



Development of forest fire risk map using geographical information systems and remote sensing capabilities: Ören case

Mehtap Ozenen Kavlak¹ · Saye Nihan Cabuk² · Mehmet Cetin³

Received: 15 January 2021 / Accepted: 17 February 2021 / Published online: 27 February 2021
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Abstract

Forest fires globally cause severe losses in vegetation, soil and habitats and inevitably have direct and indirect negative environmental impacts such as deforestation, climate change and drought. According to the official records, there has been an increase of 58% in the number of the forest fires in Turkey in the last 30 years, between 1988 and 2018. Therefore, it is vital to determine the forest fire risks in the country and develop more effective methodologies to mitigate them. From this point, in the first phase, forest fire risk map of Kütahya-Ören region was prepared via the analyses of a variety of spatial data using geographical information system capabilities. The visibility analysis for the current fire towers was also performed. The results showed that very-high and high-risk, moderate-risk and low-risk zones respectively comprised 36.86%, 60.39% and 2.76% of the total study area, and 82.8% of the region was visible from the towers. In the second phase of the study, remote sensing methods were utilized for the detection of the areas burned in October 2001 in Ören-Çamdibi region, which was officially recorded as 4 hectares. The results revealed that the actual amount of the burned area was 5.6 hectares, and 83% of the burned surfaces was classified as moderate-risk areas in the fire risk map, while 17% of it was that of very-high and high-risk zones.

Keywords Forest fire risk map · GIS · NBR · NDVI · Remote sensing · Weighted overlay

Introduction

Forests are significant for the protection of the natural balance besides being major and amongst the most precious sources providing a good number of services for the welfare and the sustainability of the environment, biodiversity and man

(Aleemahmoodi Sarab et al. 2015; Bilici 2009; Gheshlaghi 2019; İşçi 2018). However, the number of the forest fires originating from a variety of different reasons, either human-caused (negligence, intentional acts) or naturally caused (lightening), is continuously increasing worldwide, and the destructions caused by forest fires are mostly irreversible (Kuter et al. 2011; Rowell and Moore 2000; Sazawa et al. 2018). Between 1950 and 1990, 50% of the world's forests was ravaged due to a number of reasons (Ertuğrul 2005; Laurance 2010; Rudel and Roper 1997). On the contrary of this fact, the amount of the forests in Turkey is declared to have increased from 20.2 million ha to 22.3 million ha between 1972 and 2015 (Orman Genel Müdürlüğü 2015). Nevertheless, forest fires also show tendency to increase in the country. The rate of this increase is 58% for the last 30 years (1372 forest fires in 1988 and 20,167 forest fires in 2018) (Orman Genel Müdürlüğü 2018). According to the statistics of the General Directorate of Forestry, the annual number of forest fires for the last 5 years (2013–2018) in the country varies between 2149 and 3755, and the annual amount of the burned lands ranges from 3117 ha to 11,993 ha. For the same period, more than 4 million forest fire alerts

Responsible Editor: Philippe Garrigues

✉ Mehmet Cetin
mccetin@kastamonu.edu.tr

Mehtap Ozenen Kavlak
mehtapozenen@eskisehir.edu.tr

Saye Nihan Cabuk
sncabuk@eskisehir.edu.tr

- ¹ Institute of Graduate Programs, Department of Remote Sensing and Geographical Information Systems, Eskisehir Technical University, 26555 Eskisehir, Turkey
- ² Institute of Earth and Space Sciences, Department of Geodesy and Geographical Information Technologies, Eskisehir Technical University, 26555 Eskisehir, Turkey
- ³ Faculty of Engineering and Architecture, Department of Landscape Architecture, Kastamonu University, Kastamonu, Turkey

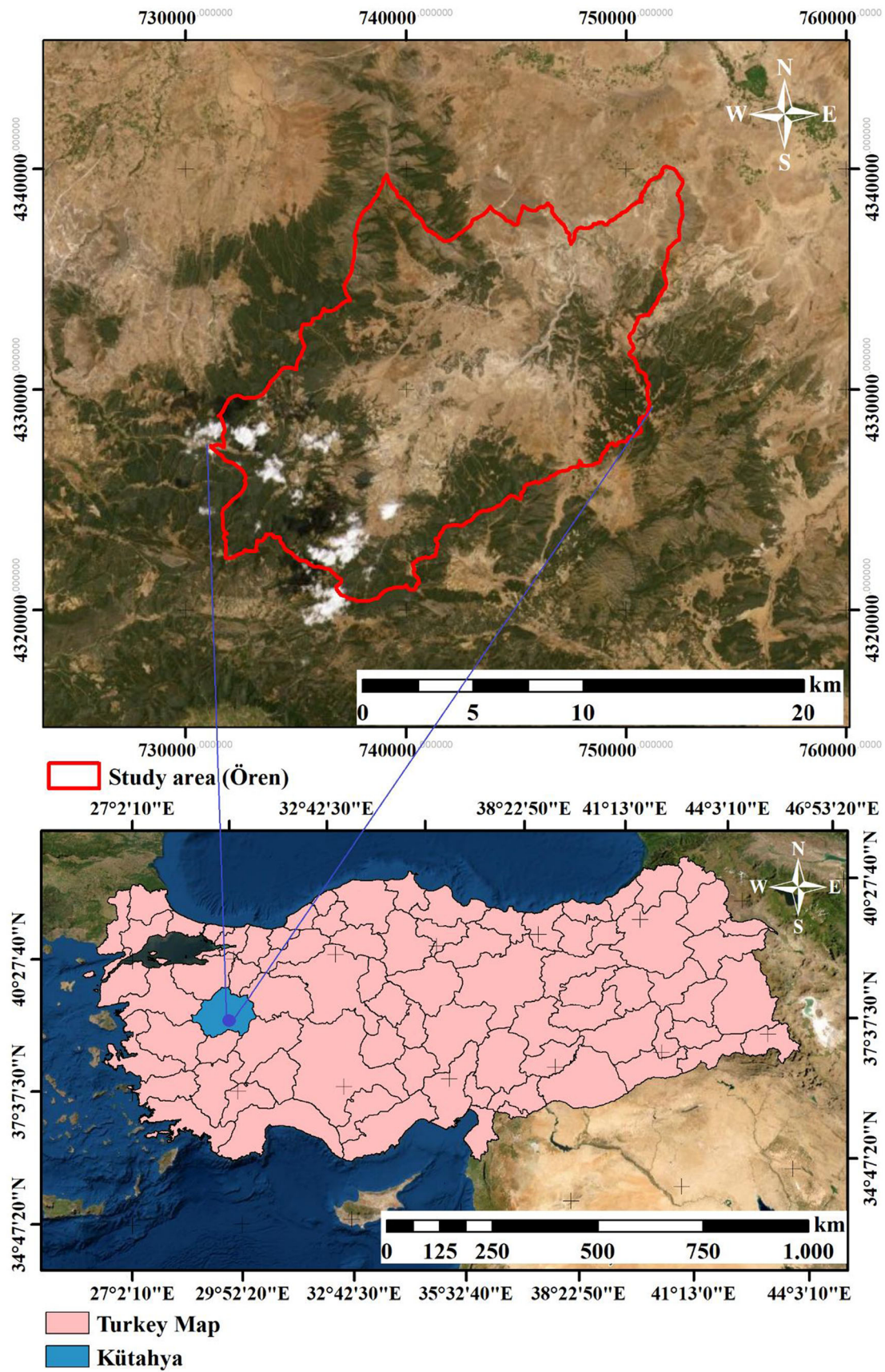


Fig. 1 Location of study area – Kütahya Forest Sub-district Directorates

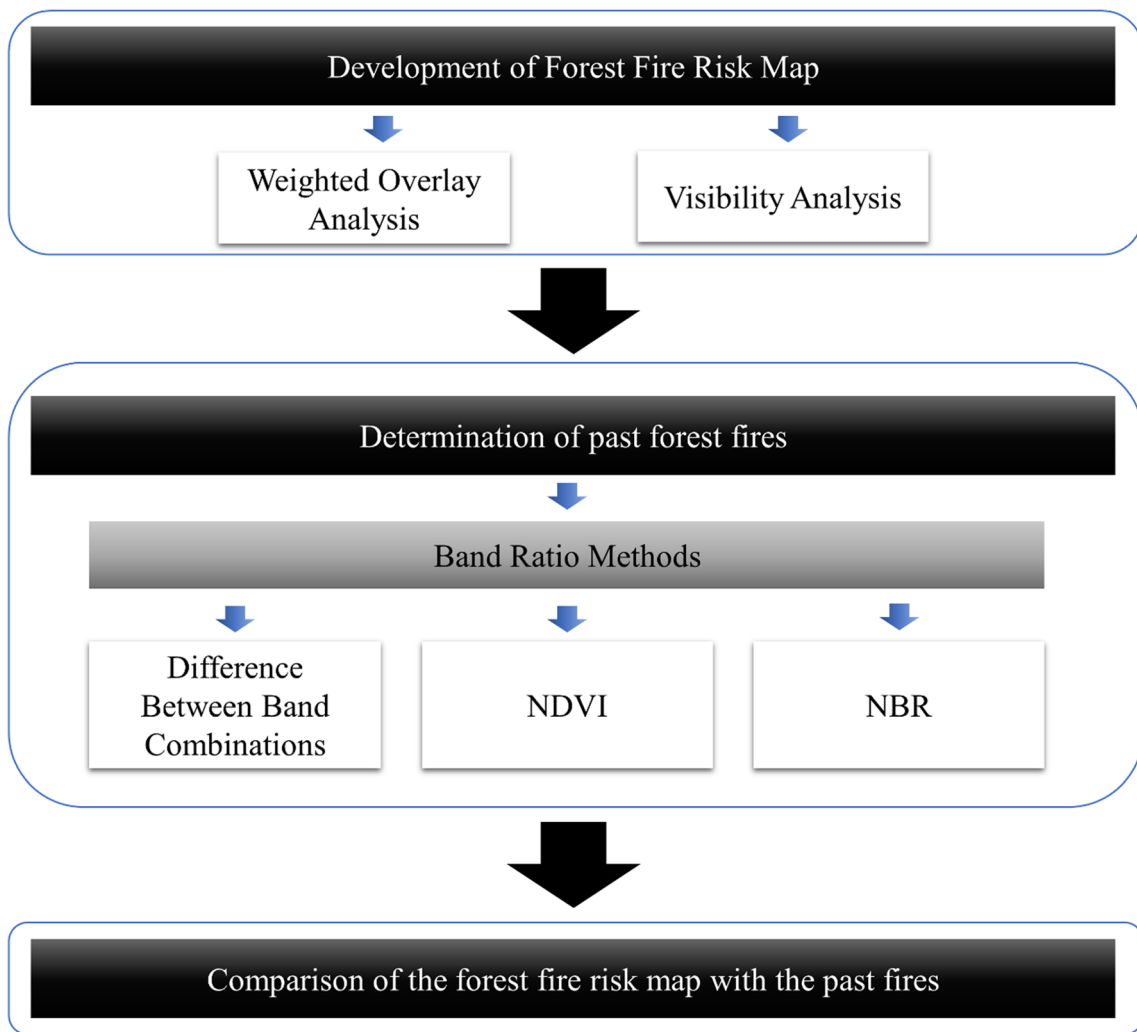


Fig. 2 Main workflow of the study

were recorded worldwide (Brushlinsky et al. 2016; Global Forest Watch Fires 2019).

In case of forest fires, it is nearly impossible to stop the natural cycle. Still, some measures can be taken to mitigate and prevent the negative impacts and ravages on the environment (Akay and Erdoğan 2017; Bailey 2001; Calfee and Little 2003; Kaysis 2019; Majlingová 2012; Peker and Atılğan 2015; Yang et al. 2007). Development of forest fire risk/danger/hazard maps is a basic requirement for the planning and protection of the forest lands (Eugenio et al. 2016). These maps are also of great importance for the conservation of the forests during the production of the development plans (Oliveira et al. 2002). Besides, forest fire risk maps provide precious inputs for developing long-term strategic plans for fire prevention and mitigation activities (Akay and Şahin 2018). Thus, forest fire risk maps make useful assets for the determination of different risk mitigation measures in line with the risk ranges/classes, as well as the determination of the appropriate locations for fire towers, emergency service

units, and water storage tanks (Goldammer et al. 2017). Moreover, risk data facilitate the planning of a variety of operations and allocation of human resources and support the protection of the critical infrastructure (FAO 2001).

Forest fire risk maps are produced using various data layers related to the risk factors that are essential for the detection of the risk zones (Jaiswal et al. 2002). There are a good number of parameters that affect the risk ranges such as forest stand types, topographic conditions, human factors and climate (Carmel et al. 2009; Gao et al. 2011; Gazzard 2012). The amount of oxygen and flare-up temperature, as well as the tree species, ages and canopy closure rate in a forest stand, are amongst the most significant factors affecting the starting, advancing and spreading of the forest fires (Bailey 2001; Bilgili 2003; Gazzard 2012; Kaysis 2019). From this perspective, there are various studies in the literature focusing on the determination of forest fires, fire behaviours, fire severity classes, risk classes and other forest management-related issues, most of which have been conducted with the utilization of

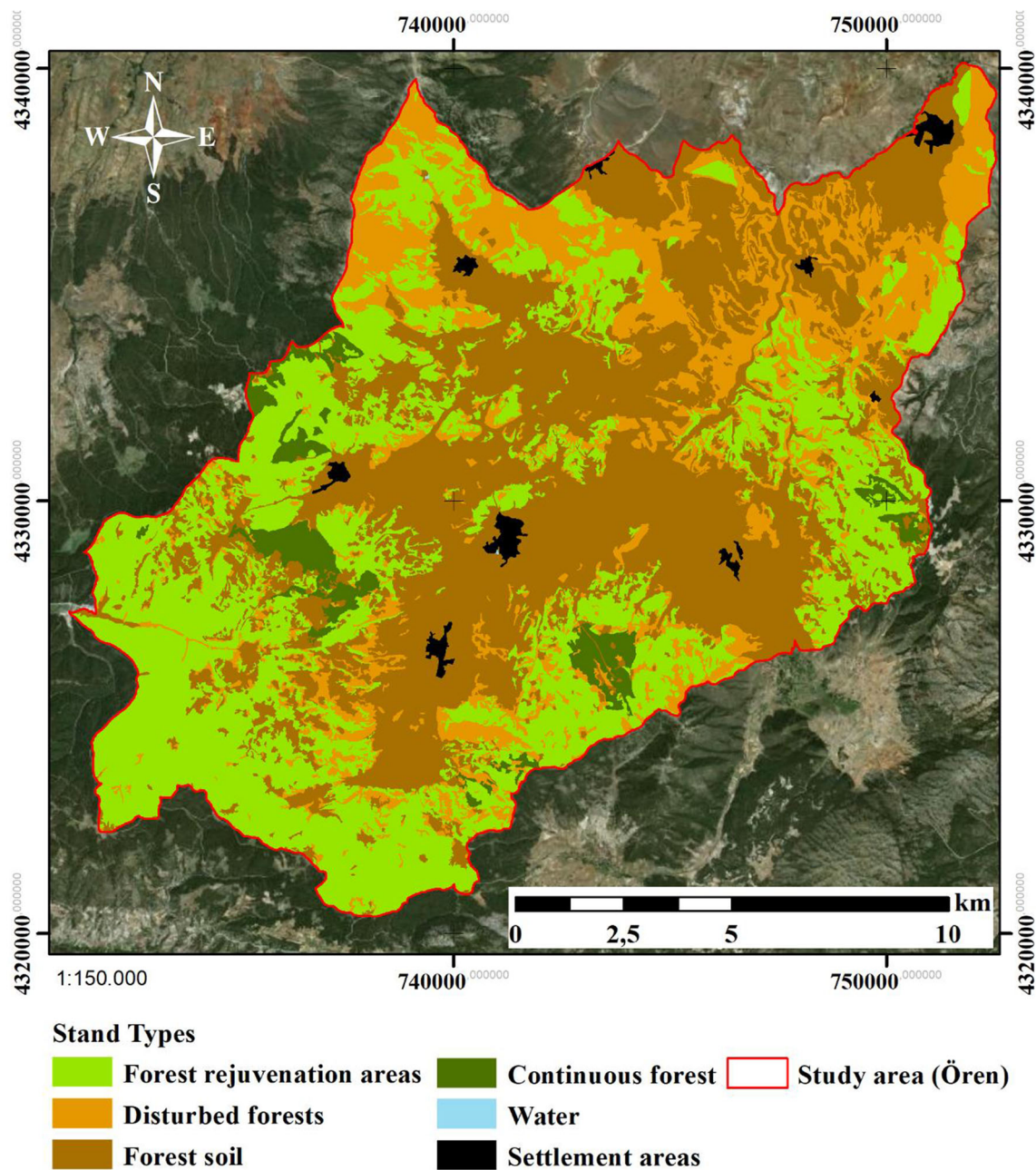


Fig. 3 Stand types map

advanced technologies such as geographical information systems (GISs) and remote sensing (RS). Today, no doubt that GIS is a unique and a widely used asset for obtaining, manipulating, analysing and presenting a good deal of spatial data that are required both for the determination of the fire risk zones and planning forest fire intervention operations (Değerliyurt and Çabuk 2015).

Accordingly, a good number of authors benefited from these technologies for the determination of the fire risks in different regions (Asri et al. 2017; Bingöl 2017; Erten et al. 2004; Jaiswal et al. 2002). Özşahin (2014) used AHP (analytic hierarchy process) method for the realization of forest fire sensitivity analysis in Antakya region. Between 1993 and 2009, kernel density

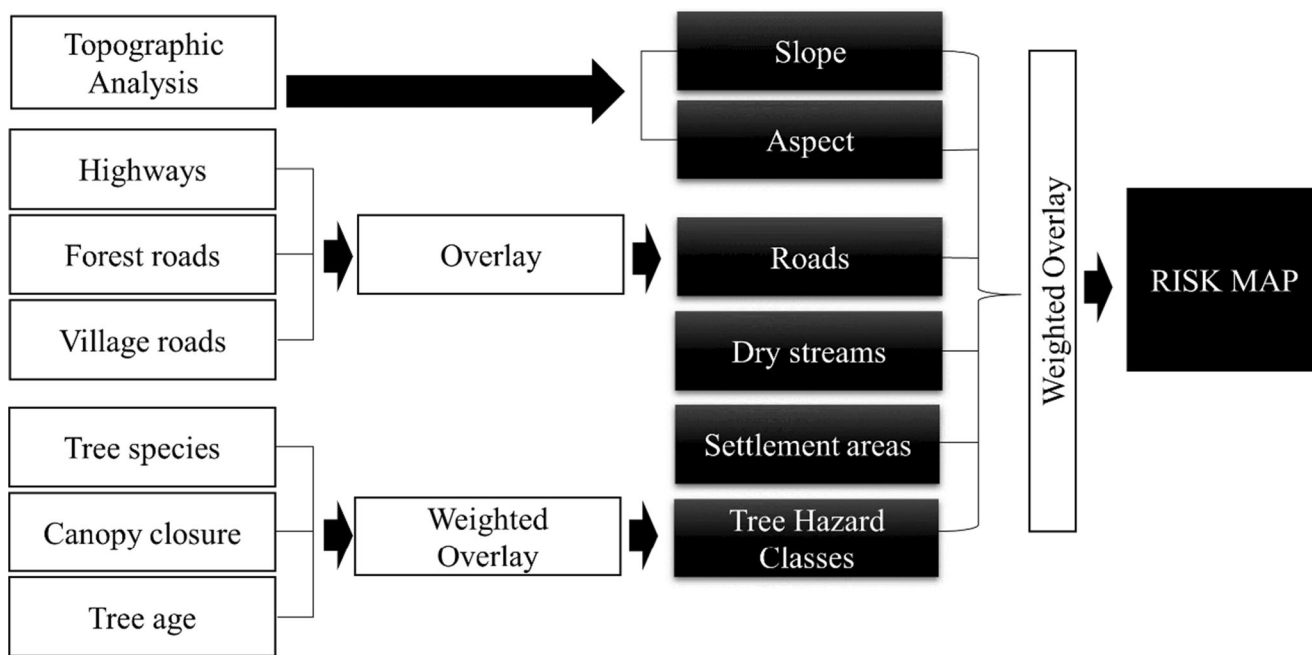


Fig. 4 Method for forest fire risk map

estimation of forest fire events in Middle East Technical University (METU) Campus, Ankara, Turkey, was made by using different bandwidth choices (Kuter et al. 2011). Yassemi et al. (2008), on the other hand, developed GIS-based forest fire simulation models and thus prepared fire risk maps according to three different scenarios. Van Wagendonk et al. (2004) utilized RS methods for the determination and comparison of the data related to fire severity, similar to that of Navarro et al. (2017), which was realized in Madeira. Kavgaci et al. (2016) and White et al. (1996) are amongst the other authors who benefited from RS technologies in their studies for the evaluation of fire severity. Meddens et al. (2016) used Landsat images in order to develop a model for the classification of the unburned regions around the fire areas, while Shafiei et al. (2010) evaluated the results of the forest fires in terms of varying reactions of different tree species against fires. Mirzaei (2016) focused on the effects of the human-caused fires on soil components in Zagros Mountains in western Iran.

In Turkey, where the number of the forest fires increased by 58% for the last 30 years, it has also become extremely necessary to determine the fire risks and adopt proactive approaches and strategies for the protection of the forests (Orman Genel Müdürlüğü

2018). In the country, Forest Management Units are assigned with the determination of precious and risky areas in line with the related legislation (Orman Genel Müdürlüğü 1995; Orman Genel Müdürlüğü 2017). Moreover, the Ministry of Agriculture and Forestry develops forest fire risk maps on national scale and realizes various projects for the determination of fire risks. Considering a number of studies, generally 5 classes are used for defining fire risk ranges varying from ‘very low’ to ‘extreme’ risk classes (Corona et al. 2013; Dong et al. 2005; Ghimire et al. 2014; Ghorbanzadeh et al. 2019; Rowell and Moore 2000; Vanha-Majamaa 2006). The General Directorate of Forestry in Turkey also classifies forest fire risks in 5 groups, in which ‘1st-degree risk’ refers to the highest risks and ‘5th-degree risk’ is the lowest. The factors affecting the severity of the risk are also determined by the Directorate (Orman Genel Müdürlüğü 1995).

According to the records of the General Directorate of Forestry, Kütahya province, comprising 6 regions, is amongst the highest risk areas (1st-degree risk areas) in terms of forest fires in the country. Considering the fire sensitivity classes of these regions, Simav, Tavşanlı, Gediz and Kütahya regions take the first place (high sensitivity), while Emet has 2nd-degree sensitivity and Domaniç region is of 3rd-degree sensitivity.

Table 1 Weighted overlay information

Data layer	Influence weight	Attributes	Risk classes/ points	Fire sensitivity
Slope	15%	> 35°	9	Very high
		35°–15°	8	Very high
		15°–10°	6	High
		10°–5°	4	Moderate
		0°–5°	2	Low
Aspect	15%	South	9	Very high
		Southwest	9	Very high
		Southeast	8	Very high
		Northwest	4	Moderate
		Northeast	4	Moderate
		North	2	Low
		East	6	High
		West	6	High
		Flat	5	Moderate
Roads	20%	0–50 m	9	Very high
		50–100 m	8	Very high
		100–200 m	6	High
		200–300 m	4	Moderate
		300–400 m	2	Low
		>400 m	1	Low
Dry streams	10%	0–50 m	9	Very high
		50–100 m	8	Very high
		100–200 m	6	High
		200–300 m	4	Moderate
		300–400 m	2	Low
Settlement areas	20%	>400 m	1	Low
		0–50 m	9	Very high
		50–100 m	8	Very high
		100–200 m	7	High
		200–300 m	6	High
		300–400 m	5	Moderate
		400–500 m	4	Moderate
		500–1000 m	3	Low
Tree hazard classes	20%	1000–1500 m	2	Low
		> 1500 m	1	Low
		See Table 2	9	Very high
			8	Very high
			7	High
		0	Restrictions	

Table 2 Weighted overlay information for tree hazard classes

Data layer	Influence weight	Attributes	Risk classes/ points	Fire sensitivity
Tree species	40%	Çk (black pine)	9	Very high
		Disturbed forests	7	High
		Dy (other leaved species – shrub)	6	High
Canopy closure	30%	0 (Forest rejuvenation areas)	9	Very high
		1 (40%)	7	High
		2 (40–70%)	8	Very high
Tree age	30%	3 (> 70%)	9	Very high
		A (0–8 years)	9	Very high
		B (8–20 years)	8	Very high
		C (20–36 years)	7	High
		D (> 37 years)	6	High
		K (Mixed – 100–120 years)	7	High

Since the determination of forest fire risks provides significant benefits such as effective and productive use of manpower, time and resources, as well as realization of efficient interventions against fires, it becomes a major task to develop forest fire risk maps especially for the high-risk areas such as Kütahya province. However, it is not possible to find forest fire risk maps prepared on local areas/scales in Turkey. According to our

Table 3 NDVI and NBR band ratio methods (Meddens et al. 2016; Navarro et al. 2017)

Name of the index	Abbreviation	Formula	
		LANDSAT 8	LANDSAT 7
Normalized burn ratio	NBR		
Normalized difference vegetation index	NDVI		
NDVI difference	dNDVI	$NDVI_{pre} - NDVI_{post}$	
NBR difference	dNBR	$NBR_{pre} - NBR_{post}$	

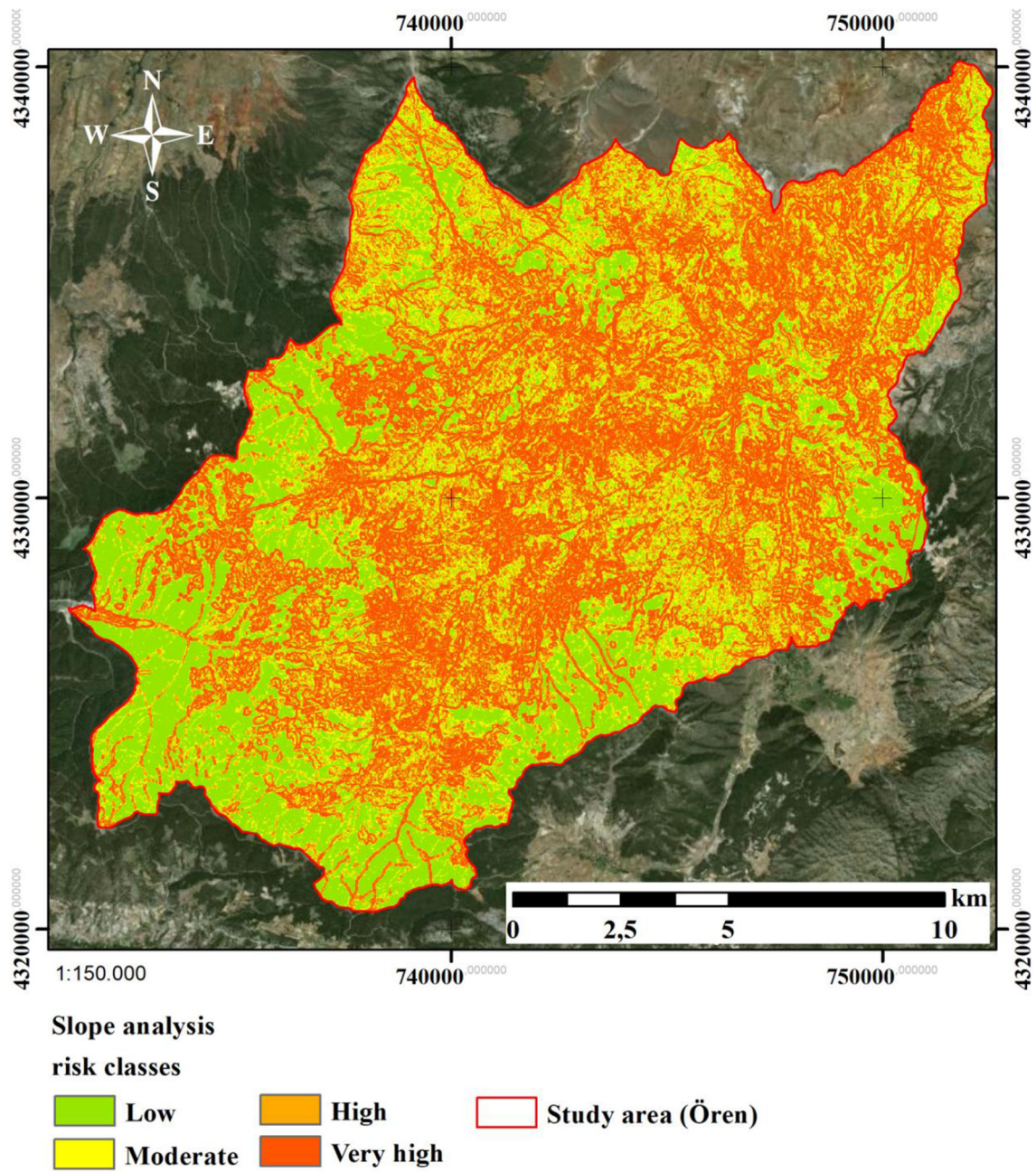


Fig. 5 Reclassified slope map

investigations, no spatial records of previous fires or forest fire risk maps were either detected for Ören Forest Sub-district Directorates territory.

From this point, the main target of this paper is to produce the forest fire risk map in Kütahya province using GIS capabilities. The selected study area comprises the Ören Forest

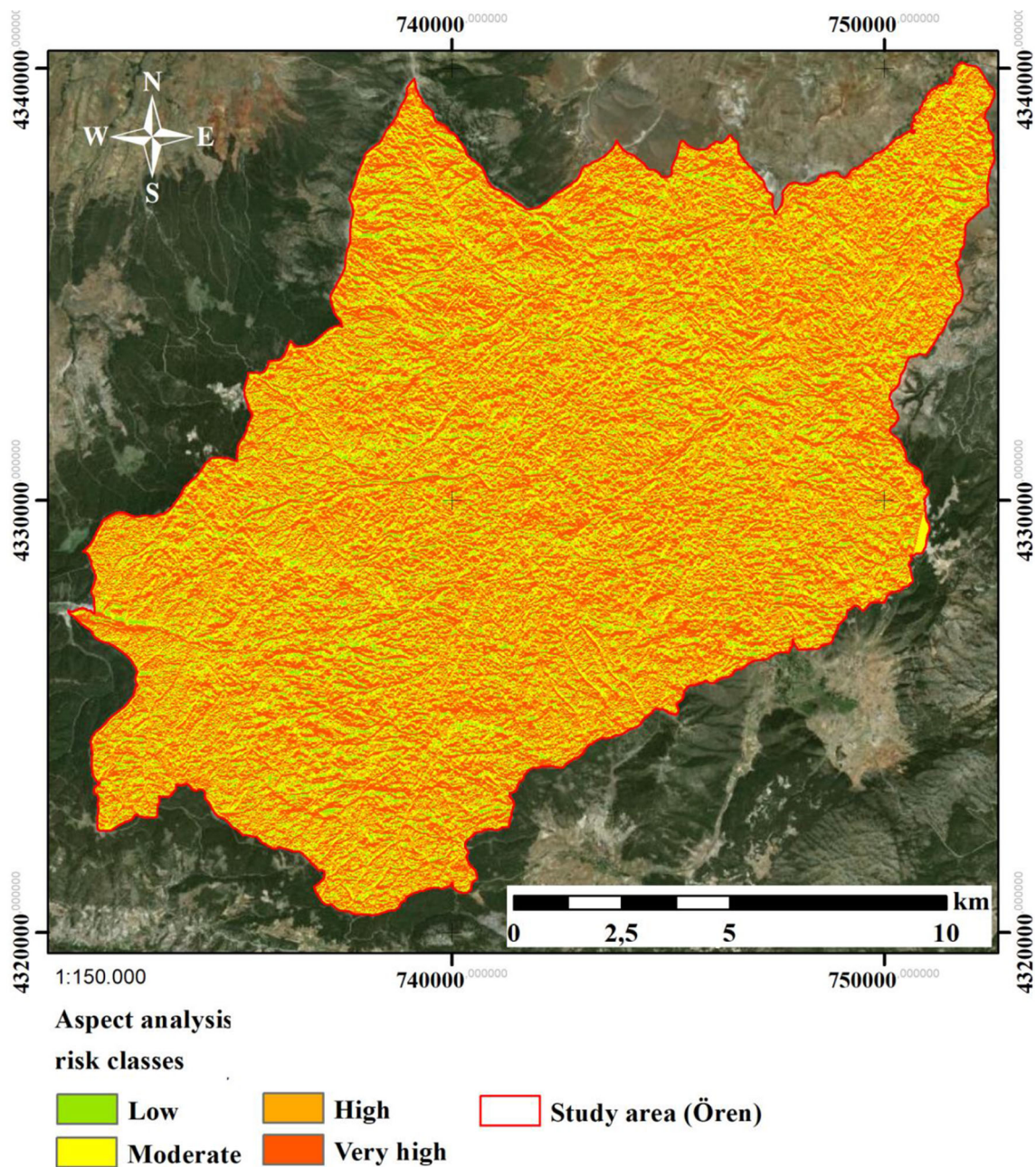


Fig. 6 Reclassified aspect map

Management Office. Within the context of the study, the location of the existing fire observation towers in the study area was also evaluated with GIS analyses for the determination of their visual accessibility over the area. Moreover, the fire in Çamdibi region, which burned 4 hectares in 2001, was examined, and the results were compared with the risk map via remote sensing (RS) and GIS methods.

Materials and Methods

Study area and material

Study area comprises Kütahya-Ören Forest Sub-district Directorates, which is one of the 10 subunits operating under Kütahya Forest Management Directorate. The Directorate was

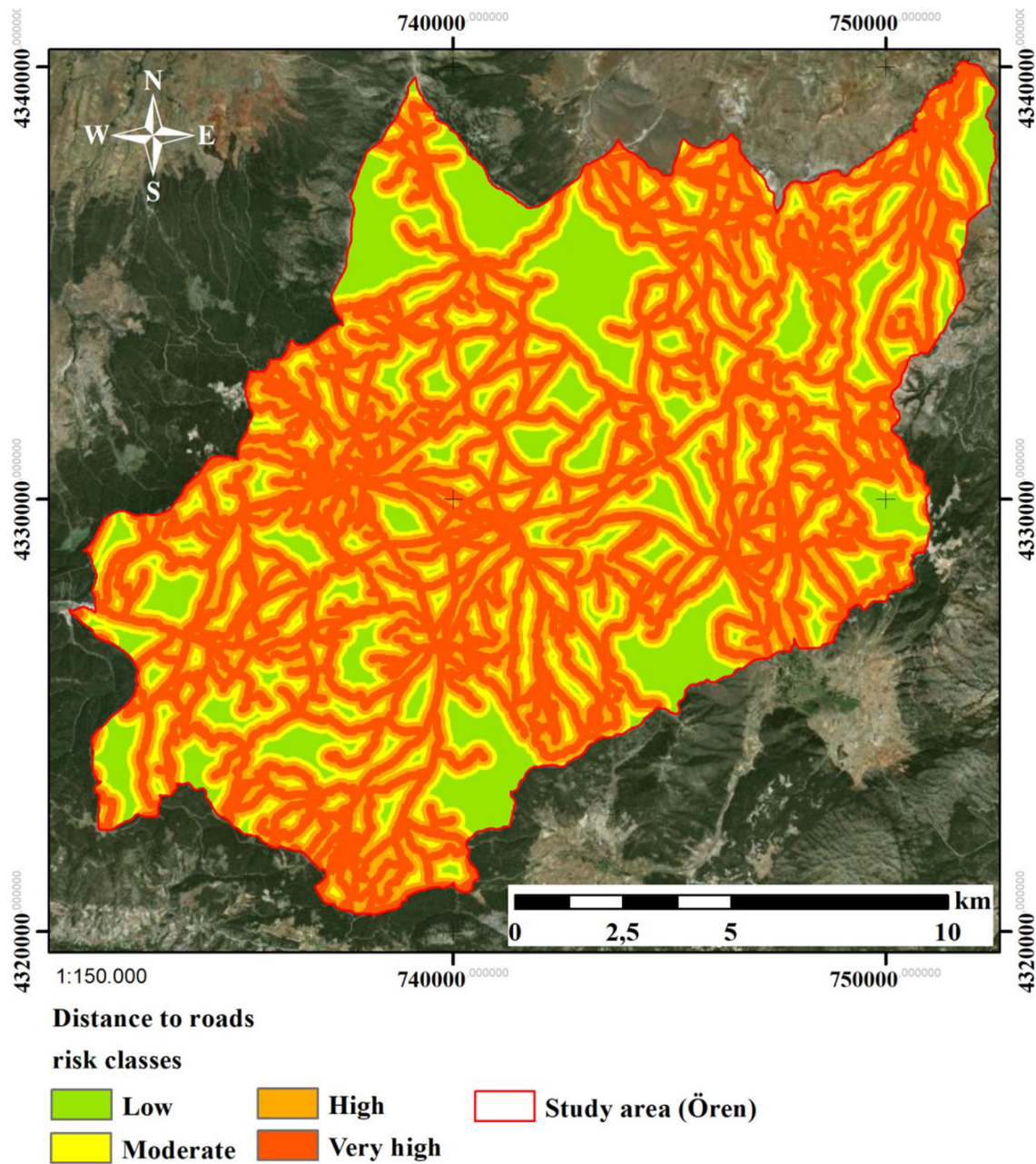


Fig. 7 Reclassified distance to road map

established in 1943, serving an overall area of 413,716 ha on the inner parts of Aegean Region within Kütahya provincial territories. Moreover, 51% (209,052 ha) of the territory is covered with forests, while 49% (204,124 ha) of it is mostly made up of open spaces. Furthermore, 58% (121,897 ha) of the forested areas are classified as normal woodlands and the ratio of the disturbed woodlands is 42% (87,155 ha).

Ören Forest Sub-district Directorates is located 980 metres above the sea level between northern latitudes of 39° 0' 0.25" and 39° 10' 26.60" and eastern longitudes of 29° 40' 39.90" and 29° 55' 24.00" (Fig. 1). The surface area of the study area is 237 km². The majority of its territories is located within Aslanapa province, and some parts of it spreads in Gediz and Altıntaş provinces (Kültür ve Turizm Bakanlığı 2019).

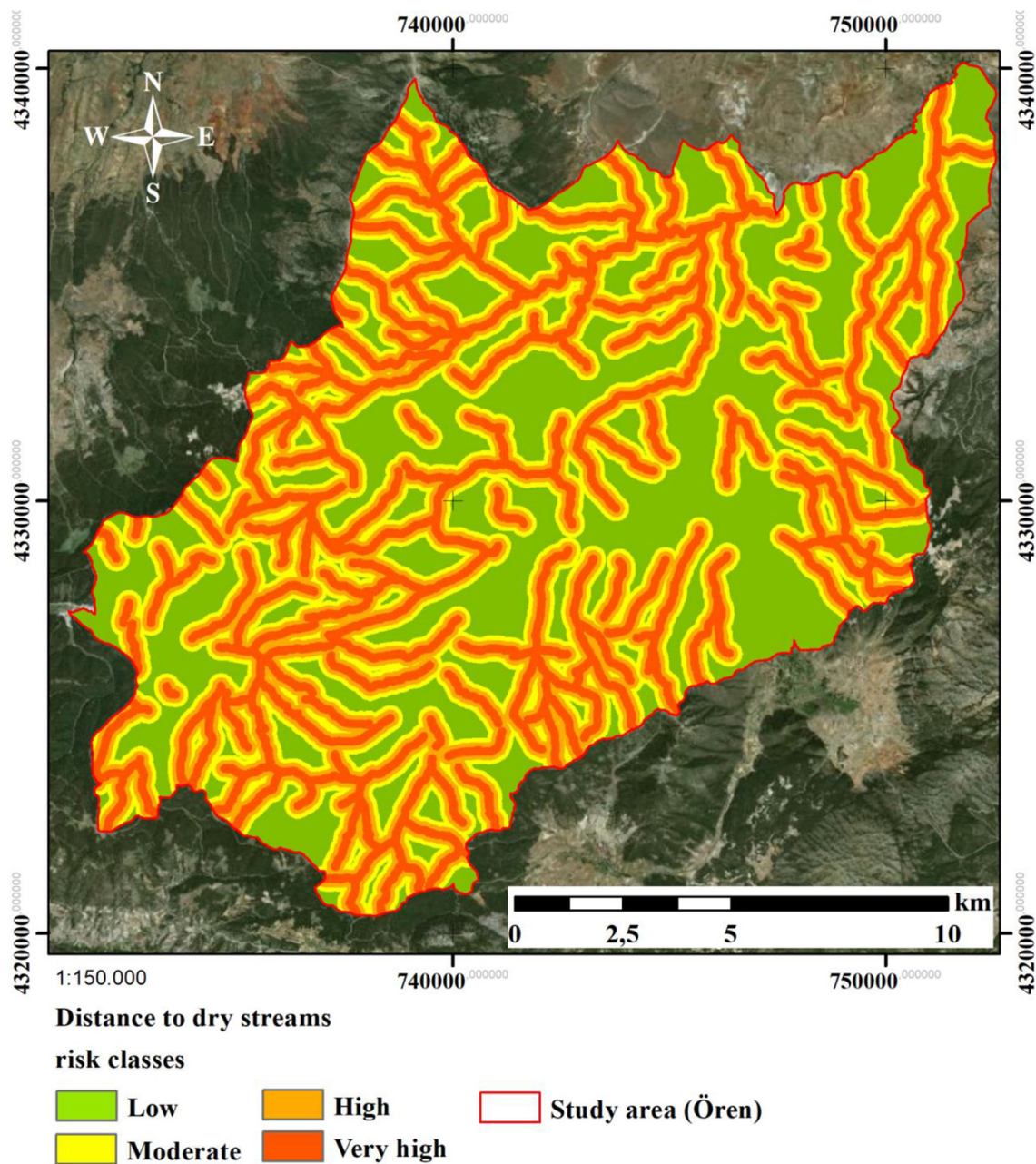


Fig. 8 Reclassified distance to dry stream map

According to the 2018 statistics of Turkish Statistical Institute (TUİK), the population of Aslanapa province is 9224 (TUİK 2018). The climate of the region has Aegean, Marmara and Central Anatolian characteristics. Summers are hot and dry. Winters are mostly cold and rainy. July and August are the hottest and January and February are the coldest months of the year (OGM 2019). Moreover, 13.759 ha of the study area is covered with forests. The main tree species in Ören forests are

black pines, junipers and scrubs. The most dominant species is black pine (8.539 ha). The other land use types within the study area are agriculture areas (8684 ha), forest soils (1068 ha), settlement areas (224 ha), grasslands (38 ha), cemeteries (5 ha) and water surfaces (2 ha). The number of settlement areas in the study is 11.

The main material of the study is the vector and the raster data of Ören Forest Sub-district Directorates. A variety of the

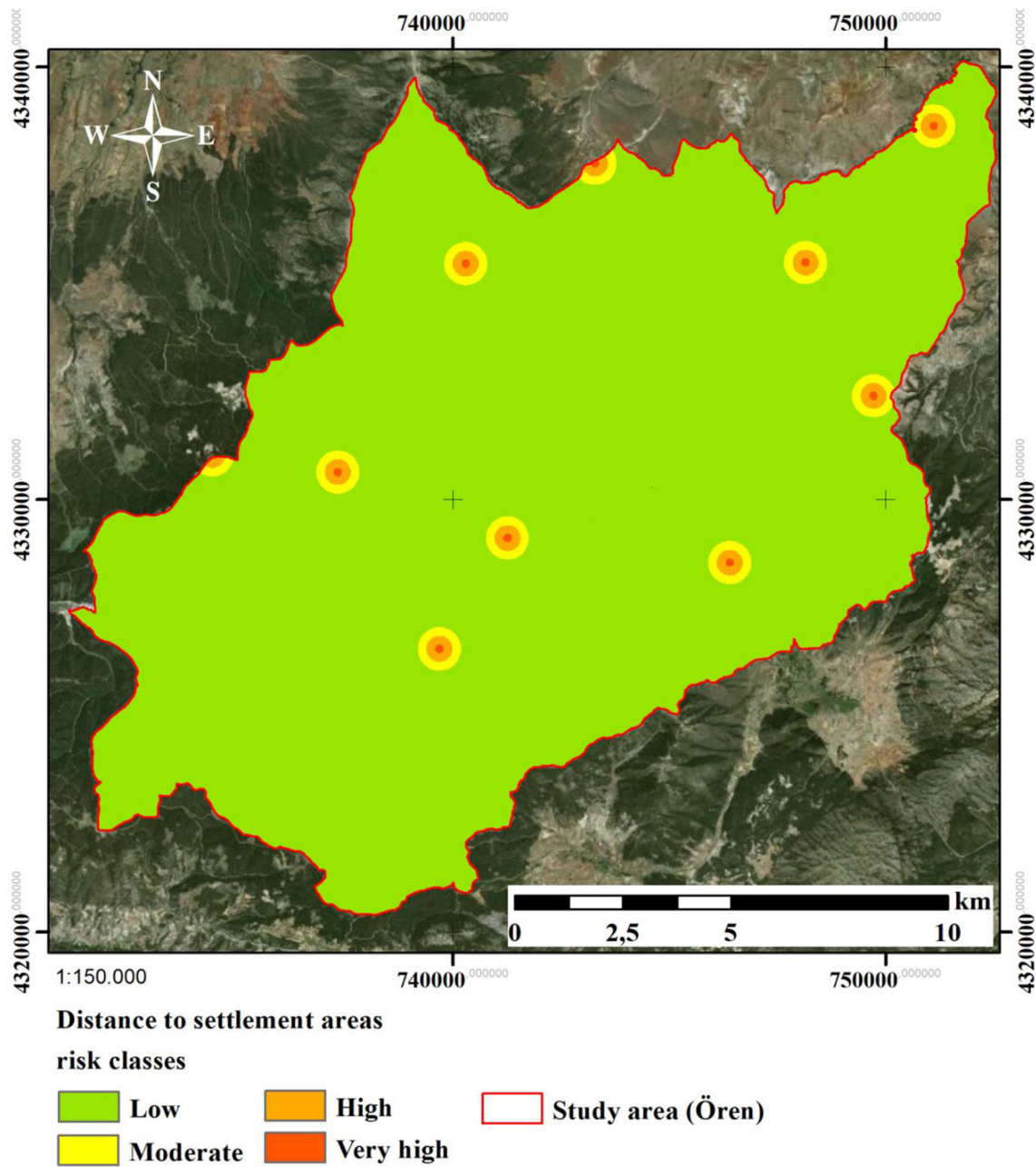


Fig. 9 Reclassified distance to settlement area map

vector data, such as stand types, settlement areas, roads and dry streams, was obtained from the Kütahya Regional Directorate. Slope and aspect maps, as well as 15-m resolution digital elevation model (DEM), which was used for the visibility analysis, were provided from NASA EARTHDATA database, and 30-m resolution LANDSAT images captured on October 2, 2001 (pre-fire) and October 18, 2001 (post-

fire) were downloaded from USGS database. ArcGIS 10.6 software was used for spatial analyses.

Methods

In this study, GIS techniques were applied to develop forest fire risk map for the study area, Kütahya Forest Sub-district

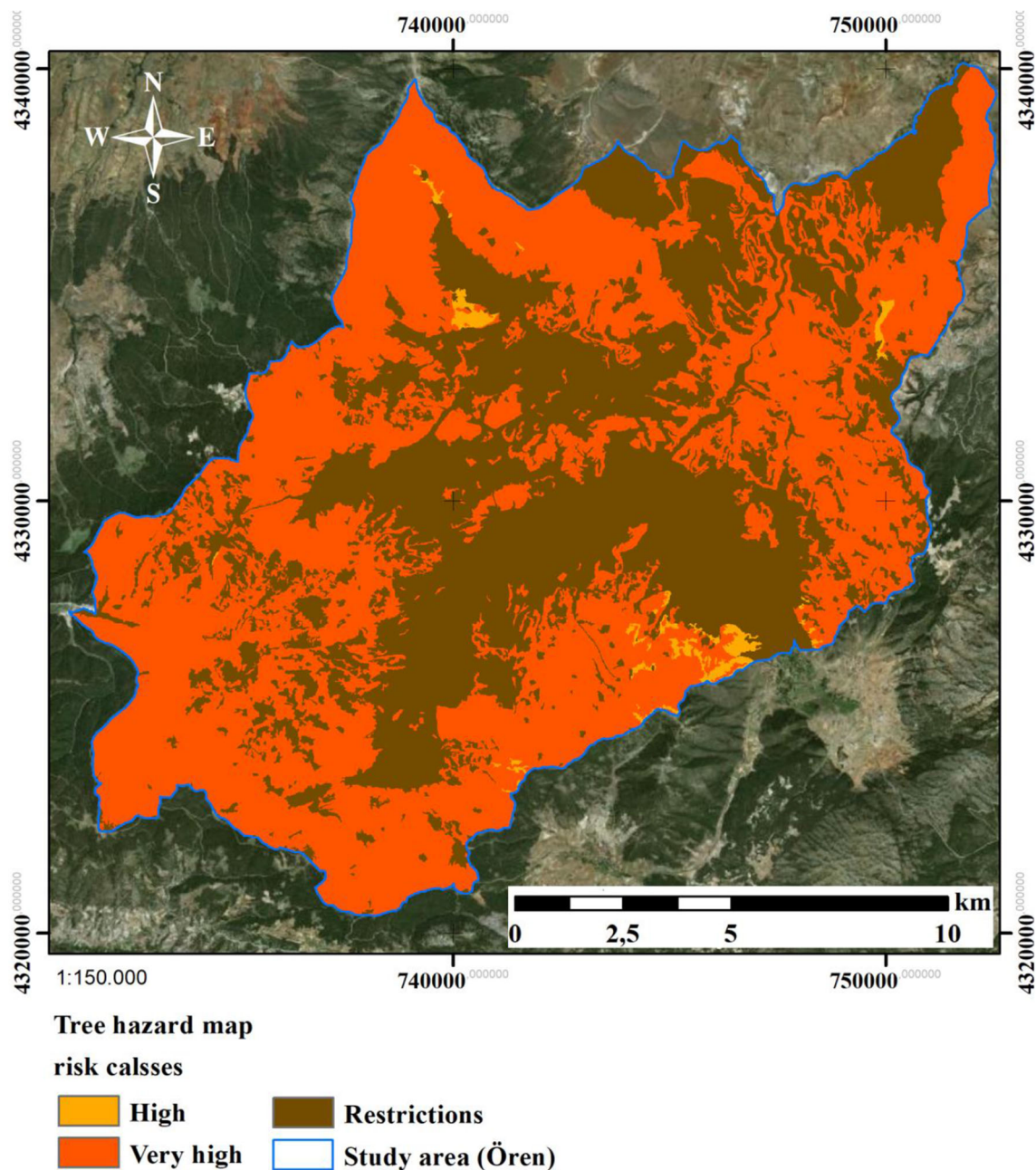


Fig. 10 Tree hazard class risk map

Directorates. Also, the risk map was compared with the past forest fires in the region. Remote sensing methods were used to detect the past forest fires within the study area. Figure 2 illustrates the main workflow.

Weighted overlay analysis

The main method of the study, which was utilized for the development of the forest fire risk map within Ören Forest

Sub-district Directorates, is weighted overlay analysis. For the production of sub-data layers such as slope and aspect, topographic analyses were performed with ArcGIS 10.6 software. Buffer analysis was used for the production of multi-buffer zones around roads, dry streams and settlement areas.

The weighted overlay process was performed in two phases. In the first phase, data layers (tree species, canopy closure and tree ages) in stand types map (Fig. 3) were classified in terms of their risk categories to produce the tree hazard

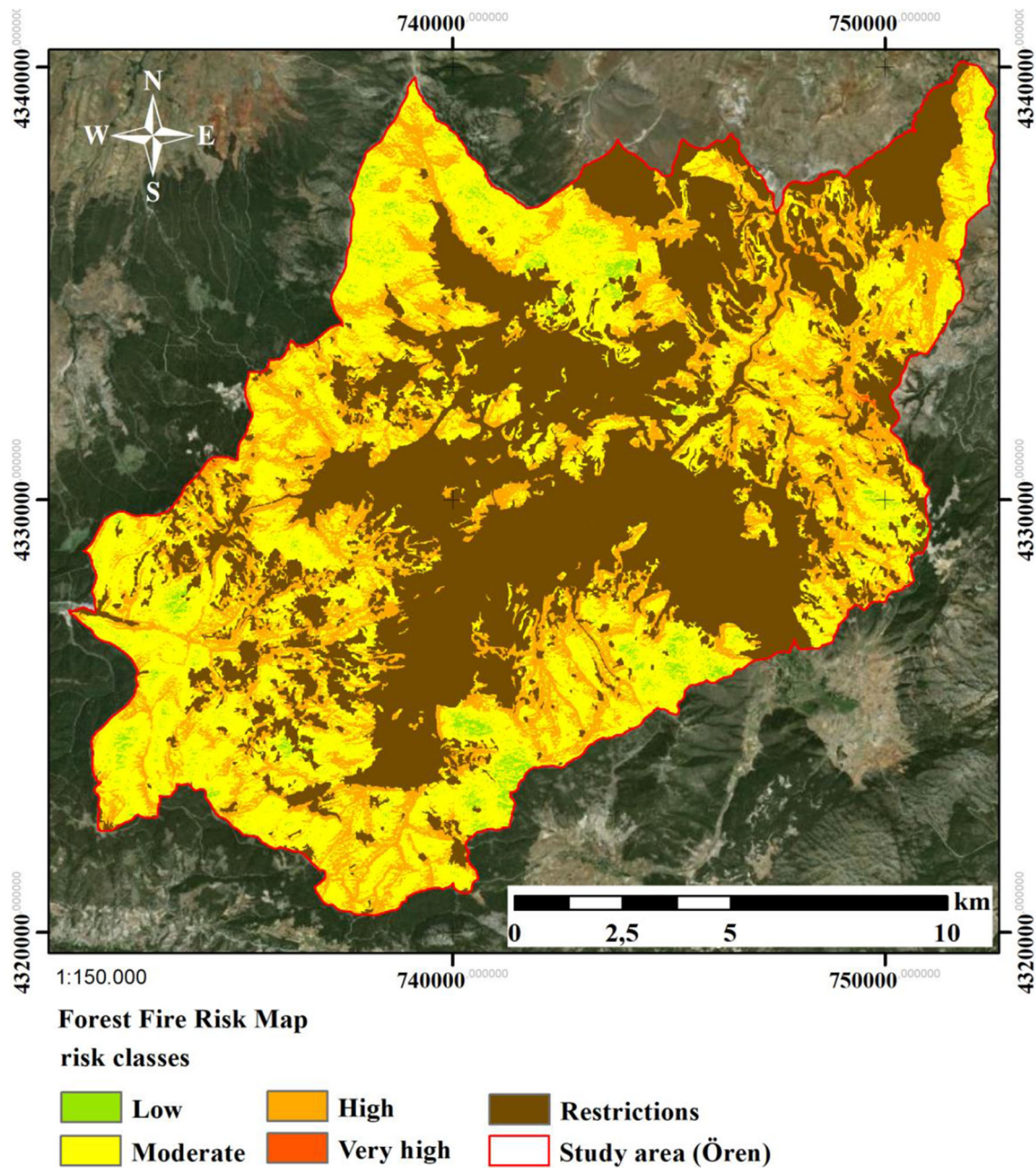


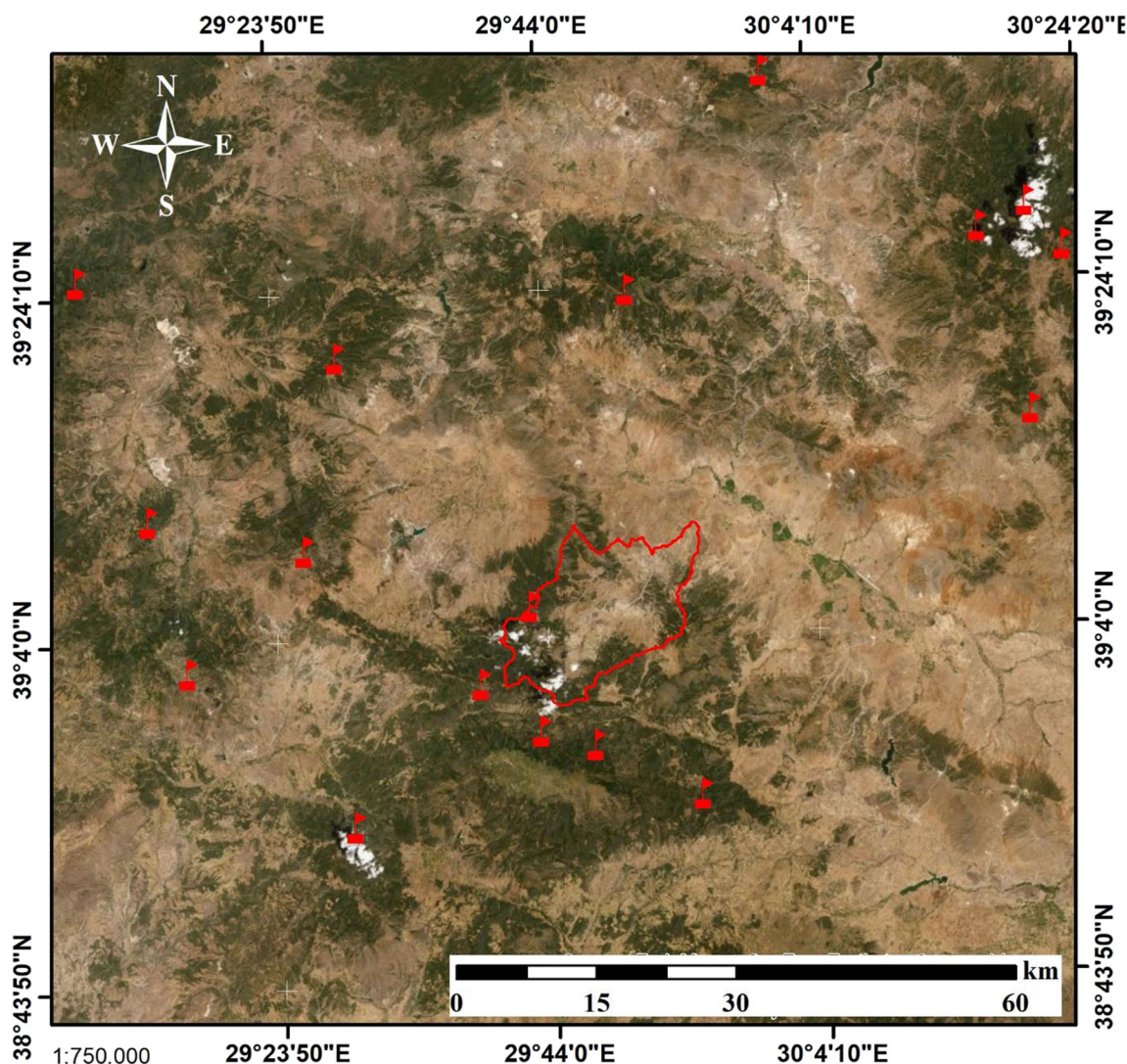
Fig. 11 Ören Forest Sub-district Directorates forest fire risk map

class map. Tree hazard class map was then used as one of the main data layers/inputs for the second-phase weighted overlay process.

During the second phase of the weighted overlay analysis, topography, settlement areas, roads and dry streams were used as main data layers besides tree hazard class maps. Each layer was appointed with influence weights and reclassified for the weighted overlay analysis.

Figure 4 illustrates the method that was applied for the development of forest fire risk map.

In weighted overlay analysis, only raster data with particular values are used as input, followed by the ordering of the attributes of each layer from the most suitable to the less, in accordance with the goal of the study. The most suitable class is usually assigned with the highest score/point in the selected working scale (ESRI 2016). Each layer of data used as input





-  Fire towers
-  Study area (Ören)

Fig. 12 Locations of fire towers in and around the study area

for weighted overlay is also given weights in relation with their influence on the study.

In this study, with regard to the main goal, the ‘most suitable class’ was referred as ‘highest risk’ and a scale of 9 was used, where 9 points was determined as the reference for the highest risk class. Data, such as settlement areas, grasslands, cemeteries, forest soils, water surfaces and agricultural lands, were determined as ‘restrictions’ and extracted from the overlay layers. Influence weights were assigned in parallel with the opinions of the professionals in the field working at Ören

Forest Sub-district Directorates. Table 1 summarizes the weighted overlay layers, risk classes and the weights of the data, and Table 2 gives the similar information for tree hazard class data layer.

Four risk classes were determined in this study as follows:

- 1, 2 and 3 points: low risk
- 4 and 5 points: moderate risk
- 6 and 7 points: high risk
- 8 and 9 points: very high risk

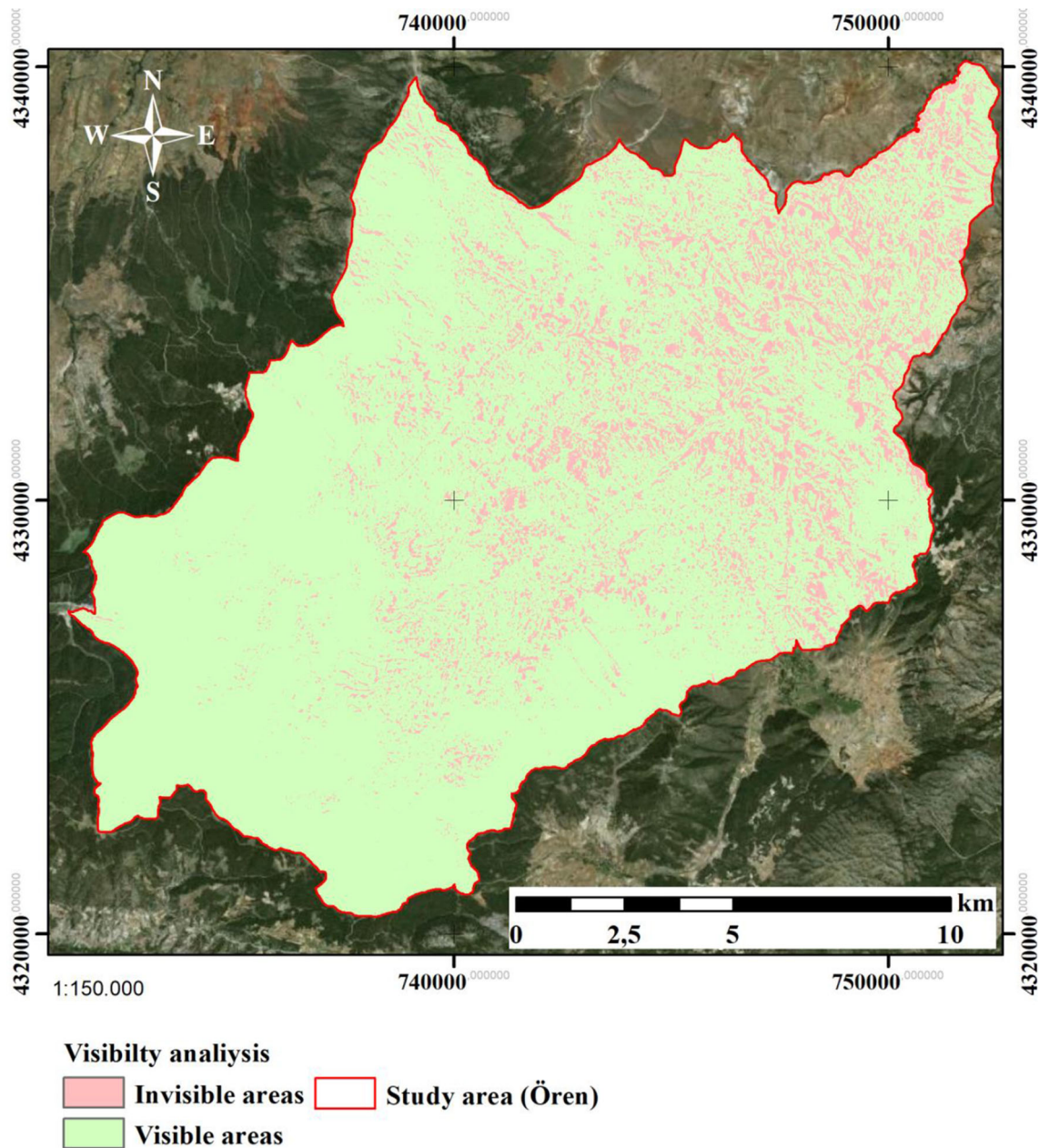


Fig. 13 Visibility analysis result map

Visibility analysis

The shape of a surface is an important factor determining the amount and the location of the lands visible to a man standing on a certain spot in the landscape. Visibility of specific locations or visibility between two different items/points is

essential for both design/planning and military works (ESRI 2018). At this point, visibility analysis is a widely benefited method used for the detection of the visible areas from certain points or vice versa. Land surface, slope, aspect, elevation and dimensions of the objects are regarded to perform an efficient visibility analysis (Popelka and Vozenilek 2010).

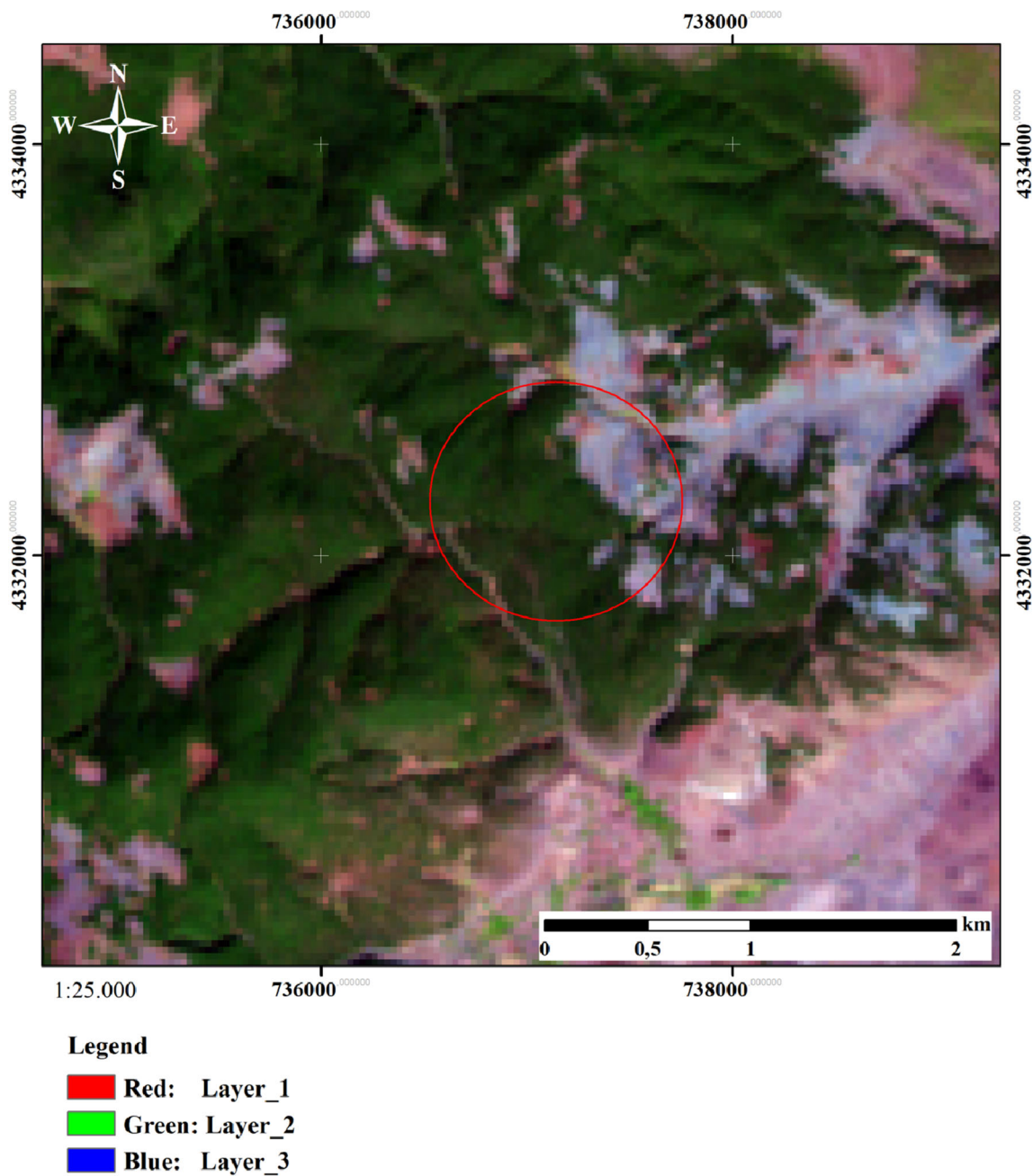


Fig. 14 543 band combination pre-fire (spectral index maps for Ören-Çambidi region – 2001)

In this study, visibility analysis was used for the determination of the visible lands/forests from the fire towers existing in and around Ören Forest Sub-district Directorates.

Band ratio methods

Remote sensing methods were utilized for the determination of the areas that were burned in the study area in 2001. To

fulfil this aim, NDVI (normalized difference vegetation index) and NBR (normalized burn ratio) methods were used. NDVI is basically the ratio of the radiation reflected from healthy vegetation to the total reflected radiation over a surface, which is calculated per pixel in a satellite image. The results range between -1 and $+1$, where $+1$ is the proof for the existence of healthy plant cover and -1 refers to bare surfaces (Sabuncu and Özener 2019).

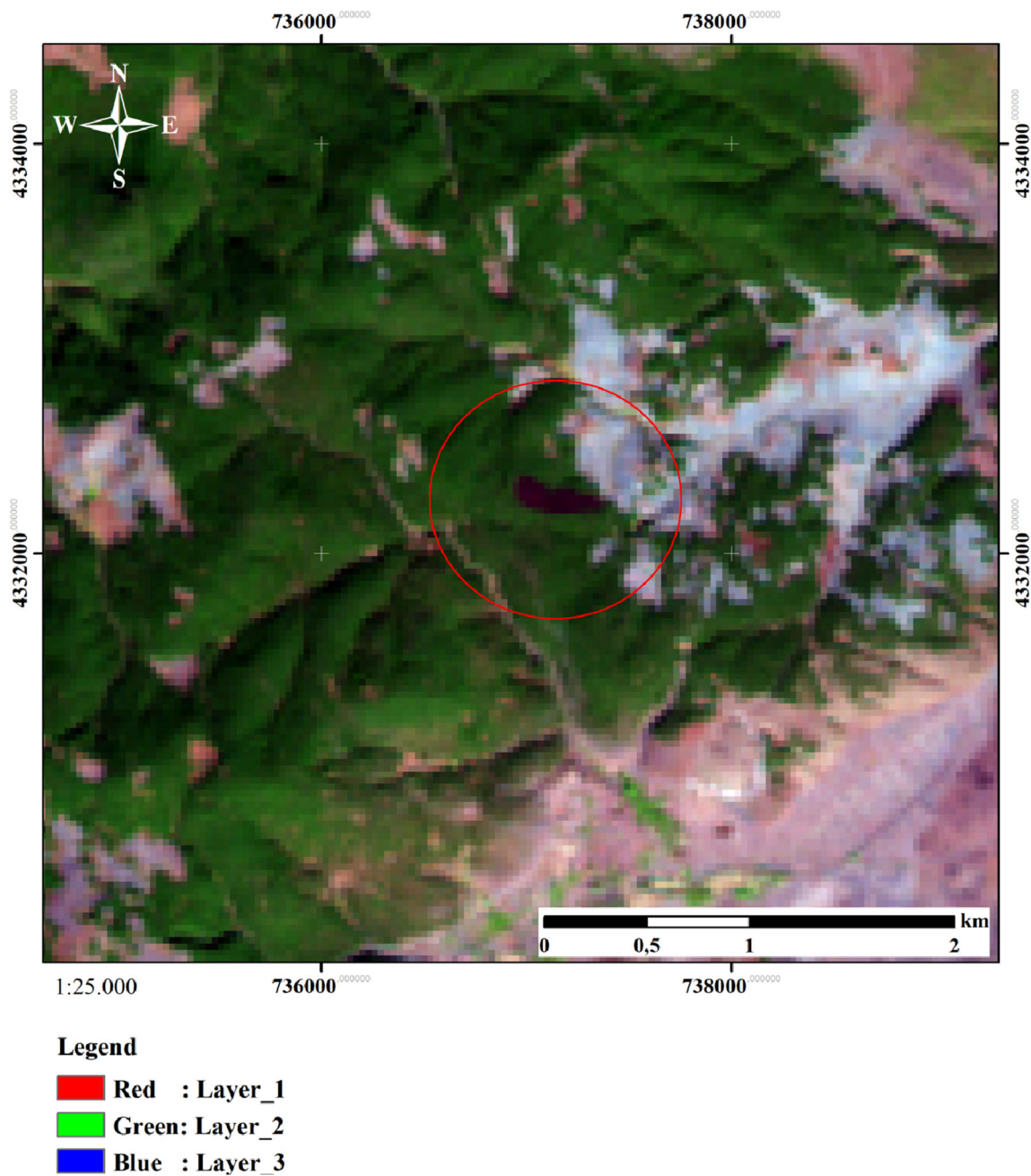


Fig. 15 543 band combination post-fire (spectral index maps for Ören-Çambidi region – 2001)

The other band ratio method, namely NBR, is mostly applied for the determination of the burned areas through the detection of the difference of the images captured from an area before and after a fire. In NBR, 7th and 4th bands of the images are used (Key and Benson 2006). NBR ratio is particularly sensitive to live plant cover, humidity content and specific changes in soil after the

fires. Therefore, NBR is a highly preferred method for burned green area detection studies (Sabuncu and Özener 2019). Table 3 summarizes the band ratio methods of NDVI and NBR. In this study, the images obtained via NDVI and NBR methods were overlaid with the forest fire risk map, so as to determine the risk classes of the burned areas and make evaluations.

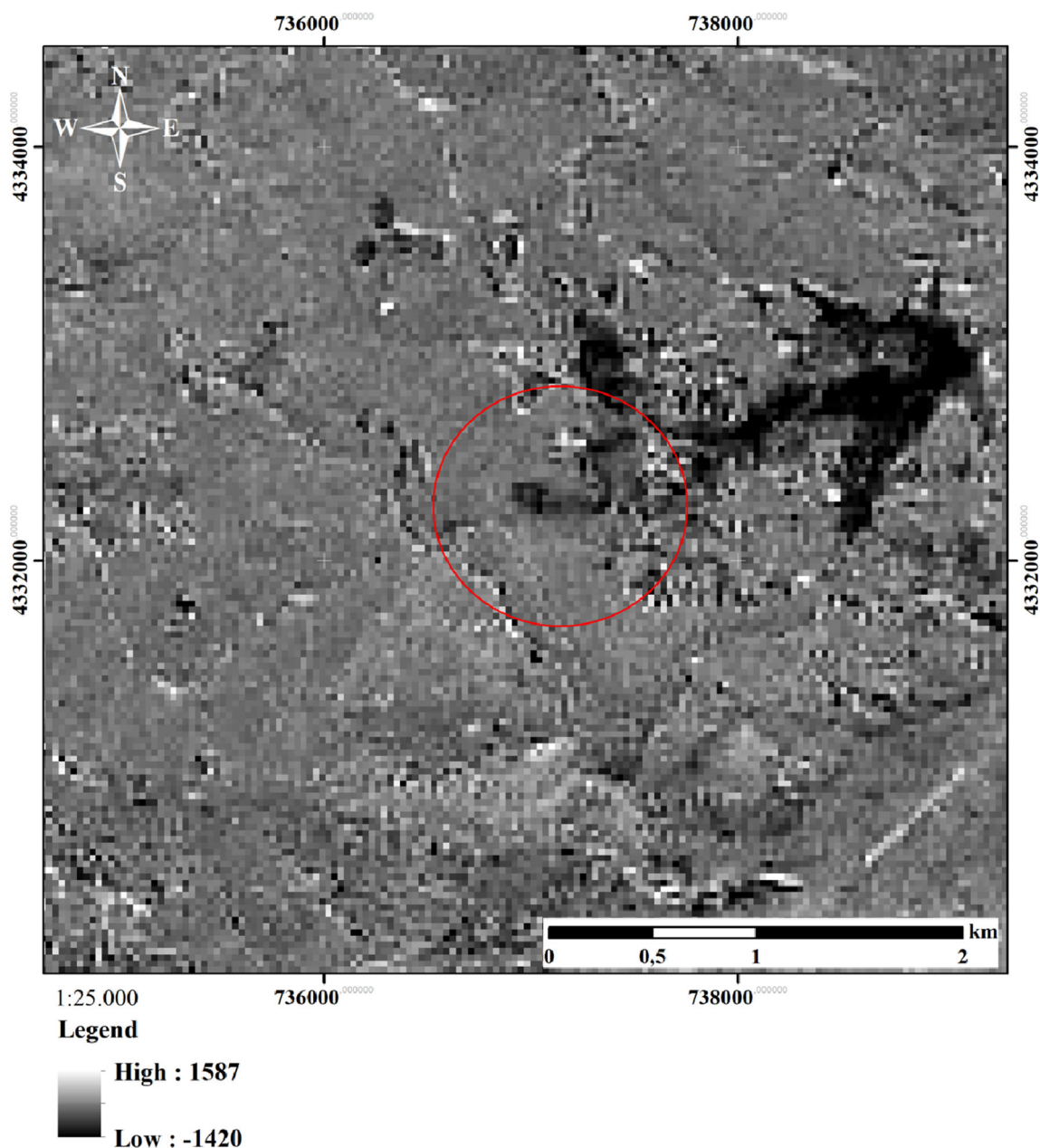


Fig. 16 d543 difference (spectral index maps for Ören-Çambidi region – 2001)

Results

This section may be divided by subheadings. It should provide a concise and precise description of the experimental results, their interpretation and the experimental conclusions that can be drawn.

Development of fire risk map

As the main goal of this study, forest fire risk map for Ören Forest Sub-district Directorates was developed via

the weighted overlay analysis of a variety of spatial data explained in previous sections of the study (Table 1 and Table 2). In accordance with the method illustrated in Fig. 4, tree hazard class map was produced. Moreover, a variety of spatial maps were also developed as data layers/inputs and reclassified with regard to their risk classes for the weighted overlay analysis. Figures 5, 6, 7, 8, 9, 10 show the weighted overlay data layers. Figure 11 gives the resulting weighted overlay analysis map that shows the forest fire risk classes of Ören Forest Sub-district Directorates.

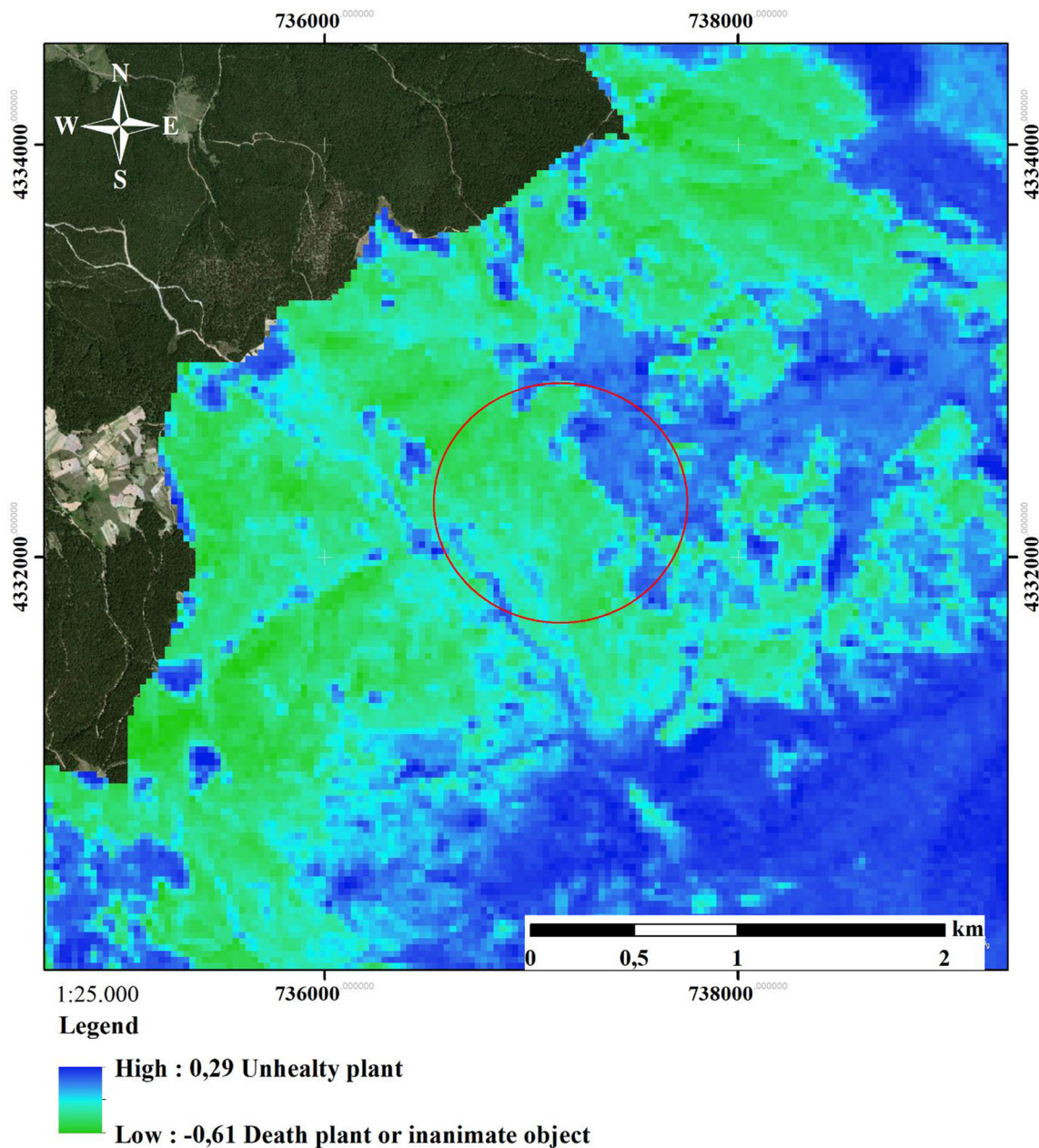


Fig. 17 NDVI pre-fire, 2001 (spectral index maps for Ören-Çambidi region – 2001)

According to the forest fire risk map given in Fig. 11, 36.86% of the study area comprises very-high and high-risk zones. The rate of the moderate-risk areas is 60.39% and low-risk lands cover 2.7% of the study area.

Evaluation of existing fire towers

For the determination of the visibility of Ören Forest Sub-district Directorates territories from the towers, 19 fire towers

located in and around the study area were used to perform the visibility analysis with ArcGIS 10.6 software. As elevation data is vital for visibility analyses, both DEM data of the study area and the tower heights were taken as main parameters. Figure 12 shows the locations of the fire towers and the resulting visibility map is illustrated in Fig. 13.

According to the visibility map, 82.8% of the study area is visible from the towers. However, 17.2% of the land is out of towers' sight.

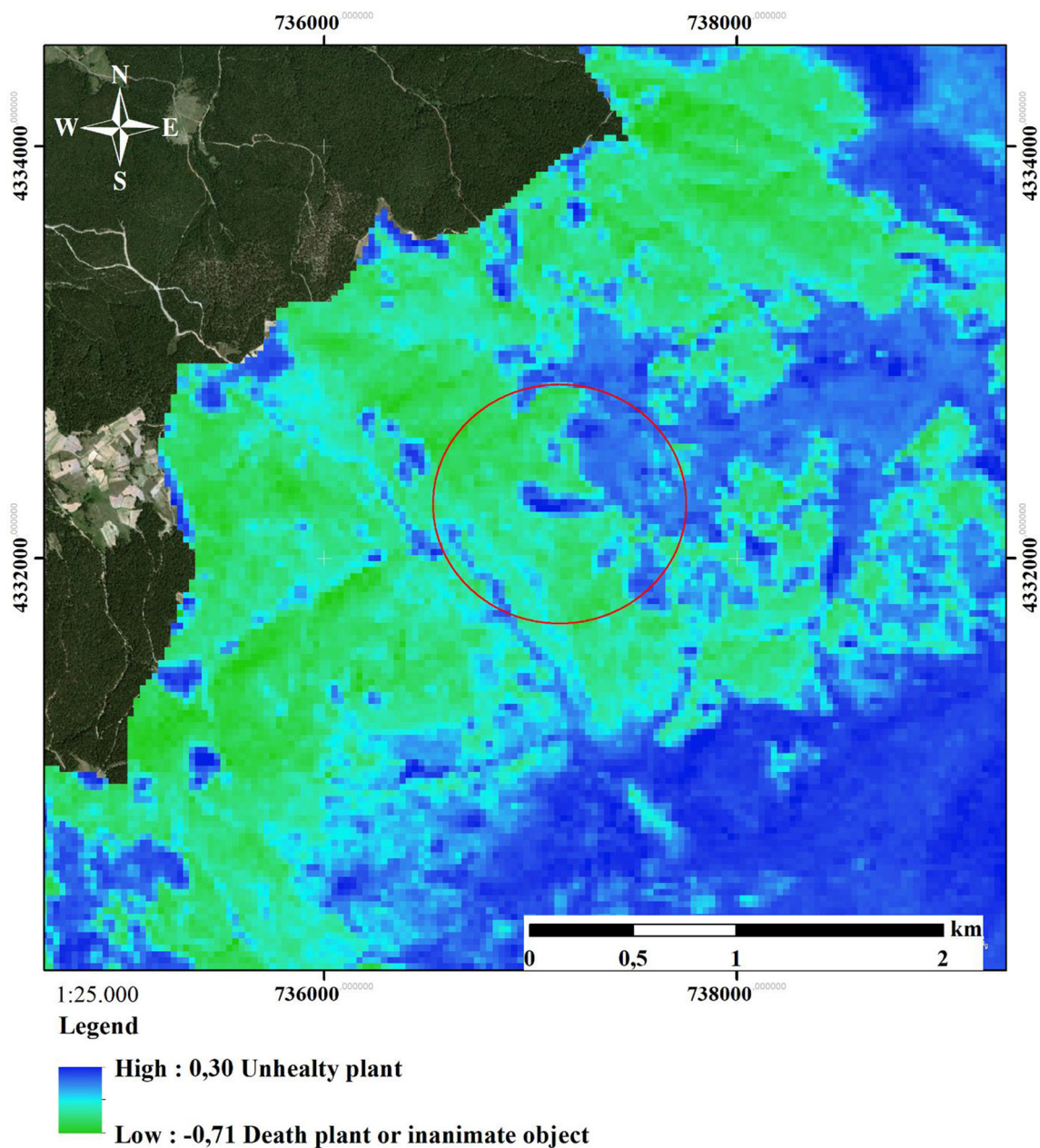


Fig. 18 2001 NDVI post-fire, 2001 (spectral index maps for Ören-Çamdibi region – 2001)

Determination of burned areas using band ratio methods

On October 3, 2001, a forest area of 4 ha within Ören-Çamdibi region was burned as recorded by the official records. Within the aim of this study, pre- and post-fire LANDSAT 7 ETM images were obtained from USGS for performing NDVI and NBR band ratio methods with ArcGIS 10.06 software. Figures 14, 15, 16, 17, 18, 19, 20, 21, 22 show the images produced throughout the process.

Determination of fire risk classes for burned areas in 2001

This phase of the study was conducted for the determination of the fire risk classes of the areas burned in 2001 in Ören-Çamdibi region, as detected via NDVI and NBR methods. To fulfil this aim, the burned areas located on dNDVI and dNBR images (Figs. 14, 15, 16, 17, 18, 19, 20, 21, 22) were digitized using ArcGIS tools and overlaid with the forest fire risk map (Fig. 23).

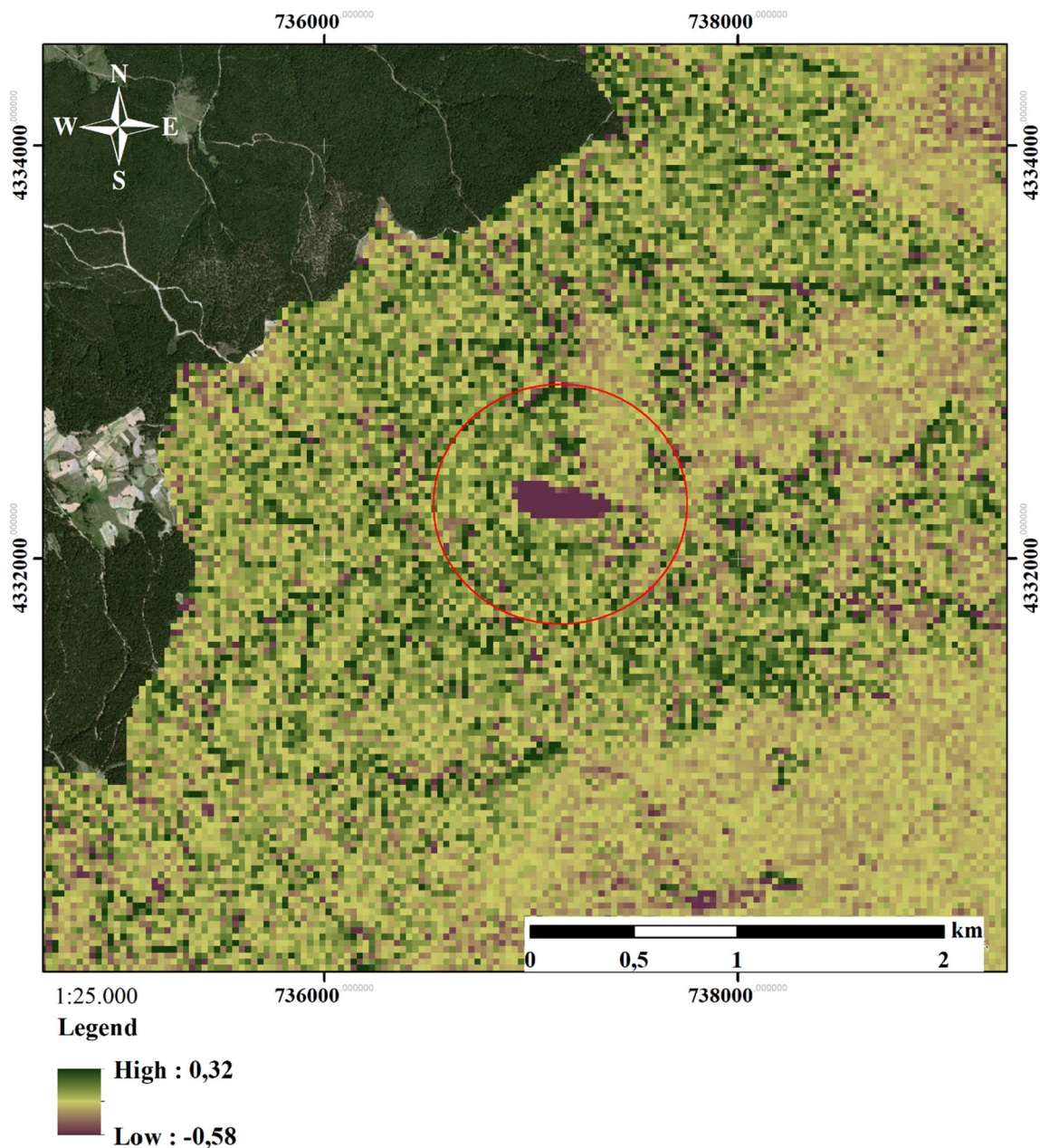


Fig. 19 dNDVI – difference (spectral index maps for Ören-Çambidi region – 2001)

According to the findings, the digitized areas cover 5.6 ha, although the official records declare a total burned area of 4 ha. It was concluded that 83% (4.65 ha) of the burned forests were classified as of moderate risk, while 17% (0.95 ha) of it was on very-high and high-risk zones.

Conclusions

The main goal of this study was the determination of forest fire risk classes in the selected study area, namely

Kütahya-Ören Forest Sub-district Directorates, with weighed overlay analysis method using GIS capabilities. As Kütahya province is listed within the highest risk areas (1st-degree risk areas) in terms of forest fires by the General Directorate of Forestry, the main motive for the selection of the study area was this critical fact, as well as the availability of the spatial data and the absence of the related works or researches in this territory. The risk maps produced by the General Directorate is on national scale, and therefore, more detailed risk determination studies on local scales are necessary for the

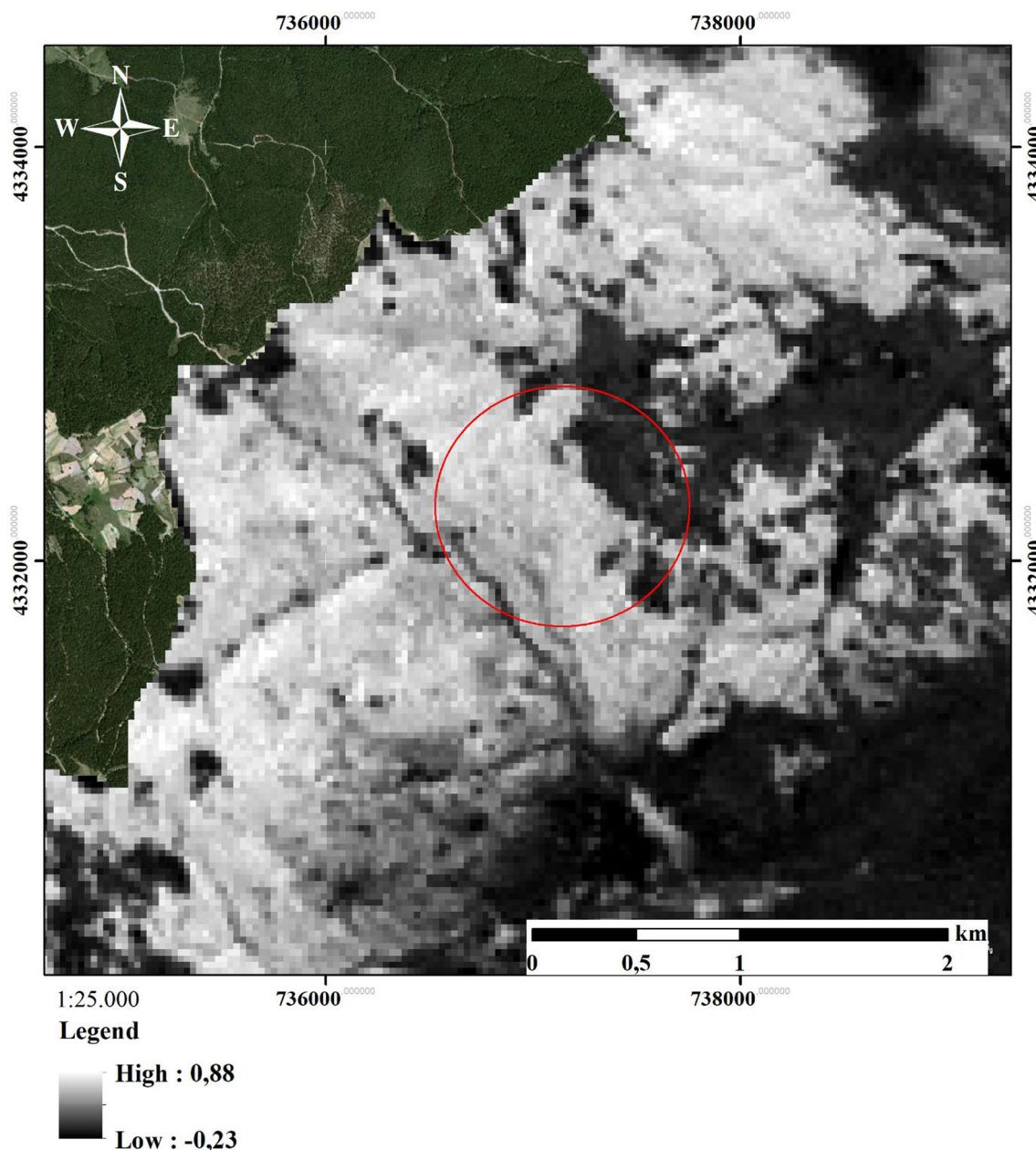


Fig. 20 NBR pre-fire, 2001 (spectral index maps for Ören-Çambidi region – 2001)

prevention and efficient management of the forests in the country.

Besides the development of the forest fire risk map, visibility analysis, NDVI and NBR band ratio methods were also utilized respectively for the evaluation of locations of the existing fire towers and spatial determination of a previous forest fire in the study area, which took place in 2001. When the band combinations used in this study were evaluated, it is concluded that Landsat 543 and combination alone was insufficient, while NDVI and NBR methods provided more accurate results in the determination of the burned areas.

Especially, NBR method stands out with its ability to classify forest fires according to their fire severity.

The forest fire risk map revealed that areas with young trees and low canopy closure caused moderate or low fire risks, and fire risk increased in parallel with the increase in canopy closure rate (Hu et al. 2017). In terms of stand types, it was found that productive black pine and juniper vegetation was more sensitive to fire risks in comparison with the disturbed forests. These facts show that stand types, tree species and canopy closure are of great importance for the determination of fire risk classes. Forest fire risk map also showed that the fire risk

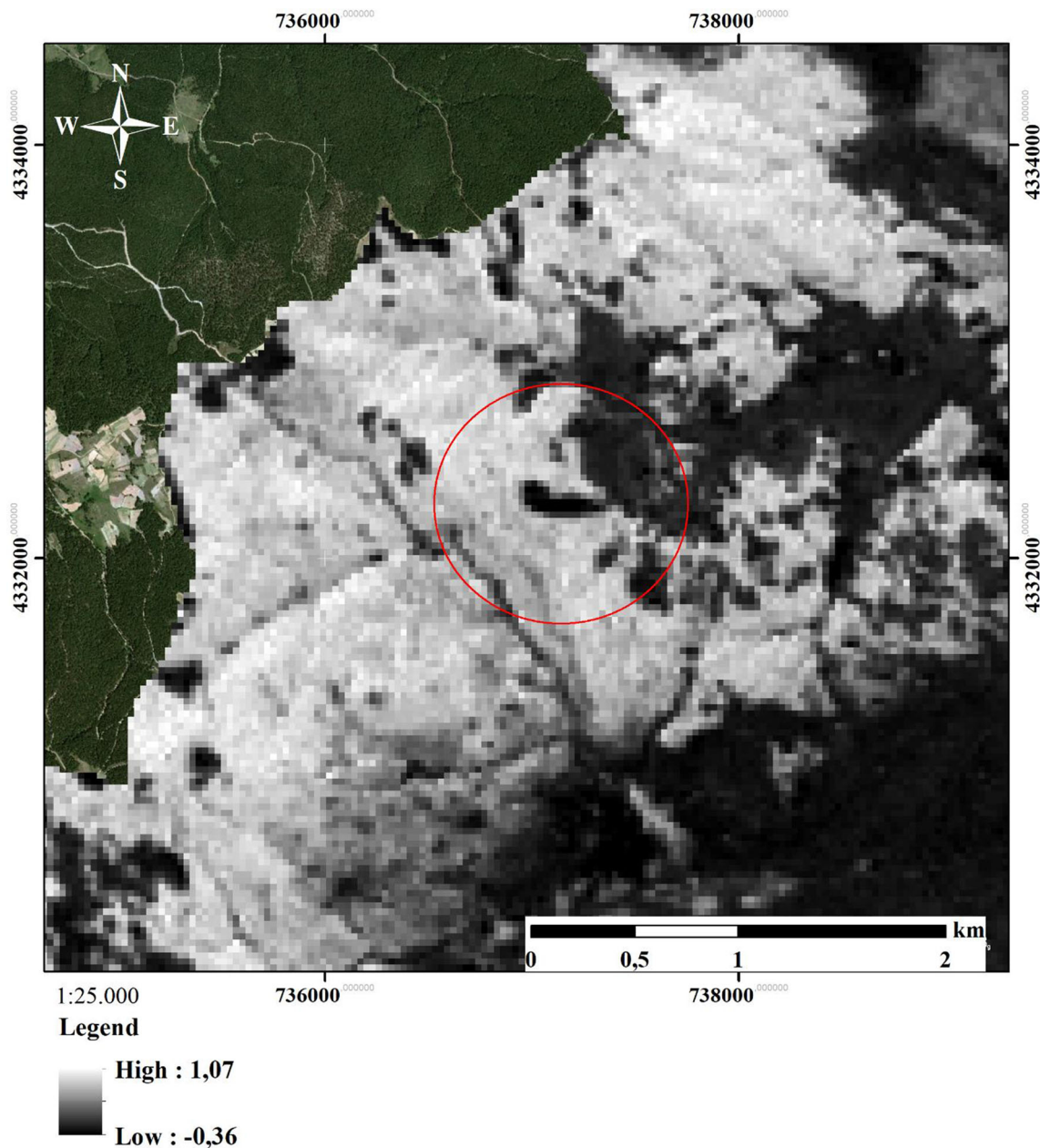


Fig. 21 NBR post-fire, 2001 (spectral index maps for Ören-Çambidi region – 2001)

was more on the peripheries of the settlement areas and roads, which is not surprising at all due to the existence of human factors. Zones around dry streams also had higher fire risks as a result of the scrubby vegetation and human activities.

Considering the locations of the existing fire towers, the visibility analysis results put forward that they had sight over the majority of the area, which is accepted suitable in the detection of smokes.

During the study, it was detected that information related to forest fires is archived as non-graphical records/data by the authorities, and therefore, it is not possible to accurately locate

the burned areas spatially unless other methods are used. This is also why the area of the burned areas on October 3, 2001, which is evaluated as the sample forest fire in this study, was calculated 40% more (5.6 ha) than the officially declared records (4 ha). To sum up, the spatial data for forests fires are unavailable in most of the Forest Sub-district Directorates, and hence, remote sensing methods are necessary for the determination of the burned area territories.

Besides the detection of the risk classes of the burned areas in 2001, which were from moderate- (83%) and very-high and

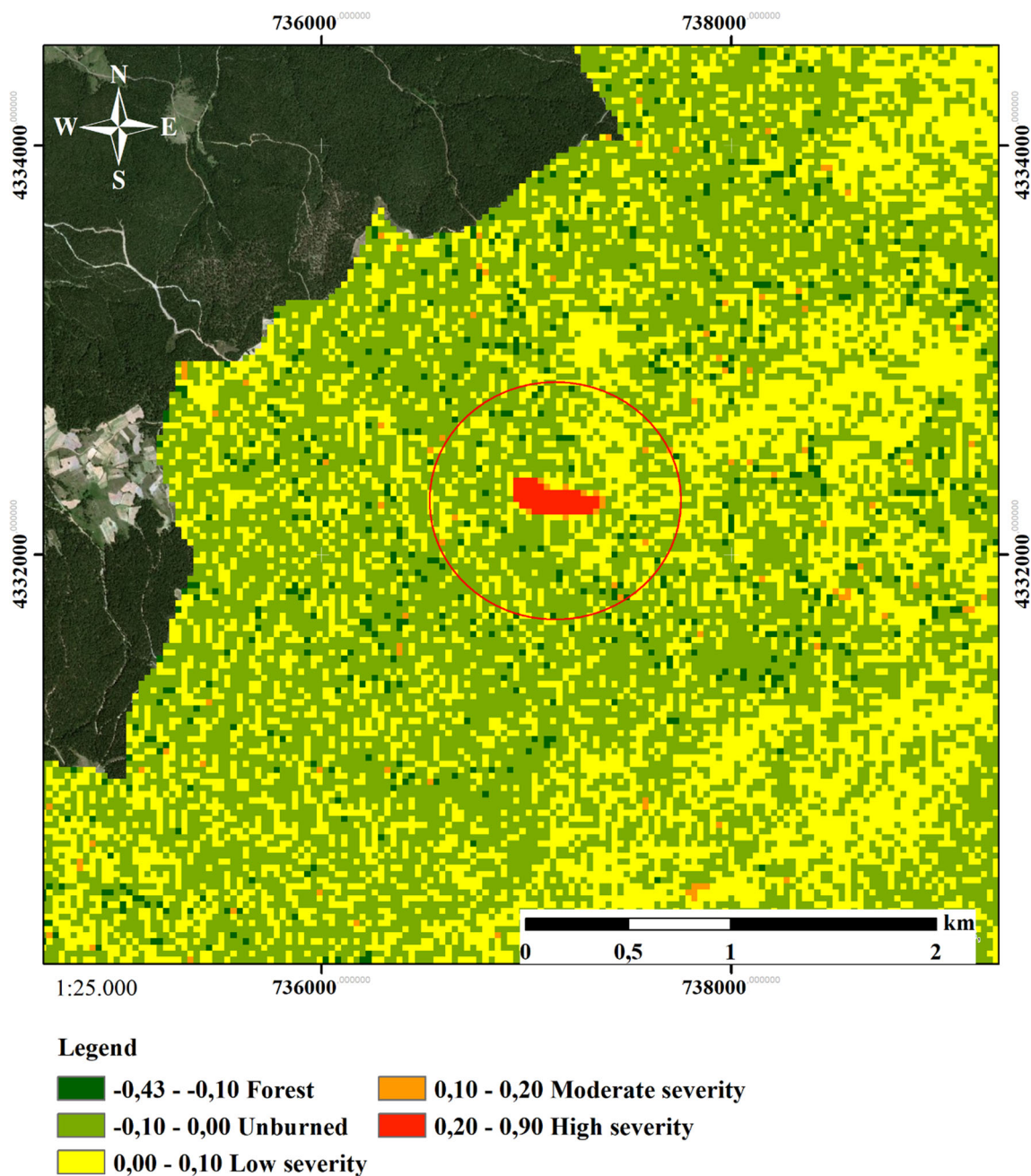


Fig. 22 dNBR – difference (spectral index maps for Ören-Çambidi region – 2001)

high-risk (17%) areas, it was also concluded from the satellite images that the burned areas were rehabilitated after the fire.

When the literature is examined, it is seen that besides the data groups also used in this study, a number of different layers such as surface temperature, vegetation humidity, agricultural lands and population density are utilized by some of the researchers (Akbulak et al. 2018; Başaran et al. 2007; Fanhua et al. 2005; Karabulut et al. 2013; Orozco 2008; Sabuncu and Özener 2019; Siachalou et al. 2009). Moreover, climate has an eminent role in the determination of the forest fire risks and taking rapid actions/cautions against

risks (Banja 2019). Nevertheless, climatic factors are ignored in this study since the major target was to produce a general forest fire risk map, rather than a dynamic model operating with seasonal and/or hourly climatic criteria.

One of the other important issues to highlight in terms of the methodology used in this study is the approach adopted for the determination of the influence weights, suitability/risk points and scale. It is necessary to underline that such an approach can differ depending on the geographical characteristics of the study area, previous experiences gained, aim and strategies of the study and applicable legislation. Therefore, it

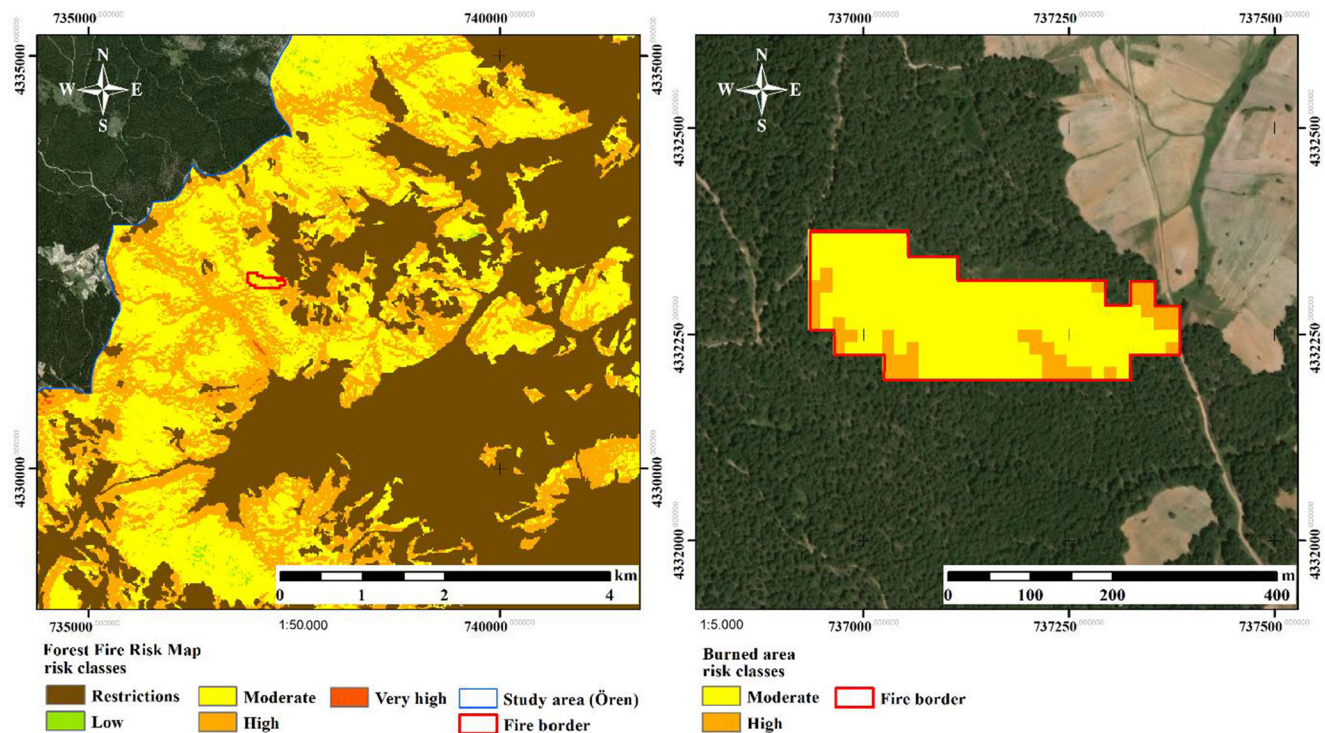


Fig. 23 Comparison of burned areas with fire risk map

is significant to examine the geographic context comprehensively and select the most appropriate method in line with the aim and context.

Acknowledgements Not applicable

Author contribution Mehtap Ozenen Kavlak, Saye Nihan Cabuk and Mehmet Cetin: Design, Resources, Writing; Materials, Data Collection and/or Processing; Materials, Literature Search, Analysis and/or Interpretation.

Funding Not applicable

Data availability Not applicable

Declarations

Ethics approval Not applicable

Consent to participate Not applicable

Consent to publish Not applicable

Competing interests The authors declare no competing interests.

References

Akay A, Erdoğan A (2017) GIS-based multi-criteria decision analysis for forest fire risk mapping. In: ISPRS Annals of the photogrammetry,

remote sensing and spatial information sciences, 2017. p 25 <https://pdfs.semanticscholar.org/77ba/6065a7aedc3695d88ef0924d8c583ee1d02d.pdf>. Accessed 08 Nov 2020

Akay AE, Şahin H (2018) Forest fire risk mapping by using GIS techniques and AHP method: a case study in Bodrum (Turkey). *Eur J For Eng* 5:25–35. <https://doi.org/10.33904/ejfe.579075>

Akbulak C, Tatlı H, Aygün G, Sağlam B (2018) Forest fire risk analysis via integration of GIS, RS and AHP: the case of Çanakkale. *Turkey J Hum Sci* 15:2127–2143 <https://j-humansciences.com/ojs/index.php/IJHS/article/view/5491>. Accessed 10 Nov 2020

Aleemahmoodi Sarab S, Fegghi J, Danehkar A, Attarod P (2015) Effects of dereference evapotranspiration and relative humidity on forest fire occurrences in Zagros Forests, west of Iran (Case study: Khuzestan province). *For Range Protect Res* 12:79–86. <https://doi.org/10.22092/ijfpr.2015.13248>

Asri G, Çorumluoğlu Ö, Özdemir E (2017) CBS destekli Orman Yangını Risk Dağılım Analizi; Antalya Örneği. In: 15. Türkiye HaritaBilimsel ve Teknik Kurultayı, Ankara, 25-28 Mart 2015 2017

Bailey RP (2001) Forest fire prevention and suppression guidelines for industrial activities. Northwest territories

Banja L (2019) Global forest watch fires. <https://fires.globalforestwatch.org/map/#activeLayers=viirsFires%2CactiveFires%2CwindDirection&activeBasemap=dark-gray&activeImagery=&planetCategory=PLANET-MONTHLY&planetPeriod=Jan%202019&x=26.827108&y=38.848728&z=6>. Accessed 14.11.2019

Başaran MA, Sarıbaşak H, Çamalan İ (2007) Using geographical information system technique in determining fire risk and hazard classes, Symposium on bottlenecks, solution suggestions and priorities within the scope of functions of forest resources:17-19

Bilgili E (2003) Stand development and fire behavior. *For Ecol Manag* 179:333–339. [https://doi.org/10.1016/S0378-1127\(02\)00550-9](https://doi.org/10.1016/S0378-1127(02)00550-9)

Bilici E (2009) A study on the integration of firebreaks and fireline with forest roads networks and it's planning and construction (a case study of Gallipoli National Park). *İstanbul Ünive Orman Fakültesi Dergisi Seri A* 59:85–101

- Bingöl B (2017) Determination of forest fire risk areas in Burdur province using geographical information systems Turkish. *J For Sci* 1:169–182. <https://doi.org/10.32328/turkjforsci.319155>
- Brushlinsky N, Ahrens M, Sokolov S, Wagner P (2016) World fire statistics. Center of fire statistics, Slovenia
- Calfee RD, Little EE (2003) Effects of a fire-retardant chemical to fathead minnows in experimental streams. *Environ Sci Pollut Res* 10:296–300
- Carmel Y, Paz S, Jahashan F, Shoshany M (2009) Assessing fire risk using Monte Carlo simulations of fire spread. *For Ecol Manag* 257: 370–377. <https://doi.org/10.1016/j.foreco.2008.09.039>
- Corona P, Köhl M, Marchetti M (2013) Advances in forest inventory for sustainable forest management and biodiversity monitoring, vol 76, 1st edn. Springer Science & Business Media, New York. <https://doi.org/10.1007/978-94-017-0649-0>. Accessed 10 Nov 2020
- Değerliyurt M, Çabuk S (2015) Defining geography with geographical information systems Eastern. *Geogr J* 20:37–48. <https://doi.org/10.17295/dcd.88722>
- Dong X, Li-min D, Guo-fan S, Lei T, Hui W (2005) Forest fire risk zone mapping from satellite images and GIS for Baihe Forestry Bureau, Jilin, China. *J For Res* 16:169–174. <https://doi.org/10.1007/bf02856809>
- Erten E, Kurgun V, Musaoglu N (2004) Forest fire risk zone mapping from satellite imagery and GIS: a case study. In: XXth Congress of the International Society for Photogrammetry and Remote Sensing, Istanbul, Turkey, Istanbul. pp 222-230
- Ertuğrul M (2005) Forest fire situation in Turkey and in the world. *Bartın Fac For J* 7:43–50
- ESRI (2016) How weighted overlay works. <http://desktop.arcgis.com/en/arcmap/10.3/tools/spatial-analyst-toolbox/how-weighted-overlay-works.htm>. Accessed 12.11.2019
- ESRI (2018) Understanding visibility analysis. <http://desktop.arcgis.com/en/arcmap/10.3/guide-books/extensions/3d-analyst/visibility-analysis.htm>. Accessed 12.11.2019
- Eugenio FC et al (2016) Applying GIS to develop a model for forest fire risk: a case study in Espírito Santo, Brazil. *J Environ Manag* 173: 65–71. <https://doi.org/10.1016/j.jenvman.2016.02.021>
- Fanhua K, Xiuzhen L, Haiwei Y (2005) The effect of fire intensity on the patterns of forest landscape in the north-slope of Da Hinggan Mountains. *J Nanjing Forestry Univer* 29(2):33–37
- FAO (2001) International handbook on forest fire protection. F.A.O. (Food and Agriculture Organization of the United Nations), Technical guide for the countries of the Mediterranean basin, France. <http://www.fao.org/forestry/27221-06293a5348df37bc8b14e24472df64810.pdf>. Accessed 5 Nov 2020
- Gao X, Fei X, Xie H (2011) Forest fire risk zone evaluation based on high spatial resolution RS image in Liangyungang Huaguo Mountain Scenic Spot. In: Proceedings 2011 IEEE International Conference on Spatial Data Mining and Geographical Knowledge Services, 2011. IEEE, pp 593-596
- Gazzard R (2012) Risk management control measure: toolkit for practitioners and advisors UK Vegetation Fire Risk Management
- Gheshlaghi HA (2019) Using GIS to develop a model for forest fire risk mapping. *J Indian Soc Remote Sens* 47:1173–1185. <https://doi.org/10.1007/s12524-019-00981-z>
- Ghimire B, Bhujel K, Rijal K (2014) Fire hazard zonation of Bardia National Park, Nepal: a disaster preparedness approach Nepal. *J Environ Sci* 2:27–33. <https://doi.org/10.3126/njes.v2i0.22738>
- Ghorbanzadeh O, Blaschke T, Gholamnia K, Aryal J (2019) Forest fire susceptibility and risk mapping using social/infrastructural vulnerability and environmental variables. *Fire* 2:50. <https://doi.org/10.3390/fire2030050>
- Global Forest Watch Fires (2019) Fire report for all. <https://fires.globalforestwatch.org/report/index.html#aotype=ALL&reporttype=globalcountryreport&dates=fYear-2018!fMonth-10!fDay-21!tYear-2019!tMonth-10!tDay-20>. Accessed 21.10.2019
- Goldammer J, Mitsopoulos I, Mallinis G, Woolf M (2017) Wildfire hazard and risk assessment. In: Glasser R (ed) Words into action guidelines - national disaster risk assessment. UNISDR, p 9
- Hu Z, Wang G, Sun X (2017) Precipitation and air temperature control the variations of dissolved organic matter along an altitudinal forest gradient, Gongga Mountains, China. *Environ Sci Pollut Res* 24: 10391–10400
- İşçi M (2018) Orman Yangınları ile Mücadele ve Faaliyetleri 2018 Yılı Değerlendirme Raporu. Muğla, OBM, Muğla
- Jaiswal RK, Mukherjee S, Raju KD, Saxena R (2002) Forest fire risk zone mapping from satellite imagery and GIS. *Int J Appl Earth Obs Geoinf* 4:1–10. [https://doi.org/10.1016/S0303-2434\(02\)00006-5](https://doi.org/10.1016/S0303-2434(02)00006-5)
- Karabulut M, Karakoç A, Gürbüz M, Kızılelma Y (2013) Determination of forest fire risk areas in Başkonuş Mountain (Kahramanmaraş) using geographical information systems International. *J Soc Res* 6: 171–179
- Kavgacı A, Örtel E, Torres I, Safford H (2016) Early postfire vegetation recovery of Pinus brutia forests: effects of fire severity, prefire stand age, and aspect. *Turk J Agric For* 40:723–736. <https://doi.org/10.3906/tar-1601-21>
- Kaysis (2019) Application principles in prevention and extinction of forest fires. Public Legislation System, Ankara
- Key CH, Benson NC (2006) Landscape assessment (LA) vol 164. General Technical Report
- Kültür ve Turizm Bakanlığı (2019) Aslanapa. <https://kutahya.ktb.gov.tr/TR-69493/aslanapa.html>. Accessed 12.11.2019
- Kuter N, Yenilmez F, Kuter S (2011) Forest fire risk mapping by kernel density estimation Croatian. *J For Eng J Theory Appl For Eng* 32: 599–610
- Laurance WF (2010) Habitat destruction: death by a thousand cuts. *Conserv Biol* 1:73–88. <https://doi.org/10.1093/acprof:oso/9780199554232.003.0005>
- Majlingová A (2012) Opening-up of forests for fire extinguishing purposes. *Croatian J For Eng J Theory Appl For Eng* 33:159–168
- Meddens AJ, Kolden CA, Lutz JA (2016) Detecting unburned areas within wildfire perimeters using Landsat and ancillary data across the northwestern United States. *Remote Sens Environ* 186:275–285. <https://doi.org/10.1016/j.rse.2016.08.023>
- Mirzaei J (2016) Impacts of two spatially and temporally isolated anthropogenic fire eventson soils of oak-dominated Zagros forests of Iran. *Turk J Agric For* 40:109–119. <https://doi.org/10.3906/tar-1406-61>
- Navarro G, Caballero I, Silva G, Parra P-C, Vázquez Á, Caldeira R (2017) Evaluation of forest fire on Madeira Island using Sentinel-2A MSI imagery. *Int J Appl Earth Obs Geoinf* 58:97–106. <https://doi.org/10.1016/j.jag.2017.02.003>
- OGM (2019) Kütahya Forest Management Directorate. <https://kutahyaobm.ogm.gov.tr/KutahyaOIM/Sayfalar/default.aspx>. Accessed 12.11.2019
- Oliveira D, Batista A, Soares R, Slutter C (2002) Fire risk mapping for pine and eucalyptus stands in Três Barras, State of Santa Catarina, Brazil. In: Forest fire research & wildland fire safety: proceedings of the IV International Conference on Forest Fire Research [and], 2002.
- Orman Genel Müdürlüğü (1995) Application principles in prevention and extinction of forest fires. General Directorate of Forestry Notification, Ankara
- Orman Genel Müdürlüğü (2015) Turkey forest assets. Ministry of Forestry and Water Affairs General Directorate of Forestry, Ankara
- Orman Genel Müdürlüğü (2017) Forest atlas. T.R. Ministry of Forestry and Water Affairs General Directorate of Forestry, Ankara
- Orman Genel Müdürlüğü (2018) Forestry statistics.
- Orozco SJ (2008) Forest fire risk model for Michoacan, Mexico. In, 2008. ITC

- Özşahin E (2014) Forest fire susceptibility analysis using GIS and AHP: the case of Antakya Forestry Operation Directorate. *Route Educ Soc Sci J* 1. <https://doi.org/10.17121/ressjournal.106>
- Peker H, Atılğan A (2015) A natural energy source wood: its combustion feature and protection methods. *Afyon Kocatepe Univ J Sci Eng Sci* 15:1–12. <https://doi.org/10.5578/fimbd.9553>
- Popelka S, Vozenilek V (2010) Landscape visibility analysis and their visualisation. *ISPRS Arch* 38
- Rowell A, Moore PF (2000) *Global review of forest fires*. CiteSeer, Switzerland
- Rudel T, Roper J (1997) The paths to rain forest destruction: crossnational patterns of tropical deforestation, 1975–1990. *World Dev* 25:53–65. [https://doi.org/10.1016/S0305-750X\(96\)00086-1](https://doi.org/10.1016/S0305-750X(96)00086-1)
- Sabuncu A, Özener H (2019) Detection of burnt areas with remote sensing techniques: the case of Izmir Seferihisar. *For Fire Nat Disasters Environ Mag* 5:1–10. <https://doi.org/10.21324/dacd.511688>
- Sazawa K, Yoshida H, Okusu K, Hata N, Kuramitz H (2018) Effects of forest fire on the properties of soil and humic substances extracted from forest soil in Gunma, Japan. *Environ Sci Pollut Res* 25:30325–30338
- Shafiei AB, Akbarinia M, Jalali G, Hosseini M (2010) Forest fire effects in beech dominated mountain forest of Iran. *For Ecol Manag* 259: 2191–2196. <https://doi.org/10.1016/j.foreco.2010.02.025>
- Siachalou S, Doxani G, Tsakiri-Strati M (2009) Integrating remote sensing processing and GIS to fire risk zone mapping: a case study for the Seih-Sou forest of Thessaloniki. In: *Proceeding of ICC, 2009*
- TUİK (2018) *Adrese Dayalı Nüfus Kayıt Sistemi*. http://tuik.gov.tr/PreTablo.do?alt_id=1059. Accessed 12.11.2019
- Van Wagendonk JW, Root RR, Key CH (2004) Comparison of AVIRIS and Landsat ETM+ detection capabilities for burn severity. *Remote Sens Environ* 92:397–408. <https://doi.org/10.1016/j.rse.2003.12.015>
- Vanha-Majamaa I (2006) *Global forest resources assessment 2005–Report on fires in the Baltic region and adjacent countries*. FAO Forestry department. Working paper FM/7/E, Rooma, Italia
- White JD, Ryan KC, Key CC, Running SW (1996) Remote sensing of forest fire severity and vegetation recovery. *Int J Wildland Fire* 6: 125–136. <https://doi.org/10.1071/WF9960125>
- Yang J, He HS, Shifley SR, Gustafson EJ (2007) Spatial patterns of modern period human-caused fire occurrence in the Missouri Ozark Highlands. *For Sci* 53:1–15. https://doi.org/10.1142/9789812706713_0001
- Yassemi S, Dragičević S, Schmidt M (2008) Design and implementation of an integrated GIS-based cellular automata model to characterize forest fire behaviour. *Ecol Model* 210:71–84. <https://doi.org/10.1016/j.ecolmodel.2007.07.020>

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