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Determination of Forest Fire Risk Using GIS: A Case Study in Nigde, Turkey

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Abstract − The main purpose of this study is to develop a statistical model to prepare forest fire risk map using GIS. In this study eight important factors were used to determining the forest fire risk such as land use/land cover type, slope, aspect, altitude, settlement, road, temperature and precipitation. The analytic hierarchy process (AHP) was used to evaluate the factors. Precipitation and temperature were the most important factors to determining the forest fire risk. The study area has approximately 10.72% low fire risk, 28.21% moderate fire risk, 43.50% high fire risk, 14.65% very high fire risk, and 2.92% extreme forest fire risk. 61.07% of the study area has a high, very high and extreme forest fire risk. In order to prevent forest fires, land cover/land use should be planned in a way that does not damage forests. Especially vehicle roads, expressways, etc. which are located near the forests, have a high fire risk. Therefore, these areas should be planned in a way that will not damage the forests. The climatic characteristics of the study area should be examined, the urban texture should not be in a way to prevent microclimatic factors such as wind and precipitation.

Keyword − *Environmental preservation, environmental management, forest, GIS, fire risk analysis*

Orman Yangını Riskinin CBS Kullanılarak Niğde Örneğinde Belirlenmesi

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Araştırma Makalesi

Öz − Bu çalışmanın temel amacı, CBS kullanarak orman yangın risk haritası hazırlamak için istatistiksel bir model geliştirmektir. Bu çalışmada orman yangını riskini belirlemek için arazi kullanımı/arazi örtüsü tipi, eğim, bakı, rakım, yerleşim, yol, sıcaklık ve yağış gibi sekiz önemli faktör kullanılmıştır. Faktörleri değerlendirmek için Analitik Hiyerarşi Süreci (AHP) kullanılmıştır. Yağış ve sıcaklık orman yangını riskini belirleyen en önemli faktörler olarak belirlenmiştir. Çalışma alanı yaklaşık %10.72 düşük yangın riski, %28.21 orta yangın riski, %43.50 yüksek yangın riski, %14.65 çok yüksek yangın riski ve %2.92 aşırı orman yangını riskine sahiptir. Çalışma alanının %61,07'si yüksek, çok yüksek ve aşırı orman yangını riskine sahiptir. Orman yangınlarını önlemek için arazi örtüsü/arazi kullanımı ormanlara zarar vermeyecek şekilde planlanmalıdır. Özellikle ormanların yakınında bulunan araç yolları, otoyollar vb. alanlarının yangın riskini yükselttiği unutulmamalıdır. Bu nedenle bu alanlar ormanlara zarar vermeyecek şekilde planlanmalıdır. Çalışma alanının iklimsel özellikleri incelenmeli, kentsel doku rüzgâr ve yağış gibi mikro iklim faktörlerini engelleyecek şekilde planlanmamalıdır.

Anahtar Kelimeler − *Çevre koruma, çevre yönetimi, orman, CBS, yangın risk analizi*

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1. Introduction

Forest fires are the primary problem for all forests in the world. If the geographical conditions not suitable for the forest fires monitoring, various methodology can be used to monitoring the fire in the forest. Forest fires affect the sustainability of forests, especially in arid regions where fire-sensitive tree species are concentrated. (Demir et al., 2009; Kumari and Pandey, 2020). Forest fires have devastating effects on forest ecosystems (Bilici, 2009). Forest fires generate too much greenhouse gas (CH4 and CO2), as well as causing trees to lose their value's and people to lose their lives. As a result of this greenhouse gas effect, forest fires cause changes in the carbon cycle and atmospheric composition (Van Der Werf et al., 2004).

Forest fires occur depending on many factors (Carmel et al., 2009). Topographic and climatic features, forest's vegetation are the main factors for the fire risk. The types of trees in the forest, the growth period characteristics of the trees and the closure of the wind that will come to the forest area, are other factors affecting the severity and growth of forest fire (Gao et al., 2011; Gazzard, 2012). For example, some studies (Bilgili, 2003) show that deciduous trees are more resistant to fire, while coniferous trees are more susceptible to fire. There is a similar relationship between the growth period of trees and the risk of fire. The fire risk is very low in the first growth stages of a tree (Sağlam et al., 2008). The risk of fire, on the other hand, will rise over time. Because the buildup of surface and crown fuels upsurges when it approaches stand age, this risk will reduce as the trees mature (Bilgili, 2003).

Topography is one of the factor that increase or decrease the fire risk in a region (Erten et al., 2004). The higher the height in an area, the higher the risk of forest fire, because there are factors such as wind. Winds cause make the fire move faster in high areas (Jaiswal et al., 2002). Along with the topography, the aspect also affects the fire risk. South facing areas have higher fire risk. Temperatures are higher and humidity is lower in certain areas than in other areas (Lin and Sergio, 2009). Factors such as these caused by land structure can change forest fire risk, as well as climatic characteristics such as precipitation, temperature and wind have an effect on fire risk. To reduce the damaging impacts of forest fires on forests, the boundaries of areas at danger of fire should be defined and mitigation measures applied. Identifying regions at danger of forest fire is critical for fire prevention. Because regions with forest fire risk are the place where the fire started, they also cause the fire to spread to other regions (Erten et al., 2004). Therefore, determining the areas with fire risk is also beneficial in evaluating the deficiencies in prevent the fire. Forest fire risk maps are created by combining many layers of data that can cause fires (Jaiswal et al., 2002).

The advanced method Geographical Information System (GIS) in conjunction with the Multi-Criteria Decision Analysis (MCDA) approach allows for quick and effective explanations of complicated geographical issues (Jaiswal et al., 2002; Carmel et al., 2009; Kumari and Pandev, 2020). Today, the determination of the forest fires using GIS has become very important for precautions and plans. Monitoring the stages before, during and after the fire is a difficult task that must be done in the most accurate and earliest way. GIS with the satellite technologies is considered as an important software in fulfilling this difficult task. Detection of forest fires, surveillance, examination of the damages, and calculation of the burning area can be done with the help of the developing satellite technologies and the GIS.

One of the most extensively utilized multi-criteria decision support systems for detecting forest fires is the Analytic Hierarchy Process (AHP). There are studies (Mohammadi et al., 2010; Eugenio et al., 2016) to determine forest fire risk using the AHP method. Forest fires are an indispensable part of forest ecosystems in the Mediterranean, also they play an important role in ensuring ecological balance. Considering the number of forest fires that occurred in 1937-2009; the total number of fires is 86,769, and the total burning area is 1,617.701 hectares (Özkazanç and Ertuğrul, 2011). In other words, approximately 1,200 fires occur every year, and 22,000 hectares of forest area disappear (Özkazanç and Ertuğrul, 2011). Although the temporal course of forest fires displays non-linear graphic in our country, it is observed that there is an increase in the amount of burning areas, and the number of fires, especially in forest fires in recent years. This situation can be associated with the growth of the factors (such as reduction of water resources, unplanned urban development, degradation of forest texture) that cause fires together with the population increase. 91% of forest fires in our country occur as a result of human activities (Ateşoğlu et al., 2015). When the studies (Pradhan et al., 2007; Malik et al., 2013; Eugenio et al., 2016; Gigovic et al, 2018) conducted to date are analysed, it has been determined that various methods are used to created forest fire risk maps. It has been determined that the studies are generally carried out in different climate types and land cover classification Therefore, how the risk of forest fire changes under different climate type and factors can be determined by these studies.Whereas, there are a few studies (Dilekçi et al., 2009; Karabulut et al., 2013; Bingöl, 2017) on forest fire risk in Turkey. These studies are generally conducted with similar climate types or factors. However, this study differs from other studies because it was made in area that have different climate types, and it makes statistical analyses using more factors. The purpose of this study is to identify forest fire risk areas using Remote Sensing and GIS technique. This study would contribute to interventions and planning in forest fire management.

It is thought that this study conducted to determine the forest fire risk will be a resource for the region, can be developed in terms of fire-related studies and will contribute to forestry activities. In addition to the main purpose of the study, its sub-goals are as follows;

- To demonstrate the application of remote sensing and GIS in disaster management, especially forest fires,
- To explain the benefits of Landsat satellite images, which are available free of charge, in many areas, especially in forestry applications.
- To investigate the factors causing forest fires,
- To analyses the advantages of AHP (Analytic Hierarchy Process)

In this context, the study focused on two main questions:

- What are the main factors increasing forest fires in Nigde?
- Which strategies will help to decrease the forest fires in urban and building scale in Nigde?

Nigde is a city with historical, social, cultural, and economic activities. Because of the rapid increase in the population living in the Nigde, there are significant changes in the land cover types. Natural landscapes in the city are transformed into stone and concrete surfaces and are pushed further away from the city centre. The biggest problem for is the unplanned and uncontrolled development of the city. Therefore, forest areas are under pressure due to human use. Forest fires occur in areas where agricultural activities are close. Therefore, creating a risk map for forest fire is important for the protection of the forests of the region. The size of the forest areas of Nigde is quite small compared to other regions of Turkey. Despite this, the fact that residential and agricultural areas are close to forest areas and the Adana - Nigde highway passes close to forest areas increases the risk of forest fire in the region. In addition, the planning of residential, traffic and industrial areas close to these areas also increases the risk of forest fires. When the literature is reviewed, it is determined that the studies about the fire risks are carried out in countries where precipitation or green areas are high. These study aims to determine the forest fire risk using GIS.

2. Material and Method

The study area includes the city of Nigde as a whole (Fig. 1). In the summertime, Nigde has a hot and dry climate, while the winters are cold and snowy. Nigde is between 34°30'10" and 34°45'00" east longitude and 37°54'00" and 38°06'30" north latitude. Nigde is 7,795.22 km^2 in size. The average annual temperature ranged from -1.0 to 22.4 ^oC, with yearly rainfall ranging from 5.2 to 48.7 mm. (General Directorate of Meteorology, 2019). In the study, the satellite image of Landsat 8 OLI dated 08.08.2019, was used to create the land cover classification map. Downloaded from (https://earthexplorer.usgs.gov/) (Table 1). The features of the bands of Landsat 8 are given in Table 2.

Table 1
The bands and their dates that were used in the study

City	Landsat	Time	Season
Nigde	LC08L1TP176034201908042019082001	August 8, 2021	Dry

Table 2
Features of a Landsat-8 OLI/TIRS image (Estoque, 2017; Soydan 2020)

Landsat 8		
Electromagnetic region	Band	Wavelength (μm)
Coastal aerosol	1	0.43 – 0.45
Blue	2	0.45 – 0.51
Green	3	0.53 – 0.59
Red	4	0.64 – 0.67
Near infrared (NIR)	5	0.85 – 0.88
Short wave infrared (SWIR) 1	6	1.57 – 1.65
Short wave infrared (SWIR) 2	7	2.11 – 2.29
Panchromatic	8	0.50 – 0.68
Cirrus	9	1.36 – 1.38
Thermal infrared (TIR) 1	10	10.60 – 11.19
Thermal infrared (TIR) 2	11	11.50 – 12.51

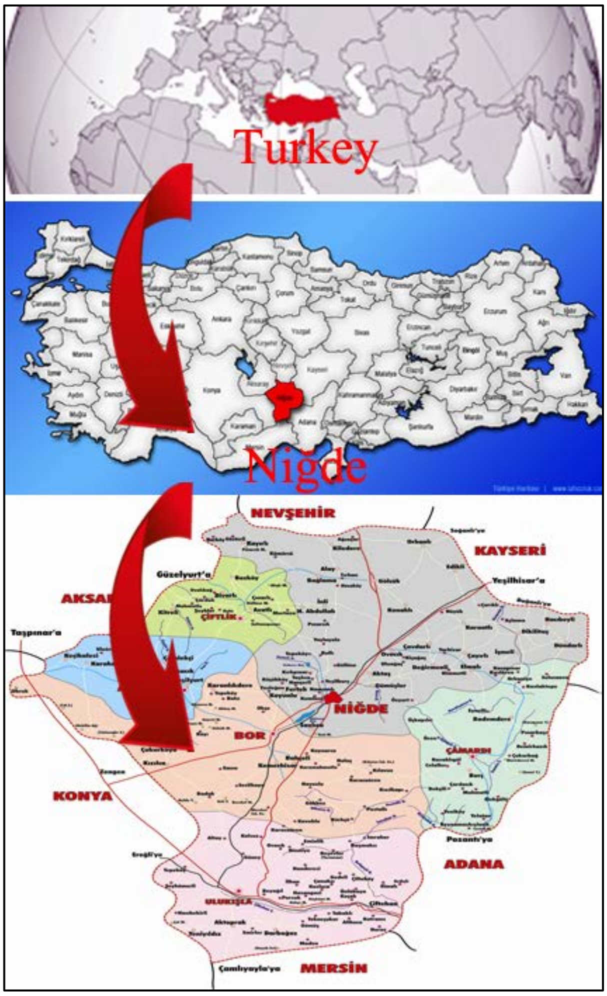

Figure 1. Location of Nigde in Turkey

Maps of aspect and slope were created using DEM (digital elevation model) data. The DEM has a resolution of 30 meters. The data was gathered from https://www.eorc.jaxa.jp/ALOS/en/aw3d30/data/index.htm. The information belong to Nigde was obtained from the Nigde Municipality. The climate data of Nigde province were obtained from the General Directorate of Meteorology. Data of the roads and settlements were obtained from the website https://www.openstreetmap.org/. The study consists of 7 stages. ArcGIS 10.3 software was used to organize the data used, classification, slope, aspect, altitude maps, and to create road and settlement distances in the study. "Raster Calculator" in software was used in obtaining the final map. In order to determine the factors causing forest fire in Nigde and to determine where the fire occurred mostly, the fire data of the study area during the years of 2010-2019 were examined. For this, the relevant documents were obtained from the Ministry of Agriculture and Forestry. A total of 15 forest fire information was obtained. Locations of previous forest fires were marked on the satellite image with their coordinates (Figure 2). In the study, a total of eight important factors, such as land use/land cover type, slope, aspect, altitude, settlement, road, temperature and precipitation, which are thought to be effective in forest fires, were determined. Maps of land use/land cover, slope, aspect, altitude, precipitation, temperature, distance to road and settlement distance were done according to the values given in Table 3. Within the scope of the study, forest fire risk map was created using the Analytical Hierarchy Process (AHP) method. The previous studies (Nuthammachot and Stratoulias, 2019; Van Hoang et al., 2020; Çoban and Erdin, 2020) were used while creating the weight values of the factors for forest fire risk.

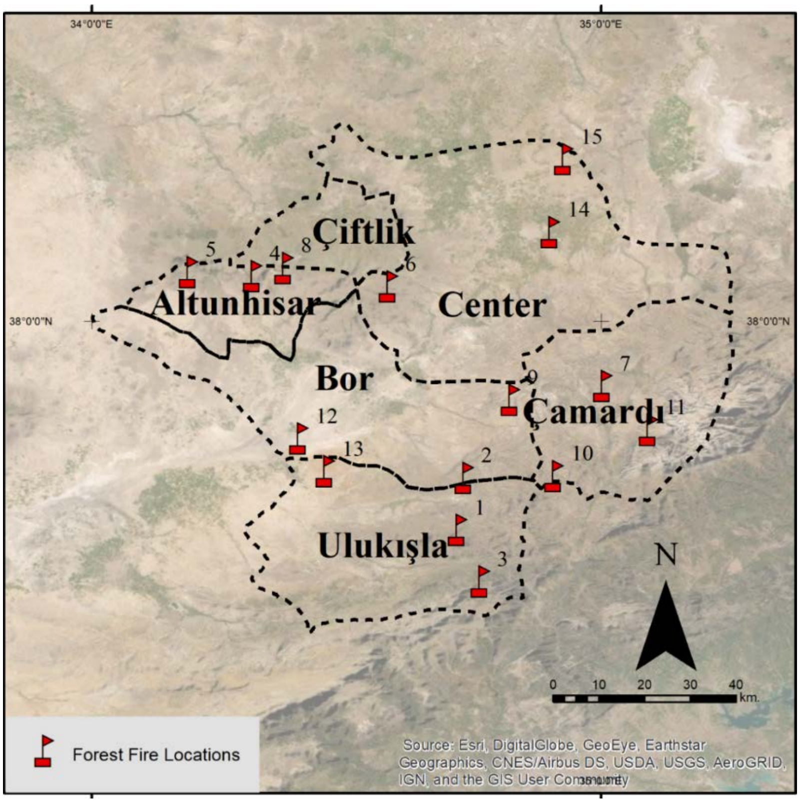

Figure 2. Previous Forest Fire Locations in Nigde

Table 3
Weightages and factors in determination of fire risk modelling

Factors	**Classification**	**Value**
Land Cover	Forest	7
	Other	1
Slope (%)	0-15	1
	15-25	2
	25-35	3
	35-45	4
	>45	5
Aspect	N, NE, NW, and FLAT	1
	E	2
	SE	3
	SW and W	4
	S	5
Altitude (m)	< 900	1
	900 – 1,200	2
	1,200 – 1,500	3
	1,500 – 1,800	4
	> 1,800	5
Distance to settlements (m)	< 500	1
	500-2000	7
	> 2000	3
Distance to roads (m)	< 100	6
	100 - 300	4
	> 300	2
Precipitation (mm)	< 15	5
	15 – 18	4
	18 – 21	3
	21 – 23	2
	> 23	1
Temperature (ºC)	< 20	1
	20 – 24	2
	24 – 28	3
	28 – 32	4
	> 32	5

2.1. Analytical Hierarchy Process (AHP)

AHP is a mathematical strategy that considers the group or individual's priorities while evaluating both qualitative and quantitative characteristics (Dağdeviren and Tamer, 2001; Toksar, 2007). It is an often utilized strategy among multi-criteria decision-making techniques because it is a straightforward, easy-to-use, and understood method. Saaty (1997) developed the following steps for applying the AHP:

Step 1:
The necessary elements and sub-factors are determined by the decision maker. At this point, a survey study or expert comments on the matter can be done.

Step 2:
Construct a set of pair-wise comparison matrices (size n x n) for each of the lower levels with one matrix for each element in the level immediately above by using the relative scale measurement shown in Table 4. The

pair-wise comparisons are done in terms of which element dominates the other (Al-Harbi, 2001).

Table 4
Pair-wise comparison scale for AHP preferences

Numerical rating	**Verbal judgments of preferences**	**Numerical rating**	**Verbal judgments of preferences**
9	Extremely preferred	5	Strongly preferred
8	Very strongly to extremely	4	Moderately to strongly
7	Very strongly preferred	2	Equally to moderately
6	Strongly to very strongly	1	Equally preferred

The values given in this scale are used in the comparison of the criteria with each other. For example, criteria 1 is located in row part, criteria 2 is located in the column part. If criteria 1 is "strongly preferred" according to criteria 2, its value will be "5". However, when the criteria 2 is located in row part and the criteria 1 is located in column part, the situation will be the opposite, and the value will be 1/5. Because criteria 2 will be preferred at the rate of 1/5 according to criteria 1. This way “A” matrix is created (Table 5).

Table 5
Matrix A

	Criteria “1”	**Criteria “2”**	**………**	**Criteria “(n)”**
Criteria “1”	W1/W1	W1/W2	………	W1/Wn
Criteria “2”	W2/W1	W2/W2	………	W2/Wn
Criteria “(n)”	Wn/W1	Wn/W2	………	Wn/Wn

Step 3:
Hierarchical synthesis is now used to weight the eigenvectors by the weights of the criteria and the sum is taken over all weighted eigenvector entries corresponding to those in the next lower level of the hierarchy (Al-Harbi, 2001).

Step 4:
Having made all the pair-wise comparisons, the consistency is determined by using the eigenvalue, λmax, to calculate the consistency index, CI as follows (Al-Harbi, 2001) (2.1):

$$CI = \frac{\lambda - n}{n - 1} \tag{2.1}$$

The matrix size is represented by the value of "n" in the formulae. The consistency ratio (CR) of CI with the proper value in Table 6 can be used to assess judgment consistency. If the CR does not exceed 0.10, it is acceptable (Al-Harbi, 2001). If it's higher, the judgment matrix is skewed. Judgments should be examined and revised in order to establish a consistent matrix (Al-Harbi, 2001). Finally, the CI value is divided by the standard correction value, known as the Random Indicator (RI), as given in Table 6, to yield the CR value, also known as consistency ratio (2.2).

$$CR = \frac{CI}{RI} \tag{2.2}$$

The value corresponding to the number of factors is selected from Table 6. For example, the RI value to be used in a 3-factor comparison will be 0.58 according to Table 6.

Table 6
Random indicator

"n"	"RI"	"n"	"RI"	"n"	"RI"
1	0.00	6	1.24	11	1.51
2	0.00	7	1.32	12	1.53
3	0.58	8	1.41	13	1.56
4	0.90	9	1.45	14	1.57
5	1.12	10	1.49	15	1.59

AHP Method in This Study

Pair-wise comparison matrix was created. Numerical rating was made between criteria according to table 4 (Table 7). The calculations for these items will be explained next for illustration purposes. Synthesizing the pair-wise comparison matrix is performed by dividing each element of the matrix by its column total. For example, the value 0.10 (C1-C1) in Table 8 is obtained by dividing 1 (from Table 7) by 10.31, the sum of the column items in Table 7 (1 + 1/3 + 1/5 + 1/4 + 1/5 + 1/3 + 5 + 3). The priority vector in Table 8 can be obtained by finding the row averages. For example, the priority of contractor A with respect to the criterion `experience' in Table 8 is calculated by dividing the sum of the rows (0.10 + 0.21 + 0.22 + 0.22 + 0.22 + 0.21 + 0.08 + 0.06) by the number of contractors (columns), i.e., 8, in order to obtain the value 0.16. The priority vector for experience, indicated in Table 8, is given below.

Table 7
Pair-wise comparison matrix

Factors	C1	C2	C3	C4	C5	C6	C7	C8
Land cover (C1)	1	3	5	4	5	3	1/5	1/3
Slope (C2)	1/3	1	3	2	3	1	1/5	1/3
Aspect (C3)	1/5	1/3	1	1/2	1	1/3	1/5	1/3
Altitude (C4)	1/4	1/2	2	1	2	1/2	1/5	1/3
Settlement (C5)	1/5	1/3	1	1/2	2	1/3	1/5	1/3
Road (C6)	1/3	1	3	2	3	1	1/5	1/3
Precipitation (C7)	5	5	5	5	5	5	1	3
Temperature (C8)	3	3	3	3	3	3	1/3	1

Table 8
Synthesized matrix for experience

Factors	C1	C2	C3	C4	C5	C6	C7	C8	Priority vector
Land cover (C1)	0.10	0.21	0.22	0.22	0.22	0.21	0.08	0.06	0.16
Slope (C2)	0.03	0.07	0.13	0.11	0.13	0.07	0.08	0.06	0.08
Aspect (C3)	0.02	0.02	0.04	0.03	0.04	0.02	0.08	0.06	0.04
Altitude (C4)	0.02	0.04	0.09	0.06	0.09	0.04	0.08	0.06	0.06
Settlement (C5)	0.02	0.02	0.04	0.03	0.04	0.02	0.08	0.06	0.04
Road (C6)	0.03	0.07	0.13	0.11	0.13	0.07	0.08	0.06	0.08
Precipitation (C7)	0.48	0.35	0.22	0.28	0.22	0.35	0.40	0.50	0.35
Temperature (C8)	0.29	0.21	0.13	0.17	0.13	0.21	0.13	0.17	0.18
λmax =8.71, CI = 0.10, RI = 1.41, CR = 0.07 < 0.1 OK.									

The model was created specifically for this study and is based on the statistical weights established in the preceding item for each variable (2.3).

IR= (0.35 X Prec + 0.18 X Temp. + 0.16 X Cover + 0.08 X Slo. + 0.08 X Road + 0.06 X Alti + 0.04 X Asp. + 0.04 X Set.) (2.3)

When the importance of the factors is compared in terms of forest fire risk, precipitation was the highest with a value of 35% ((Eq. 3, (0.35 x 100 = 35)). Then there was temperature (C8) with 18%, and land cover (C1) with 16%. Now, estimating the consistency ratio is as follows (2.4):

$$= 0.16\begin{bmatrix}1.00\\0.33\\0.20\\0.25\\0.20\\0.33\\5.00\\3.00\end{bmatrix} + 0.08\begin{bmatrix}3.00\\1.00\\0.33\\0.50\\0.33\\1.00\\5.00\\3.00\end{bmatrix} + 0.04\begin{bmatrix}5.00\\3.00\\1.00\\2.00\\1.00\\3.00\\5.00\\3.00\end{bmatrix} + 0.06\begin{bmatrix}4.00\\2.00\\0.50\\1.00\\0.50\\2.00\\5.00\\3.00\end{bmatrix} 0.04\begin{bmatrix}5.00\\3.00\\1.00\\2.00\\2.00\\3.00\\5.00\\3.00\end{bmatrix} + 0.08\begin{bmatrix}3.00\\1.00\\0.33\\0.50\\0.33\\1.00\\5.00\\3.00\end{bmatrix} + 0.35\begin{bmatrix}0.20\\0.20\\0.20\\0.20\\0.20\\0.20\\1.00\\0.33\end{bmatrix} + 0.18\begin{bmatrix}0.33\\0.33\\0.33\\0.33\\0.33\\0.33\\3.00\\1.00\end{bmatrix} = \begin{bmatrix}1.40\\0.70\\0.32\\0.47\\0.36\\0.70\\3.20\\1.70\end{bmatrix} \quad (2.4)$$

Dividing all the elements of the weighted sum matrices by their respective priority vector element, we obtain:

$$\frac{1.40}{0.16} = 8.75 \quad \frac{0.70}{0.08} = 8.75 \quad \frac{0.32}{0.04} = 8.00 \quad \frac{0.47}{0.06} = 7.84 \quad \frac{0.36}{0.04} = 9.00$$

$$\frac{0.70}{0.08} = 8.75 \quad \frac{3.20}{0.35} = 9.14 \quad \frac{1.70}{0.18} = 9.44$$

$$\lambda\text{max} = \frac{(8.75 + 8.75 + 8.00 + 7.84 + 9.00 + 8.75 + 9.14 + 9.44)}{8} = 8.71$$

Now, we find the consistency index, CI, as follows:

$$CI = \frac{\lambda_{\max -} n}{n-1} = \frac{8.71 - 8}{8 - 1} = 0.10$$

For statistical purposes, forest fire risk for the state was represented in five classes divided into natural break as follows: low risk, moderate risk, high risk, very high risk, and extreme risk. It should be remembered that this study was conducted in an area where the temperature values were not high and the amount of green areas was low. Parameters which are used in studies, may change according to climate types and land uses and land cover.

3. Results and Discussion

The map that was created within the scope of the study, are given in Figure 3-4 and. The areas and percentages of the factors are given in Table 9. Finally, all factors were used as stated in Equation 3, and the forest risk map of the study area was obtained. The study area has approximately 835.65 km^2 of area at low risk, 2,199.03 km^2 at moderate risk, 3,390.92 km^2 at high risk, 1,142.0 km^2 at very high risk, and 227.62 km^2 at extreme risk, representing 10.72%, 28.21%, 43.50%, 14.65%, and 2.92% of Nigde, respectively (Figure 5).

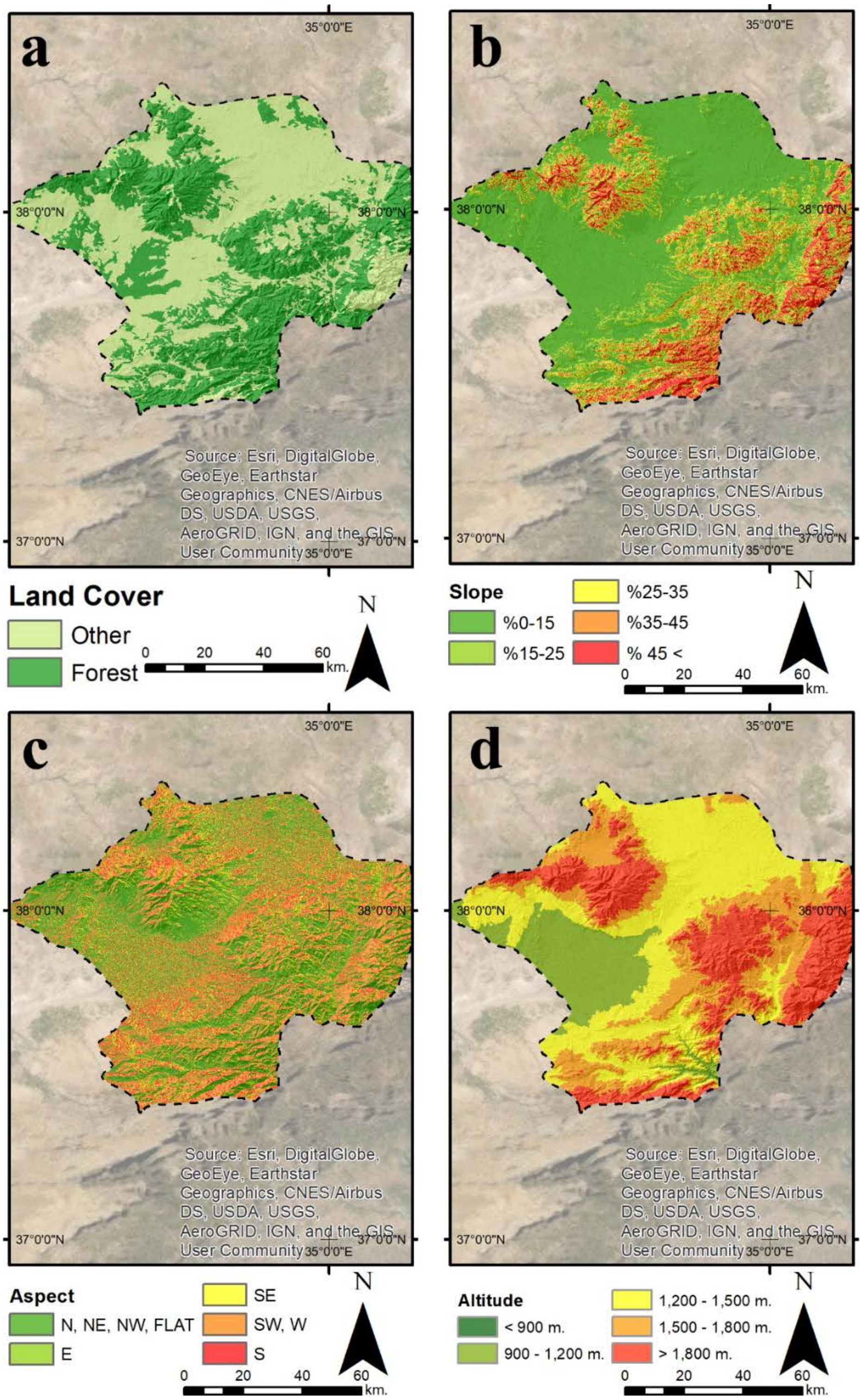

Figure 3. a) land cover, b) slope, c) aspect, d) altitude

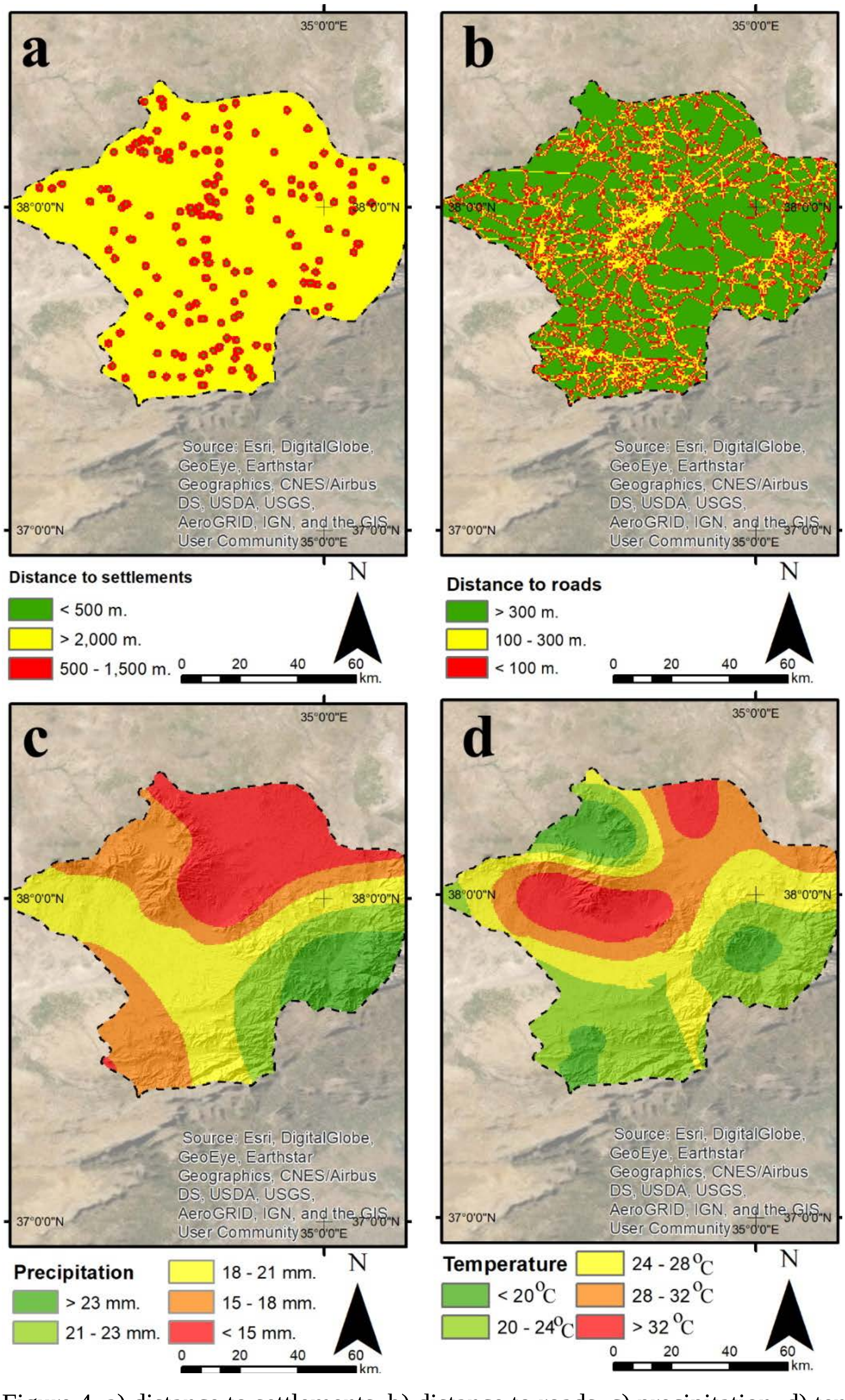

Figure 4. a) distance to settlements, b) distance to roads, c) precipitation, d) temperature

Table 9
The areas and percentages of the factors in the study area

Factors	Classification	Value	Percent (%)	Factors	Classification	Value	Percent (%)
Land Cover	Forest	7	29.69	**Slope (%)**	0-15	1	55.75
	Other	1	70.31		15-25	2	14.46
Distance to roads (m)	< 100	6	20.25		25-35	3	10.98
	100 - 300	4	16.27		35-45	4	7.97
	> 300	2	63.49		>45	5	10.83
Aspect	N, NE, NW, and FLAT	1	8.91	**Altitude (m)**	< 900	1	0.02
	E	2	26.95		900 – 1,200	2	13.99
	SE	3	28.54		1,200 – 1,500	3	36.58
	SW and W	4	6.21		1,500 – 1,800	4	24.61
	S	5	29.39		> 1,800	5	24.80
Precipitation (mm)	< 15	5	9.87	**Temperature (ºC)**	< 20	1	0.20
	15 – 18	4	13.97		20 – 24	2	5.81
	18 – 21	3	34.85		24 – 28	3	66.94
	21 – 23	2	23.71		28 – 32	4	26.17
	> 23	1	17.60		> 32	5	0.88
Distance to settlements (m)	< 500	1	1.31				
	500-2000	7	10.77				
	> 2000	3	87.92				

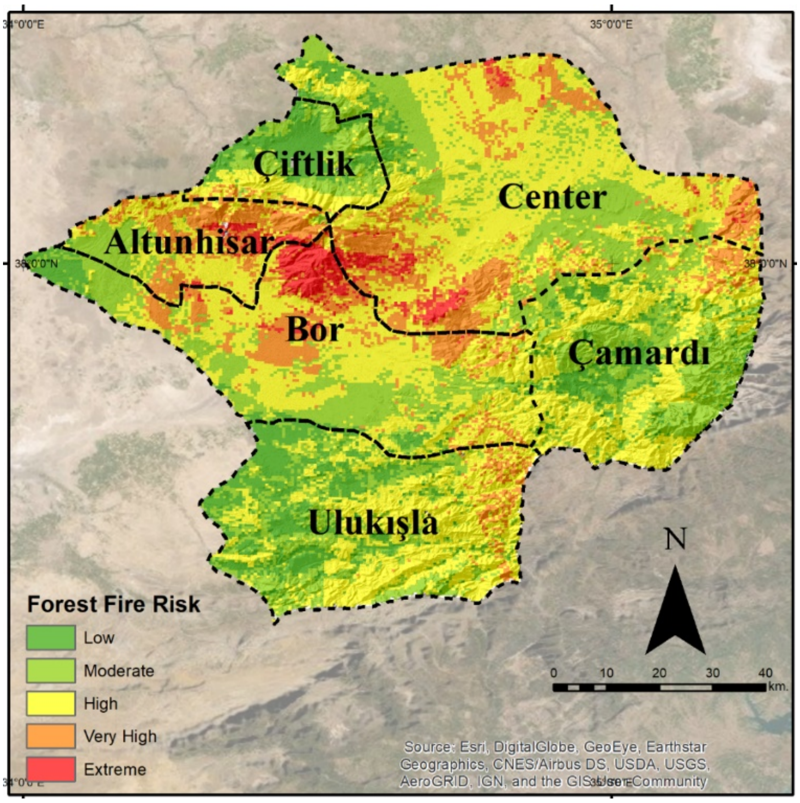

Figure 5. Forest fire risk map of Nigde

In quantitative terms, the largest portion of the study area (27.24%) was classified as very high and extreme risk, which is shown in Figure 6. Lower and upper limit values of fire hazard indices which were calculated for forest fire risk areas, are given in Table 10.

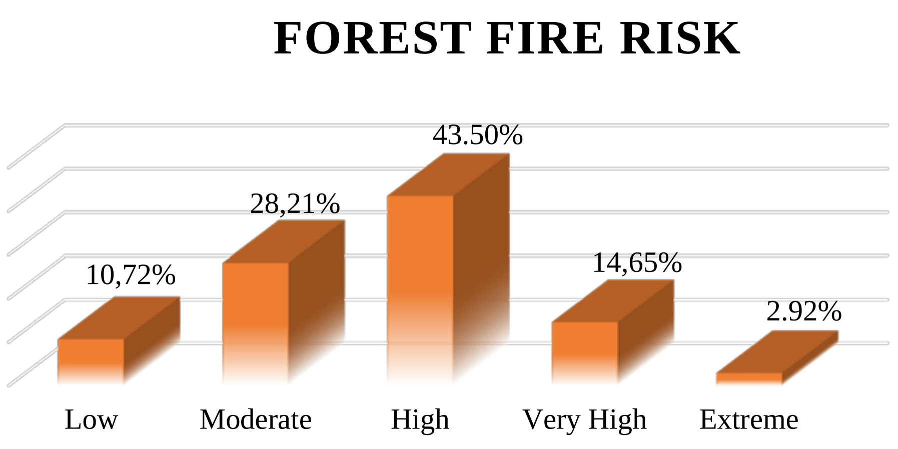

Figure 6. Forest fire risk rates

Table 10
Lower and upper limit values for forest fire risk

Risk	Lower Limit	Upper Limit
Low	1.27	2.08
Moderate	2.08	2.90
High	2.90	3.71
Very High	3.71	4.52
Extreme	4.52	5.33

The areas in which 15 fires (see Figure 2) that occurred before in Nigde, were determined on the forest fire risk map. In this way, it was determined how accurate the risk map was. Accordingly, 6 of fires were in extreme risk areas, 2 of fires in very high risk areas, 3 of the fires in high risk areas, 2 of fires in moderate risk areas, and 2 in low risk areas (Table 11). 11 of the previous fires occurred in high, very high and extreme fire risk areas. This shows that the map gives almost accurate results, even if not completely. The forest fire risk of the districts of Nigde was determined (Table 12).

Table 11
Previous fires for control fire risk map

Number	X (m)	Y (m)	Risk Value	Description
1	651788.043	4161741.211	4.91	Extreme
2	652770.255	4173164.446	4.76	Extreme
3	655922.544	4150597.626	5.20	Extreme
4	615540.740	4216452.737	3.70	High
5	604469.879	4217183.416	3.26	High
6	638951.094	4214547.191	4.26	Very High
7	676309.412	4193590.553	4.75	Extreme
8	620870.283	4218308.284	5.43	Very High
9	660392.512	4190208.839	3.58	High
10	668267.781	4173813.433	4.91	Extreme
11	684379.035	4184231.182	5.26	Extreme
12	623958.386	4181212.259	2.85	Moderate
13	628649.304	4174123.210	2.76	Moderate
14	666559.986	4226943.907	1.40	Low
15	668522.730	4242834.430	1.95	Low

Table 12
Forest fire risk in Nigde

Districts of Nigde	Risk	Percent (%)	Area (km2)	Total Area (km2)
Center	Low	15.84	362.95	2,291.43
	Moderate	70.67	1,619.34	
	High	13.49	309.14	
Bor	Low	22.43	357.08	1,591.93
	Moderate	62.90	1,001.31	
	High	14.67	233.54	
Ulukışla	Low	42.13	621.95	1,476.26
	Moderate	57.47	848.43	
	High	0.40	5.88	
Altunhisar	Low	10.09	63.00	624.58
	Moderate	62.30	389.12	
	High	27.61	172.47	
Çiftlik	Low	55.49	290.24	523.09
	Moderate	44.00	230.16	
	High	0.51	2.69	
Çamardı	Low	45.75	589.21	1,287.94
	Moderate	53.77	692.56	
	High	0.48	6.17	
Total		100.00	7,795.22	7,795.22

According to the results of the analysis, the lowest forest fire risk is in Çiftlik and Çamardı districts, and the highest forest risk is in Center and Bor district. Especially the volcanic Melendiz Mountains, located in the northwest of Niğde, attract attention as the areas with high fire risk. In these areas, most of which are covered with steppe vegetation such as *Astragalus angustifolius* Lam., *A. microcephalus* Willd., *A. acmophyllus* Bunge, *Thymus sipyleus* Boiss., *Salvia absconditiflora* Greuter & Burdet., *Festuca valesiaca* Schleich. ex Gaudin., *Eremogone ledebouriana* (Fenzl) Ikonn., *Bromus tomentellus* Boiss. and herbaceous species such as *Dactylis glomerata* L., *Stipa pulcherrima* K.Koch and *Poa bulbosa* L. are common (Kenar, 2014). The vegetation type of the area is one of the main factors affecting the fire, and plants with aromatic essential oils such as *Thymus sipyleus* and *Salvia absconditiflora* can be burn quickly and easily. Likewise, Poaceae members such as *Festuca valesiaca, Bromus tomentellus, Dactylis glomerata, Stipa pulcherrima* and *Poa bulbosa*, which spread in the area, can burn very quickly and easily, especially in dry periods. *Astragalus* species, which have branched woody stems, are among the plants that cause fire in steppe vegetation as a result of the deliberate burning by sheep herders. *Quercus pubescens* Willd., *Q. trojana* Webb, *Q. cerris* L., *Q. vulcanica* Boiss. & Held. ex Kotschy and *Quercus ithaburensis* subsp. *macrolepis* Hedge & Yalt. the remnant forests formed by the taxa spread in small communities between 1500-2000 meters. Although *Quercus* species are resistant to fire, *Juniperus oxycedrus* L. seen among these relic *Quercus* communities shows an easy and fast burn feature due to the aromatic oils it contains.

The most relevant parameters in terms of forest fire risks in the formula utilized within the scope of the study (Eq. 3.) were temperature, precipitation, and land use. According to the results of the study conducted by the Nigde Forestry Directorate in 2019, the highest forested area in Nigde is in Ulukışla district (Nigde Forestry Directorate, 2019). Most of these forests are “coppice forest”. The reason why Ulukışla district is less risky than other districts in the study is that it receives too much rain and the temperature is low. Although forested areas in Merkez and Bor districts are less than other districts, fire risk is high in this district. The reason for this is high temperature, little rainfall and proximity to roads and settlements. Excessive forest areas did not affect the fire risk as much as some of the factors used in this study. Rainfall and temperature are more important in terms of fire risk than land use. As a result of the changes in precipitation and temperature values in the districts of the study area, forest fire risk results differed. Climatic factors are the most important factors in terms of forest fire risk. Among the physical factors, the most important factor is land use/land cover because forest fire risk changes according to the land use type. Areas which have high forest presence and forest areas close to the road, have a high risk of forest fire. However, the risk of forest fire is lower in areas which have low forest presence or high urban structure. These factors are followed by slope, road, altitude, aspect and settlements, respectively. It should not be forgotten that the factors were used in Nigde where the temperature is not high, and the green areas and the amount of precipitation are low.

Weight coefficients of these factors may vary depending on regional characteristics. Topographic features are among the high environmental physical factors in fire formation and fire behaviour. Especially the altitude, slope and aspect conditions of the topography play a determining role in this context. These factors are seen as a critical parameter since the probability of forest fires decreases due to the increase in altitude. It is observed that 96% of forest fires are at altitudes lower than 1700 m. (Özşahin, 2014). These reasons for this study can be listed as follows:

- Increasing precipitation with increasing altitude,
- The temperature decreases with increasing altitude,
- Very few settlements in high areas (they are used only at certain times of the year; mostly as a summer residence),
- Most of the areas defined as forest are degraded forest lands.

Other topographic features that are effective in forest fires, are slope and aspect. In areas with high slope values, fire progression is faster, while in areas with slope decreases, the rate of fire progression is slower (Özşahin, 2014; Bingöl, 2017). Therefore, it should be more sensitive to the risk of fire, especially in high slope forest areas. Another reason for the occurrence of forest fires, especially those of human origin, is roads. Because the movements of people and vehicles on the roads, these areas are the main reason for this situation. For this reason, in the studies on forest fire sensitivity analyses, the sections of forests close to the road have been defined as areas with high fire sensitivity. AHP method was used in the study. The method was found suitable for determining the risk of forest fire. The positive properties of the method are the qualitative concepts turn into the quantitative concepts, the evaluation of the data in a certain hierarchy. The prequalification criterion may be prioritized using the AHP, and a descending-order list of contractors can be created to find the best contractors for the job. To test the sensitivity of final conclusions to modest changes in judgments, a sensitivity analysis can be undertaken (Al Harbi, 2001). However, with the increase in the number of factors which is preferred in the study, we can say that the method has problems in classification. Therefore, it can be suggested to be used in a study with a maximum of 8 factors. However, in general, the method should be preferred because it can be verified and provable in such studies.

Studies which use this method, were examined. Dilekçi et al. (2019) used AHP method in their study which was named "Zonguldak and Eregli Forest Management Directorates of Forestry Fire Risk Areas Determination”, tested the method. Kovacs et al. (2004) in their study which was named “Examining Local Ecological Knowledge of Hurricane Impacts in a Mangrove Forest Using an Analytical Hierarchy Process (AHP) Approach”, used AHP method. They examined the observations of fishermen regarding the impact of a hurricane on a mangrove forest of the Mexican Pacific, twenty-two structured interviews using an Analytical Hierarchy Process (AHP) approach were conducted in four villages of the Teacapán-Agua Brava lagoon-estuarine system. Ljubomir et al. (2019) used AHP method in the study which was named “Modeling the Spatial Variability of Forest Fire Susceptibility Using Geographical Information Systems and the Analytical Hierarchy Process”. Vadrevu et al. (2010) stated that AHP is an important decision making matrix that determines the causative factors of forest fires and can be easily used in such studies. Mahdavi et al. (2012) and Soydan (2021) emphasized that GIS and AHP are useful method to understand important factors in the management of forest fires.

The Remote Sensing and Geographic Information Systems techniques are widely and effectively used by many countries. The use of Remote Sensing and Geographic Information Systems techniques will provide significant contributions to the planners by providing effectiveness in our country's fire management plans. Especially, it is important to establish and monitor fire safety zones as soon as possible in settlements with high fire risk in the forest and adjacent forests and to prevent possible loss of life and property. Nigde is a region with more agricultural activities. Although there are many historical sites in the region, they are far from forested areas. This reduces the risk of forest fire due to human activities. However, many fire events occur in the region caused by agricultural activities. Therefore, it is necessary to raise awareness of agricultural producers in this area and to increase measures against forest fires in the Nigde region.

4. Conclusion and Recommendations

In this study, the effect of some geographic parameters on the distribution of forest fire sensitivity was analysed in Nigde. The analysis was carried out according to AHP method with GIS techniques. In the analysis, factors affecting the risk of forest fire (land use/land cover, altitude, slope, aspect, distance to settlement, distance to road lines, precipitation, and temperature) were mapped. According to the AHP method of the study, the most dominant factor which was used among the parameters for determining forest fire risk, was precipitation. In the formula for determining the fire risk created using the AHP method (Eq. 3), precipitation was the highest factor with a factor of “0.35”. This was especially the determining factor in obtaining the final risk map. Because areas with high forest area but less rainfall are less risky than areas with less forest area but high rainfall.

In urban planning, the multifaceted effects of population values, which are an important indicator in the formation of cities, should be taken into consideration. In addition to inputs such as population, transportation, green tissue, and building typology, microclimatic results should also be considered. The world's largest source of natural wealth are forests, and they must be well protected in terms of providing ecological and environmental benefits, as well as being vital in ensuring natural balance. As in the rest of the world, forest fires are the leading damages to forests in our country. Especially in the Mediterranean region, which has the most conditions for the occurrence of forest fires, the necessary measures should be taken to determine fire management and fire damage detection systematically. On the other hand, forests, especially in developing countries, are under great pressure. These countries are cutting their forests at an extreme level in order to find the necessary financial resources for them and thus destroying them. In Turkey, deliberate fires occur in forest areas. These areas are desired to be removed from forest characteristics. These areas are transformed into accommodation areas such as hotels, hostels and hostels due to their natural wealth. Such activities for economic gain cause reduced forest areas in Turkey. When the causes of forest fires between 1997-2006 occurring in Turkey examined; It was determined that 57.86% of forest fires were the result of negligence-carelessness-accident, and 13.40% of them were the result of intent (Hasdemir et al., 2009). A comprehensive fight plan should be prepared against large forest fires that occur periodically in our country. In order to meet this plan, equipment and other needs should be completed as soon as possible. The exchange of information, technology, experience and equipment between countries in combating forest fires will be the most accurate and effective way to succeed in this fight. Under the different climatic, vegetation and topography conditions of the world, it will be known in advance how to deal with similar types of fires by examining various forest fires. To this end, exchange of fire fighting personnel and scientists between countries will enable the existing information to grow and spread.

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