in *Table 10*.

Table 10. *Consistency ratios and weights of criteria and sub-criteria*

CR	Criteria	Weights	CR	Sub-criteria	Local weight	Overall weight
0.03	Human behaviour	0.5646	0.058	Proximity to settlements	0.1993	0.1125
				Proximity to the roads	0.6535	0.3690
				Proximity to the cultivated areas	0.0860	0.0486
				Proximity to the power lines	0.0612	0.0345
	Structural characteristics of forests	0.2691	0.075	Vegetation type	0.6194	0.1667
				Age of stand development	0.2842	0.0765
				Crown closure	0.0964	0.0259
	Topographic structure of forests	0.0911	0.033	Altitude	0.6334	0.0557
				Slope	0.1061	0.0097
				Aspect	0.2605	0.0237
	Climate data	0.0752	0.016	Mean temperature of warmest quarter	0.6233	0.0469
				Precipitation of warmest quarter	0.2394	0.0180
				Mean wind speed of warmest quarter	0.1373	0.0103

CR: consistency ratio

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Pairwise comparison method is frequently use to estimate the weights of the criteria in the GIS-based multiple-criteria decision-making applications (Malczewski and Rinner, 2015). This method has been tested and applied in land suitability analyses (Stoms et al., 2002; Hamzeh et al., 2016; Bozdağ et al., 2016), environmental impact assessment studies (Bojórquez-Tapia et al., 2002; Rikhtegar et al, 2014) and natural resource management (Hessburg et al., 2013).

In this study, it was concluded that the contribution of human behaviour to fire risk was over 50% (*Table 10*). In a study conducted by You et al. (2017), the weight of human activities used to calculate fire risk was found to be the first one among other factors. It is also known that proximity to the road increases the risk of fire. Şentürk (2018) examined the relationship between the locations of forest fire starting points and the roads in Istanbul and found that 427 (~ 65%) of the 660 fire starting points were located at 0-100 meters from the road. Although climate seems to have a primary effect, it is proposed that it is important to know the proximity of forests to roads and settlements (Sağlam et al., 2008; Wu et al., 2014).

The mapping of fire risk zones

All geographic layers of the sub criteria in the GIS database were recorded as raster data, and the risk classifications shown in *Table 2* were identified. Thus, the spatial distribution of the risk zones belonging to 13 sub criteria was mapped (*Figure 4*). The criteria and weights determined by AHP were formulated with the help of ArcGIS software's spatial analysis tool and applied to the related geographical layers. The resulting fire risk map was created by using ArcGIS and is presented in *Figure 5*.

When the spatial distribution of fire risk zones is examined, it is understood that only 0.49% of forest lands in the field was ranked as very high risk (*Table 11*). Given that the ratio of the areas with medium and high fire risk is close to 60% in total, it is possible to suggest that the fire risk of forestlands in the region is relatively high.

The risk assessment conducted for the study area can possible used for the Mediterranean forest ecosystems that have similar forest cover, climate and topographic features. However, it should also be remembered that risk value may change as climate and forest cover change (Jaiswal et al., 2002; Sağlam et al., 2008; Neyişçi, 2009; Küçük et al., 2017). Moreover, we suggest that risk assessment can be performed and risk zones can be mapped for any forest ecosystem if the approach and methodology developed in this study are applied.

In terms of forest fire risks, coniferous species that account for about 80% of the forests in the field are at higher risk than broad-leaved species. However, it should not be overlooked that broad-leaved forests are also susceptible to fire in the dry season (Kodandapani et al., 2009).

In this study, human behaviour was found to has the highest weight for fire risk. The importance of human behaviours for fire risk has been reported by several studies (Vadrevu et al., 2009; Eskandari and Chuvieco, 2015; Eskandari, 2017). Proximity to forest roads, which is one of the sub-criteria of human behaviours has the highest weight in terms of fire risk (You et al., 2017; Şentürk, 2018). Other researchers also confirmed that vegetation composition (Sağlam et al., 2008; Chuvieco et al., 2012; You et al., 2017), topographic structure (Vadrevu et al., 2009; Çoban and Özdamar, 2014; Eskandari, 2017) and climate (Zumbrunnen et al., 2011; Eskandari, 2017) were important criteria for fire risk.

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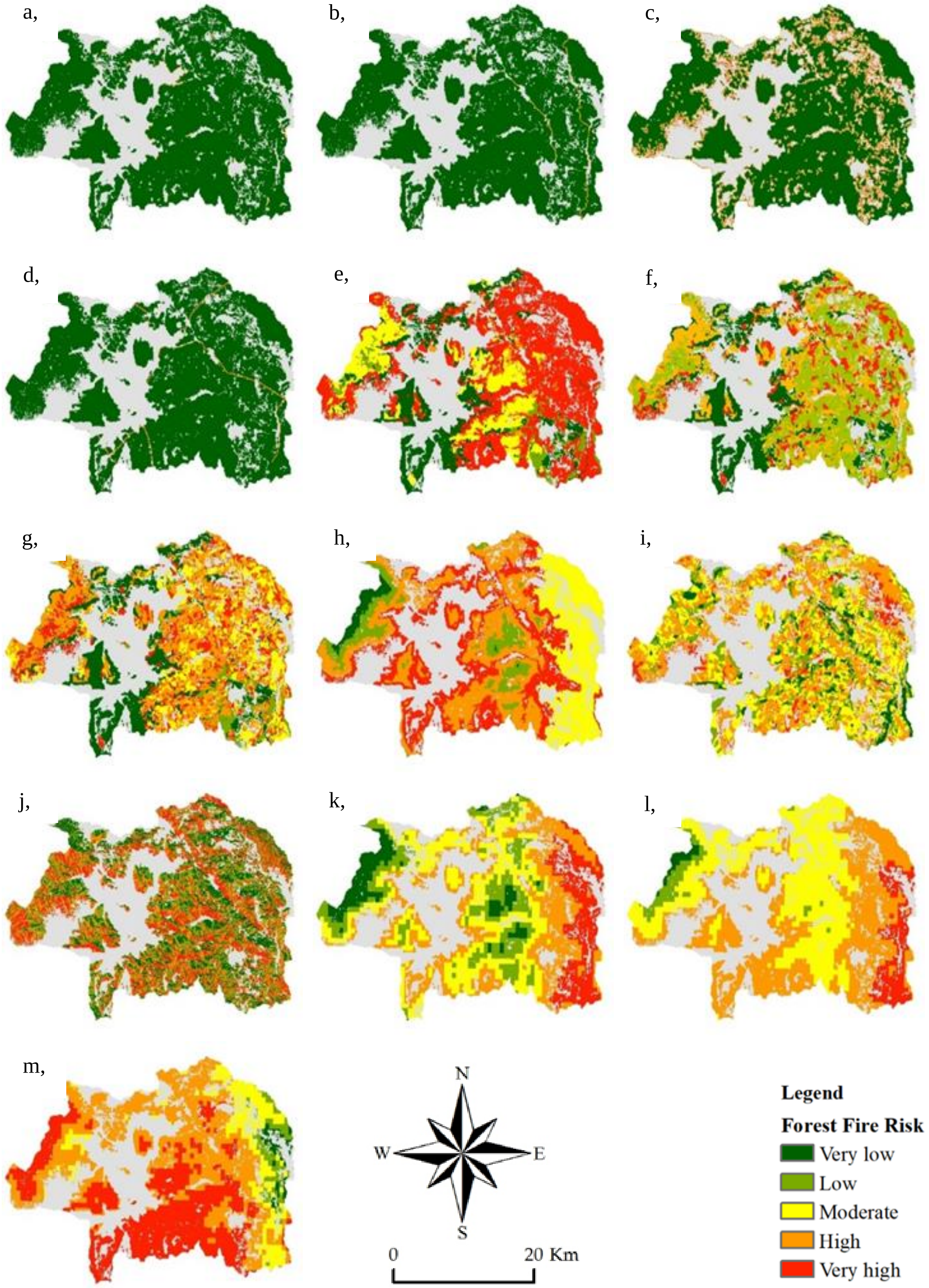

Figure 4. *Fire risk zones of the sub-criteria, a) Proximity to settlements, b) Proximity to the road network, c) Proximity to the cultivated areas, d) Proximity to the power lines, e) Vegetation type, f) Age of stand development, g) Crown closure, h) Altitude, i) Slope, j) Aspect, k) Mean temperature of the warmest quarter, l) Precipitation of the warmest quarter, m) Mean wind speed of the warmest quarter*

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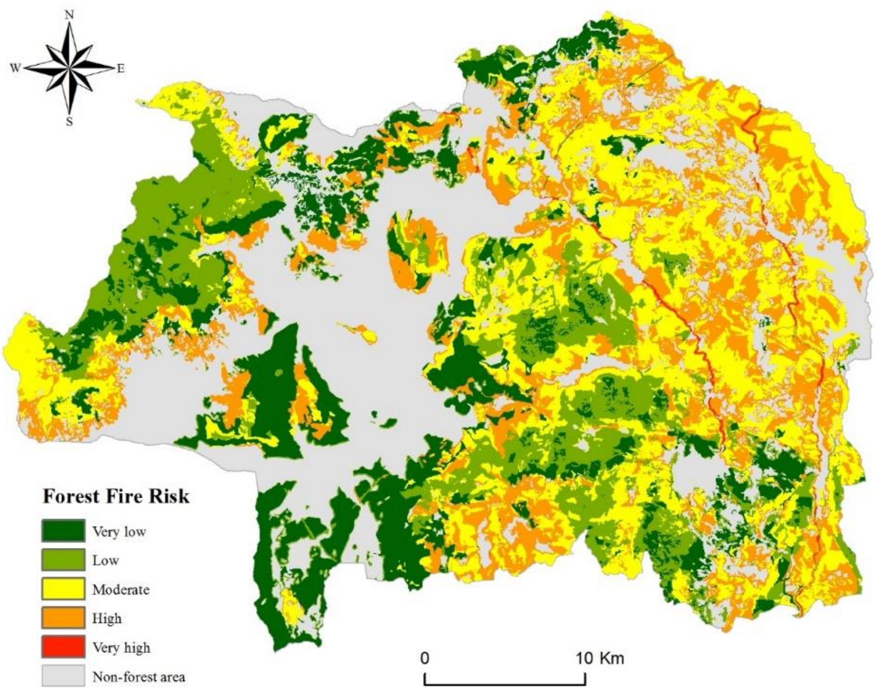

Figure 5. *Spatial distribution of fire risk zones*

Table 11. *Spatial distribution of forest fire risk*

Vegetation type	Forest Fire Risk										
	Very high		**High**		**Moderate**		**Low**		**Very low**		**Total**
	ha	%	ha	%	ha	%	ha	%	ha	%	(ha)
Calabrian and black pine	431.10	0.82	24107.93	46.10	27242.04	52.10	192.13	0.37	317.93	0.61	52291.13
Coniferous	17.09	0.08	418.80	2.02	4082.92	19.70	15186.35	73.29	1016.87	4.91	20722.03
Mixed coniferous-deciduous	1.73	0.03	16.14	0.31	48.80	0.95	3059.65	59.39	2025.74	39.32	5152.06
Deciduous	3.68	0.02	49.02	0.25	78.30	0.40	1949.93	9.92	17575.70	89.41	19656.62
Shrub grassland	31.27	2.09	107.14	7.17	903.40	60.48	421.62	28.23	30.32	2.03	1493.77
Other lands in forest area	8.57	0.79	80.18	7.39	45.22	4.17	37.08	3.42	914.31	84.24	1085.36
Total (ha)	493.44		24779.21		32400.68		20846.76		21880.88		100400.97

Conclusion

The nature has the power to find ways to compensate the damage caused by horrible catastrophes. Mediterranean forest ecosystems also have the power to cope with fire. Despite that, measures should be taken to fight forest fires as they threaten human life and lead to devastating economic loses, which may in turn lead to extremely dangerous consequence. In addition to several natural variables such as climate, topography, bedrock, vegetation cover, human factor also is also a dominant and adverse factors as regards forest fire. Therefore, it is ideal to manage so many processes from setting forestry

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policies to fight forest fires to planning land use, preserving the structural features of the natural forests, establishing forests suitable for the relevant degraded area and under extreme conditions, ensuring social and cultural development and in this way raising environmental awareness. One of the crucial elements of fight against forest fire is to create fire risk maps. In this way, fire risk zones may provide decision support in planning the fire-fighting organization. Areas at higher fire risk and thus areas where fire may potentially spread and grow can be determined and necessary measures can be taken.

In this study, the fire risk zones of first-degree fire sensitive Mediterranean forest ecosystems in Bucak were identified and mapped. In the total forestland in the study area, 0.5% of the forests were at a very high fire risk, 25% were at high risk, while 32% were at medium risk. This shows that around 60% of the forestlands are at medium and high forest fire risk. Accordingly, we can say that it is important that forest authority should take measures to prevent forest fires during fire season in this region and raise awareness of people through media and other means of communication. In addition, forest fire reports should contain accurate and detailed information about fire ignition point location and records of all events from the beginning to the end of the fire. We recommend that fire risk maps should be compared with the real fire records and fire risk assessment should be keep up to date.

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