Natural Hazards (2020) 104:73–89
https://doi.org/10.1007/s11069-020-04158-7

ORIGINAL PAPER

Producing forest fire susceptibility map via multi-criteria decision analysis and frequency ratio methods

Deniz Arca[1] · Mercan Hacısalihoğlu[2] · Ş. Hakan Kutoğlu[3]

Received: 17 December 2018 / Accepted: 2 July 2020 / Published online: 10 July 2020

Abstract

Located in the Mediterranean basin, one of the world's leading places in terms of forest fires, Turkey is one of the countries where forest fires are experienced very often due to both natural and socio-economic conditions. The objective of this study is to conduct a forest fire susceptibility analysis within the boundaries of Karabük Forestry Directorate. This analysis was conducted considering the factors affecting the forest fire risk (elevation, slope, aspect, distance to road lines, distance to settlement, land surface temperature and stand type). The factors used in the study were analyzed using geographic information systems (GIS) techniques and analytic hierarchy process method and frequency ratio method. The forest fire susceptibility map produced was classified in 5 categories including very low, low, moderate, high and very fire susceptibility. In order to see how much the forest fire susceptibility map produced corresponds to reality, the forest fire susceptibility maps and the forest fire inventory map were highly compared, and a 73.92% correspondence was detected according to the multi-criteria decision analysis method, while a 76.42% correspondence was detected in the frequency ratio method. As a result, it was concluded that high- and very high-sensitive areas were dominant in the study area, and the site had a high forest fire potential. Ultimately, this study indicated that GIS could be used as a tool to help make effective decisions during forest fire planning.

Keywords Multi-criteria decision analysis · Frequency ratio method · GIS · Forest fire susceptibility map · Karabük

✉ Deniz Arca
deniz.arca@deu.edu.tr

Mercan Hacısalihoğlu
mercanhacisalihoglu@ogm.gov.tr

Ş. Hakan Kutoğlu
shakan.kutoglu@beun.edu.tr

[1] Department of Izmir Vocational School, Dokuz Eylul University, Izmir, Turkey

[2] Zonguldak Forest District Directorate, 67000 Zonguldak, Turkey

[3] Department of Geomatics Engineering, Faculty of Engineering, Bülent Ecevit University, 67100 Zonguldak, Turkey

1 Introduction

Forests are natural resources that should be protected very well due to their contributions to sustainability of the ecological balance and to the economy. However, fires caused by natural and human reasons are the most extreme disaster for these areas. Forest fires are global phenomenon that are caused by natural or human reasons, sometimes lead to loss of life and property (Bento Gonçalves et al. 2012). Forest fires pose a major natural risk for Turkey, a Mediterranean country. Forest fires have increased in recent years as a result of climate change, global warming, socio-economic change and inappropriate forest planning and have negative effects on soil fertility and structure (Vieira et al. 2011). Forest fires that have occurred in the last 60 years in Turkey destroyed 1.5 million hectares of forest lands.

Forest fire susceptibility studies should be carried out to reduce damages of forest fires, since it is impossible to prevent occurrence of forest fires completely. Forest fire susceptibility maps zone forest areas relatively in terms of occurrence of forest fires at a certain geographical location. The main objective of forest fire susceptibility analysis is to reduce the impacts of forest fires by identifying the hazardous and risky areas. In recent years, many studies have been conducted both in the world and Turkey to identify model location of forest fires, to monitor fire formation, to organize fire extinction operations, and to determine damages caused by fire. These studies are mostly conducted with the support of geographic information systems (GIS) (Şahin and Gümüşay 2007). Thus, all data can be analyzed in a systematic and practical way (Fox and Stuart 1994; Bahadır 2010).

A forest fire occurs when many geographical parameters such as elevation, slope, aspect, distance to road and settlement come together under appropriate conditions. GIS provides great convenience in evaluation of a large number of geographic parameters with variable values and in analysis of the events and phenomena emerging under control of these geographic parameters (Karabulut et al. 2013).

In this study, Merkez and Ovacık districts of Karabük province located in the Western Black Sea Region were selected as the study area. The objective of the study is to produce forest fire susceptibility map for the study area using multi-criteria decision analysis and frequency ratio methods. The factors such as elevation, slope, aspect, distance to road lines, distance to settlement, land surface temperature and stand type were used to produce forest fire susceptibility map of the study area. The forest fire susceptibility map produced as a result of the study was categorized in five susceptibility classes, and these data were examined by superposing the same with the forest fire inventory map of the region for the years 2012-2016 and comparing the truth values obtained for each susceptibility range.

2 Study area

Karabük province, which is located in the Western Black Sea Section of the Black Sea Region and has a surface area of 4.109 km^2, is located between 40° 57′ and 41° 34′ north latitudes and 32° 04′ and 33° 06′ east longitudes. It is adjacent to Bartın province (80 km) in the north, to Kastamonu province (112 km) in the northeast and east, to Çankırı province (193 km) in the southeast, to Bolu province (134 km) in the southwest and to Zonguldak province (102 km) in the west. (URL-1).

Karabük province consists of 6 districts including Merkez, Safranbolu, Yenice, Eskipazar, Eflani and Ovacık. This study was conducted within the boundaries of Karabük

Forestry Directorate including Merkez and Ovacık districts of Karabük province. The site location map of the boundaries of the study area is presented in Fig. 1. Forests are extremely widespread in Karabük, where mountains occupy a wide area. 65% of the surface area of the province is covered by forest, 22% by agricultural area, and the rest is covered with pasture, settlement and other areas.

3 Data layers used in forest fire susceptibility analysis

Selecting the factors appropriately is one of the most important points in production of the forest fire susceptibility map. The factors such as elevation, slope, aspect, distance to road lines, distance to settlement, land surface temperature and stand type were utilized to produce forest fire susceptibility map as part of the study. The existing forest fire inventory map was utilized with the aim of determining accuracy of the forest fire susceptible areas specified as a result from the analysis.

3.1 Forest fire inventory map

Forest fire inventory maps indicate the current forest fire starting points on the land. Identifying the location of forest fires and their impact areas correctly is of great importance in production of forest fire inventory maps. Forest fire susceptibility maps are of ultimate importance as they serve as the basis for hazard and risk modeling. The objective of forest fire inventory maps is to show distribution of forest fires (Hacisalihoglu 2018).

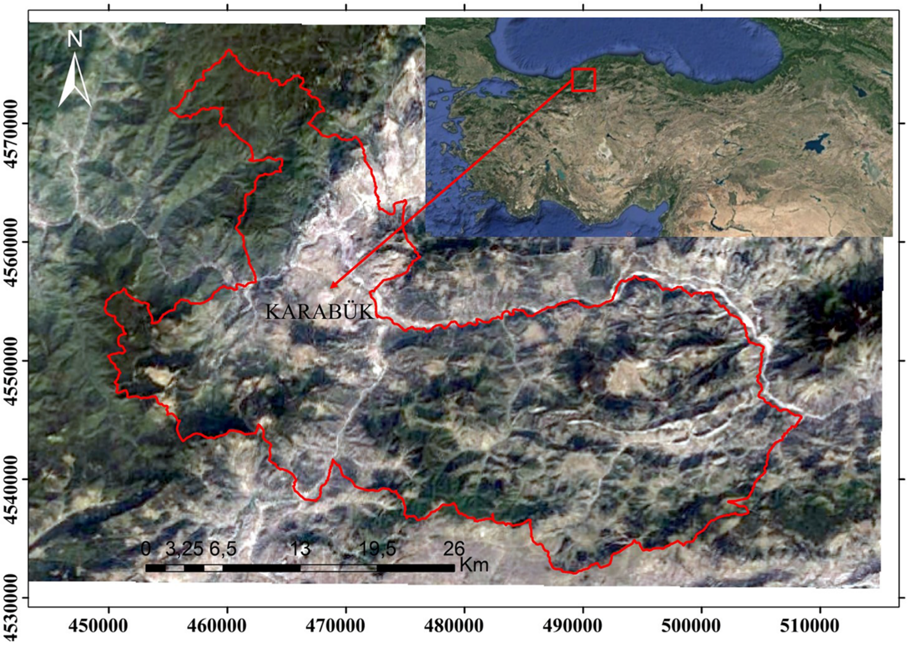

Fig. 1 Location map of the study area

Forest fire inventory map of the study area was generated by transfer into the digital medium, with the help of ArcGIS 10 software, of geographic information and feature information of 123 forest fires included in fire registry forms (2012–2016) of Zonguldak Regional Directorate of Forestry, Karabük Forestry Directorate (Fig. 2).

3.2 Elevation

One of the parameters frequently used in forest fire susceptibility studies is elevation. As the temperature decreases in high areas, the risk of fire outbreak is lower (Gai et al. 2011). On the other hand, the fact that the humidity decreases as the elevation increases leads to an increase in distribution risk of a possible fire (Özelkan 2008). Continuous data in which elevation values expressed by surfaces are required so that the elevation data can be used in GIS analyzes. These continuous data are known as Digital Elevation Model (DEM). DEM data were obtained from 1/25,000-scale digital topographic map sheet of the study area using “Create TIN” command menu in ArcGIS 10 software. In the study, the elevation values obtained from DEM data were defined being divided into 8 classes with 250-m intervals. The elevation map produced is presented in Fig. 3a.

3.3 Slope

In forest fires, slope is one of the most important factors to be considered in forest fire susceptibility studies, as it affects both the rate and direction of fire. Normally, highly sloping areas do not pose a high risk of fire; however, in places with high slope, the rate of progress and spread of fire is high as well. Because sudden slope changes dry surface fuel and

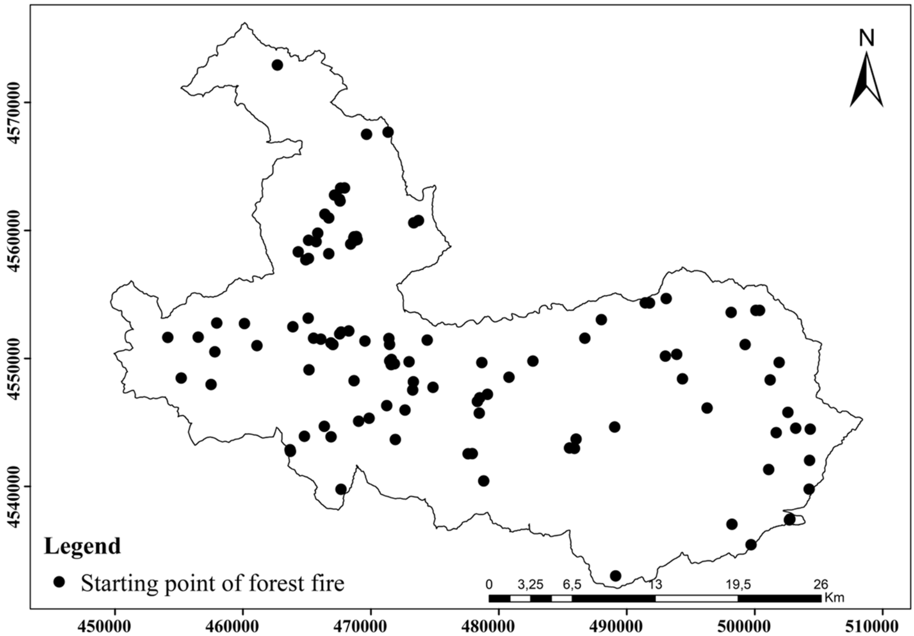

Fig. 2 Forest fire inventory map of the study area

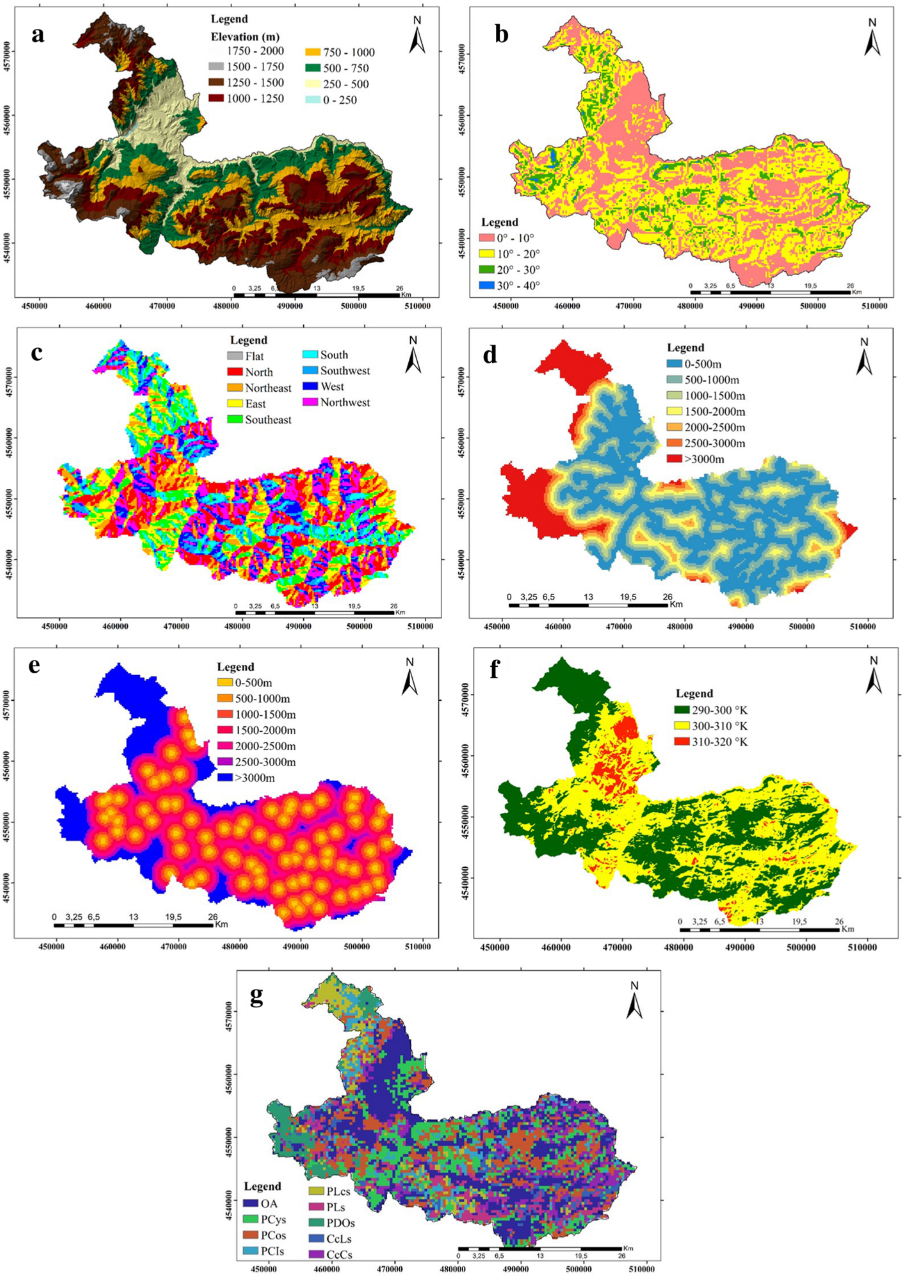

Fig. 3 Forest fire susceptibility parameters used in this study **a** elevation, **b** slope, **c** aspect, **d** distance to road, **e** distance to settlement, **f** land surface temperature, **g** stand type

increase spread of fire by providing a rapid surface flow (Jaiswal et al. 2002; Vadrevu et al. 2010; Gai et al. 2011).

In this study, an elevation map produced from 1/25,000-scale digital topographic map sheet of the study area was used to obtain the slope data. On the slope map produced, the lowest slope degree was 0, and the highest slope degree was 39 (Fig. 3b). The slope map was divided into 4 classes with 10° intervals to be used in susceptibility analyzes. 0°-20° slope class of the study area makes 89.59% of the total area, and around 91.87% of the existing forest fires occurred between these slope classes.

3.4 Aspect

Aspect is one of the basic topographic factors that should be considered in forest fire susceptibility analyzes, due to its effect on sunshine duration and humidity (Karabulut et al. 2013). The significance of the aspect in forest fire susceptibility lies in the fact that it gives relationship of terrain with sunlight and wind and thus greatly influences fire ignition and spread (Jaiswal et al. 2002).

In the Northern Hemisphere where our country is located, fire risk is high on the southward slopes, as the sunshine duration here is more dominant than the north (Özelkan 2008). East facing aspects receive more direct sunlight than the west aspects (Anderson 1982; Bennie et al. 2008). The north-facing aspect has lower temperatures due to less sunlight, so there is less risk of forest fire (Shakesby et al. 2003).

In calculation of the data of slope orientation change (aspect), the digital terrain model (DTM) that was formed for the study area was utilized. On the aspect map produced as part of this study (Fig. 3c), − 1° section covers plain areas (sea, lake, etc.), while 0°–360° range covers 9 geographic directions at 22.5° intervals.

3.5 Distance to road

Forest fires can be caused by nature as well as human. Because of human, vehicle movements and activities on them, roads provide a wide ground for outbreak of human-induced fires. In general, parts of forests that are close to road pose a risk high in terms of fire (Karabulut et al. 2013). Buffer zones were formed at 500-m intervals on the road network of the study area in order to research the effect of road factor on forest fire susceptibility (Fig. 3d).

3.6 Distance to settlement

Parts that are close to settlement, just like roads, pose a high risk for outbreak of fires as a result of human activities, accidents or negligence (Jaiswal et al. 2002; Erten et al. 2005; Joaquim et al. 2007). On the other hand, today, the fact that human activities spread over large areas leads to an increase in fire risk in such areas that are away from settlements (Karabulut et al. 2013).

Buffer zones were formed at 500-m intervals from the settlements of the study area in order to research the effect of settlement factor on forest fire susceptibility (Fig. 3e).

3.7 Land surface temperature

Land surface temperature (LST) is one of the factors to be considered in forest fire susceptibility analysis. LST is a parameter that plays an important role in many ecological modeling such as digital weather forecast, drought index, climatic diversity, determination of energy and water cycle in the atmosphere (Şahin et al. 2011). In this study, land surface temperature map was obtained using the mono window algorithm method developed by Qin et al. (2001). In order to produce LST map (Fig. 3f) were benefited two Landsat 8 and one Landsat 5 data acquired on different dates and the meteorological data (temperature and humidity) obtained on the same date with Landsat images from the Directorate of Meteorology. Meteorological and satellite data acquisition dates are given in Table 1.

3.8 Stand type

Vegetation is one of the most important factors that determines the starting point of forest fires and the fire behavior (Erten et al. 2005; Van de Water and Safford 2011). According to water demands of plants, the response of each plant to fire is different. In other words, those plants with low water demand are more susceptible to fire than those with high water demand (Karabulut et al. 2013).

The stand type map of the study area was obtained from Zonguldak Regional Directorate of Forestry. The stand type map of the study area was categorized in 9 classes including Productive Coniferous young stand (PCys), Productive Coniferous old stand (PCos), Productive Coniferous Leafy stand (PCls), Cavernous closed Coniferous stand (CcCs), Productive Different Old stand (PDOs), Productive Leafy Coniferous stand (PLcs), Productive Leafy stand (PLs), Cavernous closed Leafy stand (CcLs), Open Areas or areas without tree (OA) (Fig. 3g).

4 Methods used in the study

Models based on GIS techniques that were developed to examine and analyze the relationships between different numbers of variables provide great advantages in analyzing and guiding characteristics of ecological problems (Küçükönder and Karabulut 2007; Özşahin and Kaymaz 2013). Multi-criteria decision analysis and frequency ratio methods were used to create forest fire susceptibility maps of the study area.

Table 1 Meteorological data obtained simultaneously when the satellite passes

Landsat data	Meteorological data	
Acquisition date	Temperature (°C)	Humidity (%)
30 August 2006	19.8	44.0
25 July 2013	24.3	37.3
17 July 2016	27.9	42.6

4.1 Multi-criteria decision analysis

Multi-criteria decision analysis is the process of benefiting from a set of alternative resolutions in solution of decision problems and incompatible data and opposite criteria having these criteria (Malczewski 1999). Analytic hierarchy process (AHP) and weighted linear combination (WLC) methods are the leading methods that are preferred most in solution of multi-criteria decision analysis (Ayalew et al. 2004; Zhao et al. 2008; Malczewski et al. 2003). WLC method developed in compliance with AHP was used within the scope of this study. AHP is a method that is not only used in ranking of alternatives according to significance level, but also in analysis and resolution of complex decision-making problems. While performing the analysis operations with this method, people work in a hierarchic structure including all criteria, functions and objects (Yager and Kelman 1999).

AHP begins with paired comparison of factors. AHP Rating Scale developed by Saaty is utilized for the numerical values required to perform paired comparison (Table 2). In the phase of the comparative decision making and formation of preference matrix, the second step of the AHP, the parameters identified in the first stage are compared to each other. The next process in obtaining the comparison matrix is determination of the criteria weights from the summarized relative significances of preferences created for each matrix elements (Boroushaki and Malczewski 2008).

The fact that the comparison matrix enables versatile evaluation allows to determine the criteria with relative significance as well as to determine consistency levels in development of proportions (Saaty 1977). The consistency ratio defines the probability of randomly created matrix grading. The maximum consistency ratio recommended by Saaty is 0.10. If a value above this ratio is obtained, it is necessary to re-establish the problem more accurately and to review the process (Drobne and Lisec 2009). The consistency ratio is calculated as follows;

$$\mathrm{CR} = \frac{\mathrm{CI}}{\mathrm{RI}} \tag{1}$$

RI is the random index value, while CI is the consistency index value that provides the consistency separation criteria. CI value is obtained as follows;

$$\mathrm{CI} = \frac{(\lambda - n)}{(n - 1)} \tag{2}$$

here λ refers to consistency vector average, while n is the criteria number.

Table 2 AHP evaluation scale

Importance degree	Definition
1	Equal degree important
3	First criteria is a little more important than second
5	First criteria is important than second
7	First criteria is more important than second
9	First according to criterion second, it has the strongest possible prescription or is preferred
2,4,6,8	Intermediate values are used when compromise is necessary.

The next stage after obtaining AHP and paired comparison matrix elements and finding factor weights is to combine the criteria with each other and produce the result map. At this stage, the weighted linear combination (WLC) method is used. The purpose of using this method is to normalize the feature values of each factor and to create a conformity index by collecting each normalized criterion. In case of equality, *m* refers to the decision option and n refers to the criteria number (Voogd 1983).

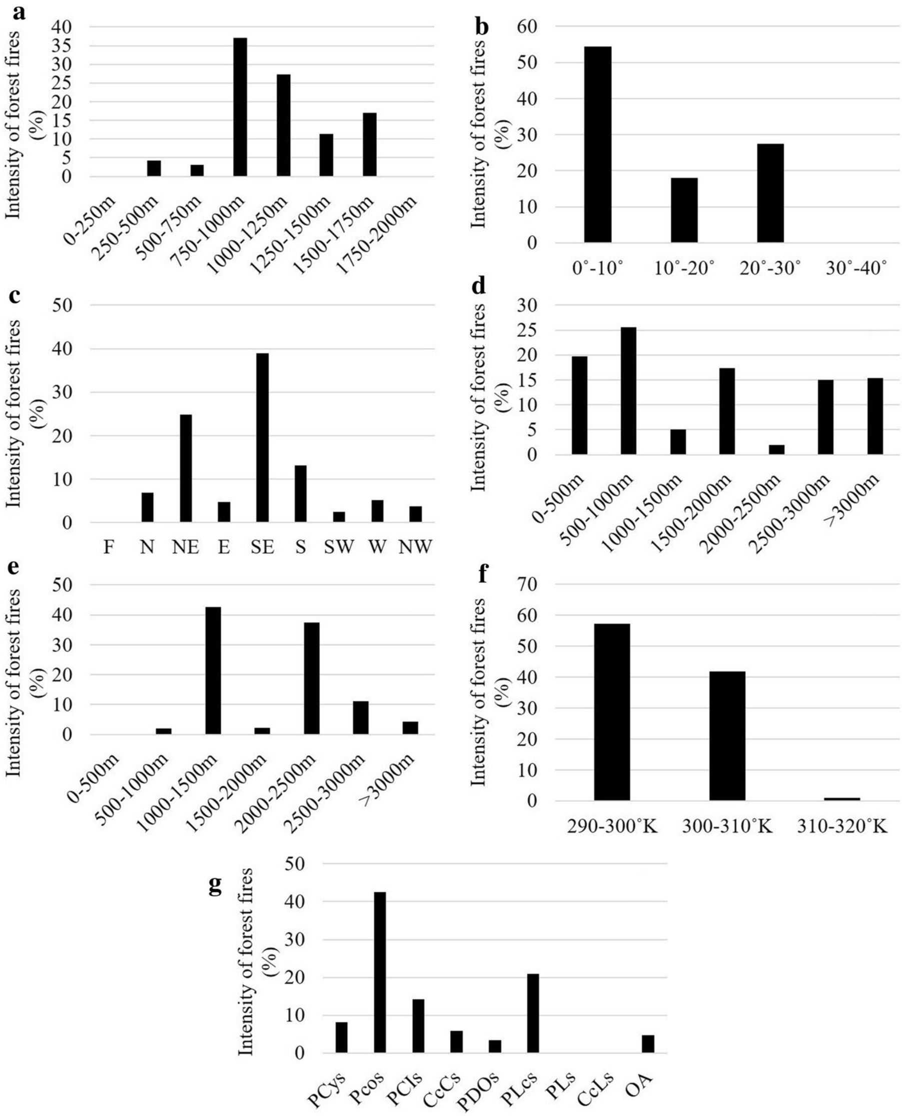

Fig. 4 Frequency values of factors used in forest fire susceptibility map production **a** elevation, **b** slope, **c** aspect, **d** distance to road, **e** distance to settlement, **f** land surface temperature, **g** stand type

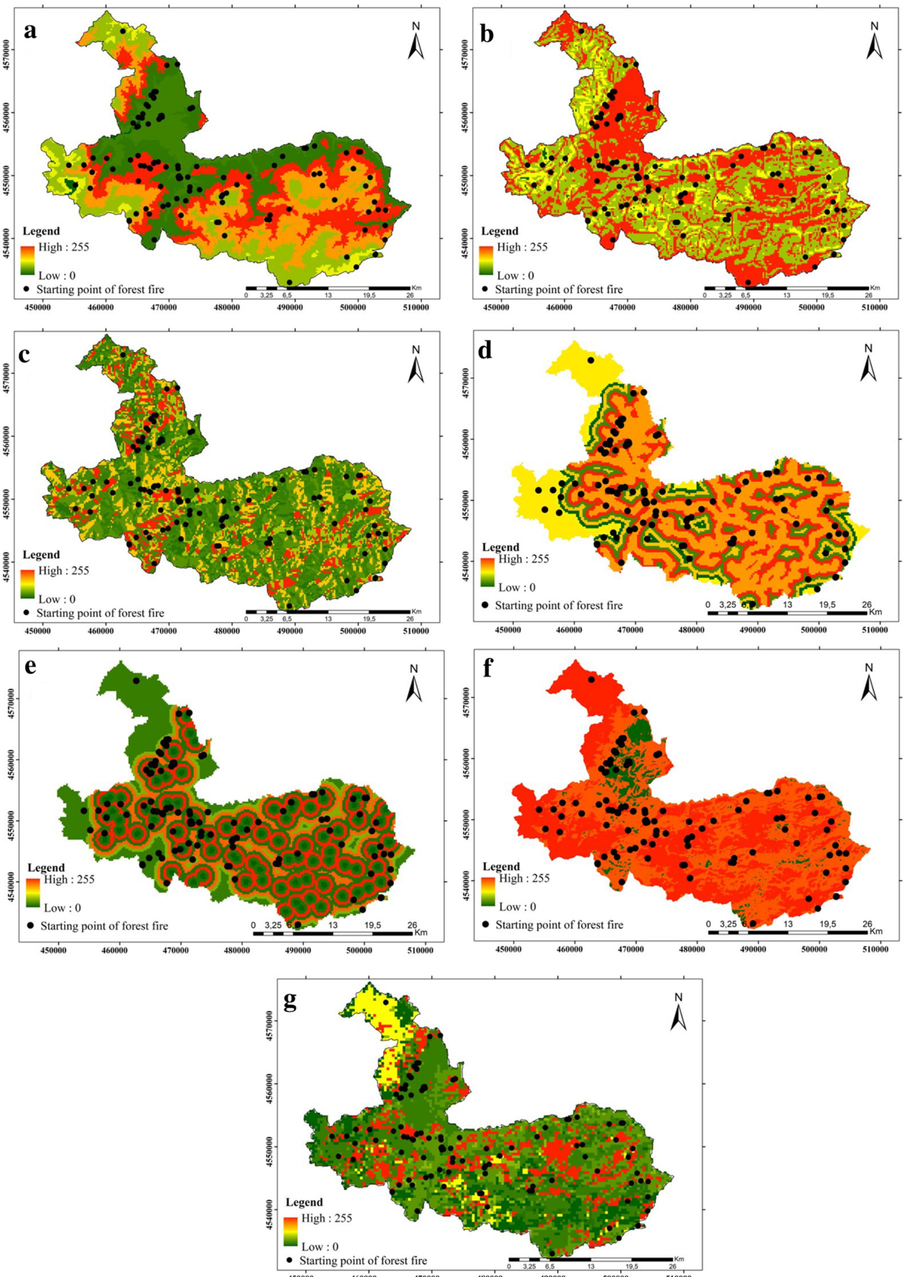

Fig. 5 Maps obtained after normalization of factors used in the production of susceptibility maps **a** elevation, **b** slope, **c** aspect, **d** distance to road, **e** distance to settlement, **f** land surface temperature, **g** stand type

$$e_i = \sum_{j=1}^{n} w_j * r_{ij}, (\dot{I} = 1, \dots, m) \tag{3}$$

The first step in development of multi-criteria decision analysis in the digital GIS database is to standardize features of factors/criteria. Each criterion in available data has its own feature values, and is different from and incompatible with other criterion values. For this reason, it is necessary to perform normalization processes before the processes of collecting decision rules (AHP and WLC) and factors (Kavzoglu et al. 2010). Figure 4 presents the frequency values of each factor used in the study, which were created using the forest fire inventory map. In this way, it is seen which factor is how much sensitive to any forest fire situation in which range. In the light of obtained values, eigenvalues of the factors were normalized by scoring in the range of 0-255 (Fig. 5).

Following normalization of factors, paired comparison method was applied with the aim of determining relative significance of each factor to each other. The comparison values used in the method were chosen by decision-makers. Also, literature and expert opinions were utilized to determine these values within the scope of this study. The weight of each criterion was calculated and indicated after the comparison matrix (Table 3). In the study area, the criterion with the highest weight was slope. Slope was followed by elevation, aspect, land surface temperature, stand type, distance to road lines and distance to settlement, respectively.

The consistency ratio was calculated to determine whether or not the values in the created comparison matrix and the calculated weights were consistent. The consistency ratio was found to be 0.03. This rate was below 0.10, which was accepted as the highest value (Saaty 1977). Thus, it was not necessary to repeat the paired comparison method. Following the results obtained, all criteria were collected using WLC method, and the forest fire susceptibility map was created.

4.2 Frequency ratio method

The frequency ratio method has a probability model that is understandable and easy to apply, and it is widely used in the literature thanks to this feature. The frequency ratio was defined as the ratio of the occurrence probability to the non-occurrence probability of an event (Lee et al. 2004; Lee and Evangelista 2005; Erener et al. 2010). The frequency ratio method was used to research the correlation between locations of the past forest fires and each factors affecting the subject forest fire. For this reason, factors affecting each forest

Table 3 The pair-wise comparison matrix and parameter weights

Parameters	Slope	Elevation	Aspect	Land surface temperature	Stand type	Distance to road	Distance to settlement	Parameter weights
Slope	1	2	2	3	6	2	2	0.27
Elevation	1/2	1	1	3	5	1	1	0.16
Aspect	1/2	1	1	3	5	2	2	0.20
Land surface temperature	1/3	1/3	1/3	1	3	1/2	1/2	0.07
Stand type	1/6	1/5	1/5	1/3	1	1/4	1/4	0.04
Distance to road	1/2	1	1/2	2	4	1	1	0.13
Distance to settlement	1/2	1	1/2	2	4	1	1	0.13

fire were categorized, and the frequency ratio value in each category of each factor was calculated using GIS functions. Formula No. 4 was used to calculate the frequency ratio.

$$\mathrm{FR} = \frac{\mathrm{PLO}}{\mathrm{PIF}} \tag{4}$$

here PLO is the percentage of forest fire presence occurring within each sub-category of a parameter affecting the forest fire; the PIF is the percentage of each category of a parameter affecting the forest fire. In the frequency ratio calculation table, PLO was calculated as A/B and PIF as C/D. In these correlations, B refers to the total forest fire cell number in the study area, while D refers to the total cell number in the study area (Erener and Lacasse 2007). If the calculated frequency ratio values are above 1, the risk of forest fire is higher; on the contrary, the lower the value is than 1, the lower this relationship will be. Based on this approach, a probability schedule was prepared using the existing forest fire data and related parameter relationships to calculate the frequency ratio values (Table 4).

The frequency ratio calculated for each category was assigned to the relevant layer in ArcGIS 9.3.1; then the forest fire susceptibility map was created by overlapping all layers.

5 Discussion

In this study, two different methods were used to produce forest fire susceptibility maps, and forest fire inventory map was utilized to test the accuracy of these methods. The forest fire susceptibility maps created were reclassified to make it easier to interpret them, and as a result, five forest fire susceptibility classes were created from very low susceptibility level to very high susceptibility level. Areal and percentage distributions of susceptibility classes in the study area were determined as a result of analyzes, and it was determined how much each group was effective in which area.

As a result of the analyzes made on the forest fire susceptibility map created via multi-criteria decision analysis method, very low forest fire susceptibility was found to be 0.62%, low susceptibility 4.87%, moderate susceptibility 39.95%, high susceptibility 50.91% and very high susceptibility 3.65% (Fig. 6).

In order to determine the accuracy of the forest fire susceptibility map, the forest fire susceptibility map was overlapped with the forest fire inventory map of the study area, and distributions of the existing forest fire areas by their susceptibility classes were determined. Accordingly, very high susceptibility was determined to be 8.50%, high susceptibility 65.42%, moderate susceptibility 22.83%, low susceptibility 3.25% and very low forest fire susceptibility 0.00%. As a result, 73.92% of the existing forest fire values were found to occur in the high and very high susceptibility areas of the forest fire susceptibility map.

As a result of the analyzes made on the forest fire susceptibility map created via the frequency ratio method, very low was 1.86%, low was 5.01%, medium was 20.39%, high was 46.20% and very high was 26.54% (Fig. 7).

In order to determine the accuracy of the forest fire susceptibility map, the forest fire susceptibility map was overlapped with the forest fire inventory map of the study area, and distributions of the existing forest fire areas by their susceptibility classes were determined. Accordingly, very high susceptibility was determined to be 29.27%, high susceptibility 47.15%, moderate susceptibility 21.14%, low susceptibility 2.44% and very low forest fire susceptibility 0.00%. As a result, 76.42% of the existing forest fire values were found to occur in the high and very high susceptibility areas of the forest fire susceptibility map.

Table 4 Frequency ratio values and parameter associations that were used in the calculation

Parameter	Value	Number of forest fire		Fire-affected area		Frequency ratio
		Piece	%(A)	Ha	%(B)	(B/A)
Elevation (m)	0–250	0	0.00	0.00	0.00	0.00
	250–500	46	37.40	22.59	11.23	0.30
	500–750	19	15.45	6.71	3.34	0.22
	750–1000	20	16.26	86.70	43.10	2.65
	1000–1250	19	15.45	60.47	30.06	1.95
	1250–1500	17	13.82	22.70	11.28	0.82
	1500–1750	1	0.81	2.00	0.99	1.22
	1750–2000	1	0.81	0.01	0.00	0.00
Slope (°)	0–10	61	49.60	148.67	73.90	1.49
	10–20	52	42.28	41.41	20.59	0.49
	20–30	9	7.31	11.09	5.51	0.75
	30–40	1	0.81	0.01	0.00	0.00
Aspect	Flat	0	0.00	0.00	0.00	0.00
	N	24	19.51	19.55	9.72	0.49
	NE	30	24.39	86.91	43.20	1.77
	E	15	12.20	8.37	4.16	0.34
	SE	13	10.57	58.83	29.24	2.77
	S	8	6.50	12.12	6.02	0.93
	SW	6	4.88	1.69	0.84	0.17
	W	10	8.13	6.09	3.03	0.37
	NW	17	13.82	7.62	3.79	0.27
Distance to road lines (m)	0–500	43	34.96	76.93	38.24	1.09
	500–1000	39	31.71	90.58	45.02	1.42
	1000–1500	20	16.26	9.20	4.57	0.28
	1500–2000	8	6.50	12.55	6.24	0.96
	2000–2500	5	4.07	0.88	0.44	0.11
	2500–3000	2	1.62	2.71	1.35	0.83
	> 3000	6	4.88	8.33	4.14	0.85
Distance to settlement (m)	0–500	4	3.25	0.11	0.05	0.01
	500–1000	24	19.51	5.63	2.80	0.14
	1000–1500	24	19.51	111.97	55.66	2.85
	1500–2000	40	32.52	9.74	4.84	0.15
	2000–2500	14	11.38	57.39	28.53	2.51
	2500–3000	11	8.95	13.59	6.75	0.75
	> 3000	6	4.88	2.75	1.37	0.28
Land Surface temperature (°K)	290–300	34	27.64	72.29	35.93	1.30
	300–310	83	67.48	128.69	63.97	0.95
	310–320	6	4.88	0.2	0.10	0.02

Table 4 (continued)

Parameter	Value	Number of forest fire		Fire-affected area		Frequency ratio
		Piece	%(A)	Ha	%(B)	(B/A)
Stand type	PCys	36	29.27	21.27	10.58	0.36
	PCos	54	43.90	165.00	82.02	1.87
	PCIs	4	3.25	4.05	2.01	0.62
	CcCs	15	12.20	6.46	3.21	0.26
	PDOs	2	1.63	0.51	0.25	0.15
	PLcs	1	0.81	1.5	0.75	0.92
	PLs	1	0.81	0.005	0.00	0.00
	CcLs	3	2.44	0.02	0.00	0.00
	OA	7	5.69	2.37	1.18	0.21

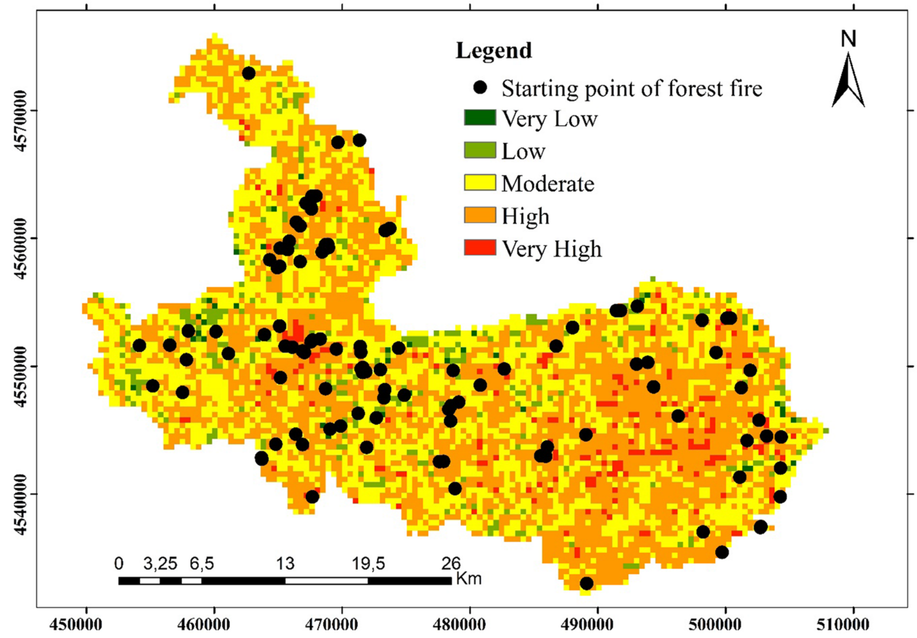

Fig. 6 Forest fire susceptibility map generated by the multi-criteria decision method

6 Conclusions

In this study, it was aimed to determine conformity of AHP method and the frequency ratio methods in order to identify the risky forest fires areas with high accuracy. The region located within the boundaries of Karabük Forestry Directorate, where forest fires occur very frequently, was selected as the study area. In line with the results obtained in the study,

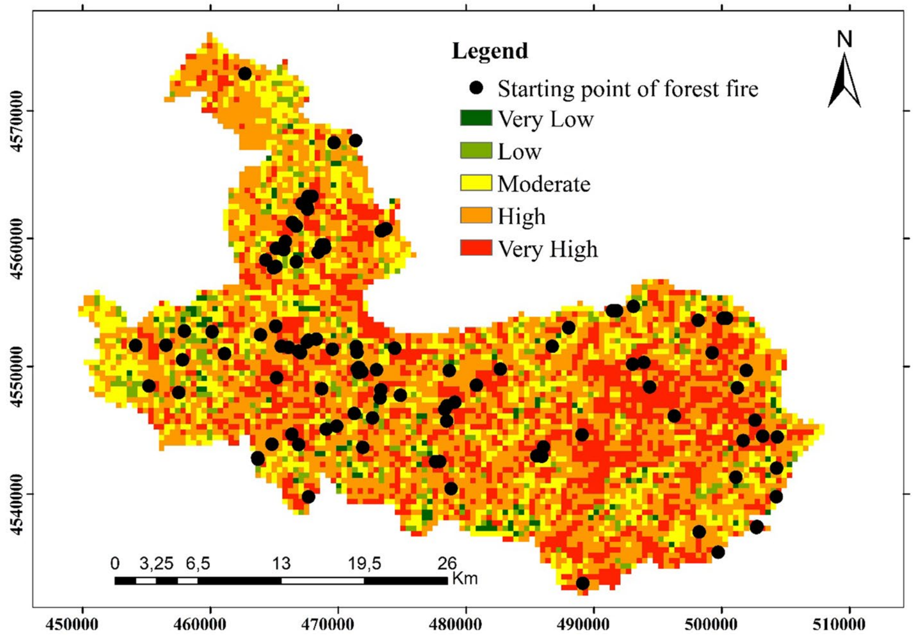

Fig. 7 Forest fire susceptibility map generated by the frequency ratio method

it could be said that the multi-criteria decision analysis and frequency ratio methods were very powerful methods in preparation of risk maps (73.92% and 76.42%, respectively).

Knowing the main criteria that affect formation of the forest fire susceptibility map and the map with very risky and risky areas would make a significant contribution to prevent or provide early response for possible fires in Karabük province and its surroundings.

References

Anderson HE (1982) Aids to determining fuel models for estimating fire behavior. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station, Ogden UT, General Technical Report INT-122

Ayalew L, Yamagishi H, Ugawa N (2004) Landslide susceptibility mapping using GIS-based weighted linear combination, the case in Tsugawa area of Agano River, Niigata Prefecture, Japan. Landslides 1(1):73–81

Bahadır M (2010) Surface and geostatistical analysis of forest fires occurring in turkey during 1998–2007. J New World Sci Acad 5(3):146–162

Bennie J, Huntley B, Wiltshire A, Hill MO, Baxter P (2008) Slope, aspect and climate: spatially explicit and implicit models of topographic microclimate in chalk grassland. Ecol Model 216:47–59

Bento Gonçalves A, Vieira A, Ubeda X, Martin D (2012) Fire and soils: key concepts and recent advances. Geoderma 191:3–13

Boroushaki S, Malczewski J (2008) Implementing an extension of the analytical hierarchy process using ordered weighted averaging operators with fuzzy quantifiers İn Arcgıs. Comput Geosci 34:399–410

Drobne S, Lisec A (2009) Multi-attribute decision analysis in gis: weighted linear combination and ordered weighted averaging. Informatica (Slovenia) 33(4):459–474

Erener A, Lacasse S (2007) Landslıde susceptibility mapping using Gıs, TMMOB geographical information systems congress, October 30–November 02, KTU, Trabzon

Erener A, Şebnem H, Duzgun B (2010) Improvement of statistical landslide susceptibility mapping by using spatial and global regression methods in the case of more and romsdal (norway). Landslides 7:55–68

Erten E, Kurgun V, Musaoğlu N (2005) Forest fire risk zone mapping by using satellite imagery and GIS. 10. Turkey Scientific and Technical Conference, 28 March -1 April of 2005, Ankara

Fox L, Stuart JD (1994) Detecting changes in forest condition following wildfire using image processing and GIS. ASPRS Technical Papers: 1994 ASPRS-ACSM Annual Convention. American Society of Photogrammetry and Remote Sensing, pp 197–206

Gai C, Weng W, Yuan H (2011) GIS-based forest fire risk assessment and mapping. In: 2011 fourth international joint conference on computational sciences and optimization (CSO), 15–19 April 2011, Yunnan, China, ISBN: 978-1-4244-9712-6, IEEE, pp 1240–1244

Hacısalihoglu M (2018) Forest information system design and aplication. M.Sc. Thesis, Bülent Ecevit University, Graduate School of Natural and Applied Sciences Department of Geomatics Engineering, p 93

Jaiswal RK, Mukherjee S, Raju KD, Saxena R (2002) Forest fire risk zone mapping from satellite imagery and GIS. Int J Appl Earth Observ Geoinf 4(1):1–10

Joaquım GS, Bahaaeddın AE, Josep RC (2007) Remote sensing analysis to detect fire risk locations. GeoCongres, 2007, Quebec, Canada

Karabulut M, Karakoç A, Gürbüz M, Kızılelma Y (2013) Determınatıon of forest fire risk areas using geographical information systems in Başkonuş Mountaın (Kahramanmaraş). J Int Soc Res 6(24):171–179

Kavzoglu T, Şahin EK, Çölkesen İ (2010) Gıs-based landslıde susceptıbılıty mappıng usıng multıcrıterıa decısıon analysıs method: the case of Trabzon Provınce 3. In: Remote sensing and geographic ınformation systems symposium, 11–13 October 2010, Gebze

Küçükönder M, Karabulut M (2007) Landfill site selection in Kahramanmaraş using multiple criteria analyses. J Geograph Sci 5(2):55–76

Lee S, Evangelista DG (2005) Landslide susceptibility mapping using probability and statistics models in Baguio City, Philippines. In: 31st international symposium on remote sensing of environment, Saint Petersburg, Russia

Lee S, Choi J, Min K (2004) Landslide hazard mapping using gıs and remote sensing data at Boun, Korea. Int J Remote Sensing 25:2037–2052

Malczewski J (1999) GIS and Multicriteria Decision Analysis. Wiley, New York, p 392, ISBN: 0-471-32944-4

Malczewski J, Chapman T, Flegel C, Walters D, Shrubsole D, Healy MA (2003) GIS - multicriteria evaluation with ordered weighted averaging (OWA): case study of developing watershed management strategies. Environ Plan A 35(10):1769–1784

Özelkan E (2008) Risk assessment of forest fire by using satellite data, Kas Sample. M.Sc. Thesis, Istanbul Technical University, Institute of Informatics, İstanbul, p 71

Özşahin E, Kaymaz ÇK (2013) Ecological impact assessment and analysis of Camili (Macahel) biosphere reserve area (Artvin, NE, Turkey). Global Adv Res J Geography Reg Plan (GARJGRP) 2(6):121–138

Qin Z, Karnieli A, Berliner P (2001) A mono-window algorithm for retrieving land surface temperature from Landsat TM data and its application to the Israel-Egypt border region. Int J Remote Sens 22(18):3719–3746. https://doi.org/10.1080/01431160010006971

Saaty TL (1977) A scaling method for priorities İn Hierarchical structures. J Math Psychol 15:234–281

Şahin K, Gümüşay ÜM (2007) Internet Gıs And Its Usage In Forest Fıre. Journal of map 73(138):69–83

Şahin M, Yıldız BY, Şenkal O, Peştemalcı V (2011) Estimating land surface temperature of İzmir's City center by using satellite data, Süleyman Demirel University. J Nat Appl Sci 15(1):36–45

Shakesby RA, Chafer CJ, Doerr SH, Blake WH, Wallbrink P, Humphreys GS, Harrington BA (2003) Fire severity, water repellency characteristics and hydrogeomorphological changes following the Christmas 2001 Sydney forest fires. Aust Geogr 34:147–175

URL-1 http://www.karabuk.gov.tr/karabuk-tarihi, Ziyaret tarihi: 25.05.2017

Vadrevu KP, Eaturu A, Badarinath KVS (2010) Fire risk evaluation using multicriteria analysis—a case study. Environ Monit Assess 166(1–4):223–239

Van de Water KM, Safford HD (2011) A Summary of fire frequency estimates for california Vegetation before euro-American Settlement. Fire Ecology 7(3):26–58

Vieira A, Bento Gonçalves A, Martins C, Leite F, Mendes L (2011) Geographical information technology to support research on forest fires and soil erosion. In: 3rd international meeting of fire effects on soil properties, 15–19 March 2011, University of Minho- Guimarães, Portugal, pp 186–191

Voogd H (1983) Multicriteria evaluation for urban and regional planning. Pion Ltd, London

Yager RR, Kelman A (1999) An extension of the analytical hierarchy process using OWA operators. J Intell Fuzzy Syst Appl Eng Technol 7(4):401–417

Zhao QS, Huang QY, Guo JM, Zhu HG (2008) Integrated risk assessment of hazardous chemical installations using GIS and AHP. In: 2008 4th international conference on wireless communications, networking and mobile computing, 1–31, 10633–10637