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Original Research

Evaluation of Forest Fire Risk with GIS

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Abstract

This paper uses GIS to describe and evaluate forest fire risk considering the most important factors affecting fire behavior at fine scales. The study was implemented in Yeşilova Forestry Enterprise in the Mediterranean city of Kahramanmaraş, Turkey. To determine an overall fire risk index for the study area, fire risk rating (extreme, high, moderate, or low) was assigned to decision variables (i.e. species composition, stand development stage, stand crown closure, slope, insolation, settlements, and roads) according to their risk potentials. Additionally, the visibility analysis of fire towers was carried out for monitoring of forests in the case study area. Finally, visibility analysis and a forest fire risk map were evaluated together for determining the efficiency of fire towers. Results indicated that more than half of the total forested area (65.7%) was classified as low category in the fire risk map. According to visibility analysis, the existing fire tower was able to monitor only 37% of forest areas; therefore, it was essential to consider new fire towers for monitoring the overall study area. After locating a potential new fire tower in the study area, it was found that about 71.8% of the area was with the visible zones of two fire towers.

Keywords: fire risk map, fire tower, GIS, Mediterranean region, visibility analysis

Introduction

Forest fire is a main source of forest destruction, causing enormous environmental and economic damage, as well as loss of human life, especially in the large forest fires that occur in the Mediterranean Basin [1, 2]. The forest fires negatively effect sustainable development of forest ecosystems and wildlife. Besides, fire-damaged trees can be more susceptible to deterioration factors such as fungus and insects, which can reduce quality of timber volume and economic value of forest trees dramatically [3, 4]. According to fire statistic data, about 12,000 hectares of forested area has burned in more than 2,000 forest fires in Turkey every year [5].

Evaluation and understanding of the forest fire risk map and its spatial pattern are essential for Mediterranean region forests [1]. Fire risk maps have been commonly used in many countries [6]. The forest fire risk map helps not only information of the fire potential evaluation, but also forest managers, decision makers, and fire fighters.

A fire risk map depends on many factors, such as topography, vegetation type, distances from roads, and proximity to settlements [2, 7]. Topography is an important factor in fire behavior. Fire flames move to uphill slopes easily while downhill slopes least rapidly [8]. Aspect plays a crucial role in spreading forest fires. The south-facing areas are more sensitive to fire than other aspects [9, 10]. Human activities in settlement areas may dramatically increase forest fire risks. Thus, forests located near roads have more fire tendency [8].

Fire detection is one of the most effective ways for preventing large forest fires. Determining spatial location of a fire tower correctly is very important to detecting and controlling forest fires [11]. The sooner the fire is detected and the better the information such as its spatial location, accessibility, and actual size [12], thus the most effective appliance for detecting and monitoring forest fires is fire towers [13].

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Geographical information systems (GIS) are convenient and fundamental tools for spatio-temporal analyses of forests. GIS has been effectively used in monitoring and detection of forest fires, analyzing fire tower locations, alternative fire tower locations, and firefighting strategies. There are many studies related to forest fire risk maps using GIS, which has been an important tool [10, 14-17]. However, there are few studies evaluating visibility analysis and forest fire risk maps together.

The present study is to prepare a forest fire risk map by integrating topographical and stand-type maps with GIS for the Yeşilova Forestry Enterprise located in Kahramanmaraş, Turkey. Within this framework, the objectives of this study are:

a) to generate and evaluate a fire risk map using vegetation variables, topographic factors, and human factors using GIS technologies
b) to evaluate visibility analysis and forest fire risk map together for determining the efficiency of existing fire towers
c) to suggest new fire tower locations for effective forest fire fighting.

Material and Methods

Study Area

The study area is located in Yeşilova Forestry Enterprise, which covers part of Kahramanmaraş Regional Directorate of Forestry located in the Mediterranean region of Turkey (256000-281000 E, 4137000-4159000 N, UTM ED 50 datum Zone 37N) (Fig. 1). The Kahramanmaraş Regional Directorate of Forestry, which is mostly vulnerable to forest fires due to being in the Mediterranean region with high temperatures and low to nonexistent precipitation during the fire season, is a sub-temperate forest zone. The vegetation type in the case study area is forest vegetation and the dominant tree species is brutian pine (Pinus brutia Ten.). This vegetation type is especially vulnerable to fire risk. Of the 32,624.0 ha total area, 18,485.0 ha (56%) is forested and the rest is non-forested.

GIS Database

The fundamental data used in this research are forest cover type map (2002), topographic map of Yeşilova Forestry Enterprise with 1/25,000 scale, and location information of existing fire towers. A forest cover type map was obtained from Kahramanmaraş Regional Directorate of Forestry in digital format. A forest cover type map was used to get stand information, such as species composition, development stage, and crown closure. Settlements and an agriculture land map was derived from reclassifying forest cover type map using GIS.

First of all, topographic maps were scanned, saved in *.tiff picture format, and then registered for digitizing topographic maps. Contour lines in rectified topographic maps were digitized using GIS (ArcGIS 10TM) with a 1/2,000 to 1/4,000 screen view scale and under root mean square (RMS) error 3 m. Elevation values related to study area were entered into the spatial database.

The slope and insolation maps were prepared using digitized contour line in topographic maps by producing Digital Elevation Model (DEM) with ArcGIS 10. The road map was produced using a topographic map. The "create" tool was used to create buffer zones around the road and settlement and agricultural land locations. Corridors of 100, 200, 300, and 400 m perimeters were generated around the roads, settlements, and agricultural lands.

Determination of Fire Risk Index

Fire risk index (FRI) was determined based on vegetation variables (i.e. stand crown closure, stand composition, development stage), topography (i.e. insolation and slope), and human factors (i.e. distance from road and distance from settlement and agriculture land) (Table 1). Vegetation type that influences forest fire ignition and fire severity is one of the most fundamental factors. It is necessary to separate vegetation types according to its combustion features such as stand composition, stand crown closure, and development stage [18]. Topography is an important factor that

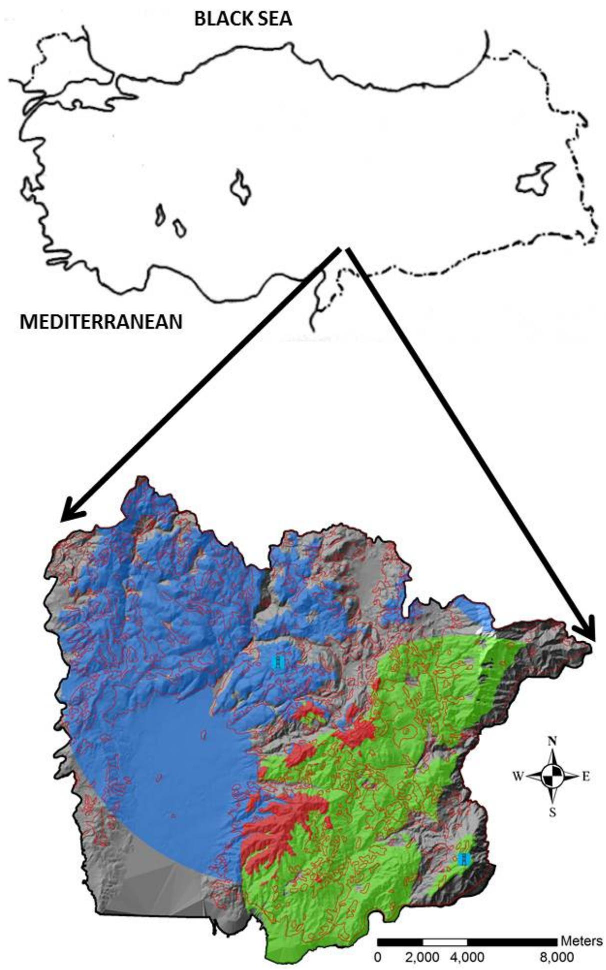

Fig. 1. The geographic location of the study area.

Table 1. Fire risk variables and classes.

Variables	Classes	Value assigned	Fire risk
Species composition (weight= 10)	(1) Black pine + Calabrian pine	5	Extreme
	(2) Beech+Fir	4	High
	(3) Degraded areas	3	Moderate
	(4) Oak + Coppice	1	Low
Stand crown closure (weight= 10)	(5) Bare Land and < 11%	1	Low
	(6) 11%-40%	2	Moderate
	(7) 41%-70%	3	High
	(8) 71%>	5	Extreme
Development stage (weight= 10)	(9) Regenerated (average dbh: < 8 cm)	2	Low
	(10) Regenerated and young (average dbh: < 0-8 and 8-19.9 cm)	5	Extreme
	(11) Young (average dbh: 8-19.9 cm)	5	Extreme
	(12) Young and mature (average dbh: 8-19.9 cm) and 20-35.9 cm	4	High
	(13) Mature (average dbh: 20-35.9 cm)	3	Moderate
	(14) Mature and overmature (average dbh: 20-35.9 and >36 cm)	2	Low
	(15) Overmature (average dbh:>36 cm)	1	Low
Slope (weight= 5)	(16) 0-5%	1	Low
	(17) 5-15%	2	Moderate
	(18) 15-35%	3	High
	(19) > 35%	5	Extreme
Insolation (weight= 3)	(20) 0-23 N	1	Low
	(21) 23-68 NE	2	Moderate
	(22) 68-113 E	2	Moderate
	(23) 113-158 SE	3	High
	(24) 158-203 S	5	Extreme
	(25) 203-248 SW	5	Extreme
	(26) 248-293 W	2	Moderate
	(27) 293-338 NW	2	Moderate
	(28) 338-360 N	1	Low
Distance from settlement and agriculture land (weight= 2)	(29) 0-100	5	Extreme
	(30) 100-200	3	High
	(31) 200-300	2	Moderate
	(32) 400 <	1	Low
Distance from road (weight= 2)	(33) 0-100	5	Extreme
	(34) 100-200	4	High
	(35) 200-300	2	Moderate
	(36) 400 <	1	Low

Table 2. Fire risk index (FRI) level intervals for fire risk map.

Vegetation Variable (SC+CC+DS)	Slope (%) (S)	Insolation (°) (IS)	Distance from settlement and agriculture land (SA)	Distance from road (R)	Fire risk index (FRI)	Fire risk class
ESC+CC+DS	E_S	E_{IS}	E_{SA}	E_R	210	Extreme
ESC+CC+DS	H_S	H_{IS}	H_{SA}	H_R	188	Extreme
ESC+CC+DS	M_S	M_{IS}	H_{SA}	H_R	180	Extreme
ESC+CC+DS	M_S	L_{IS}	H_{SA}	H_R	177	High
HSC+CC+DS	M_S	M_{IS}	H_{SA}	H_R	140	High
HSC+CC+DS	M_S	L_{IS}	H_{SA}	H_R	137	Moderate
MSC+CC+DS	M_S	M_{IS}	M_{SA}	M_R	104	Moderate
MSC+CC+DS	M_S	L_{IS}	M_{SA}	M_R	101	Low
LSC+CC+DS	L_S	L_{IS}	L_{SA}	L_R	52	Low

E – extreme, H – high, M – moderate, L – low

affects forest temperature, moisture, and wind behavior [19]. Highest slope degree has more fire risks compare to low slope degree [8]. In terms of insolation, south-facing areas suffer a greater water stress than the rest and, consequently, the probability of a fire event and fire sprawl increase [10]. Settlements near/inside forested areas may cause fire risk because inhabitants may cause accidental fires. Distance from settlement and agriculture land is a fundamental factor for predicting the possibility of forest fires [8].

Determining FRI, first of all, fire risk rating (i.e. extreme, high, moderate, or low) was assigned to decision variables according to their fire risk potential. Second, each fire risk class was scaled from 1 to 5 [15] (Table 1) and then all the layers were overlaid. A higher rating shows that the variable has a high level of influence on fire risk. Third, all layers were integrated through GIS and FRI and calculated using the following formula [8, 15]:

$$FRI = 10(SCi+CCj+DSk)+5Sl+ 3ISm+2SAn+2Ro$$

...where FRI is fire risk index, SC is species composition (5 classes), CC is crown closure (5 classes), DS is development stage (6 classes), S is slope factor (4 classes), IS is insolation factor (9 classes), SA is settlements and agricultural land (4 classes), and R is road (4 classes). The subscripts (i, j, k, l, m, n, o) show subclasses identified by the fire risk. Finally, the fire risk map was produced according to fire risk index (FRI) level intervals (Table 2)

Visibility Analysis

Fire towers have great importance in preventing fire spread through early detection of fire location. There is only one fire tower in the case study area. In this study, the visibility analysis was carried out with the view shed analysis tool in GIS, using a digital elevation map and geographical

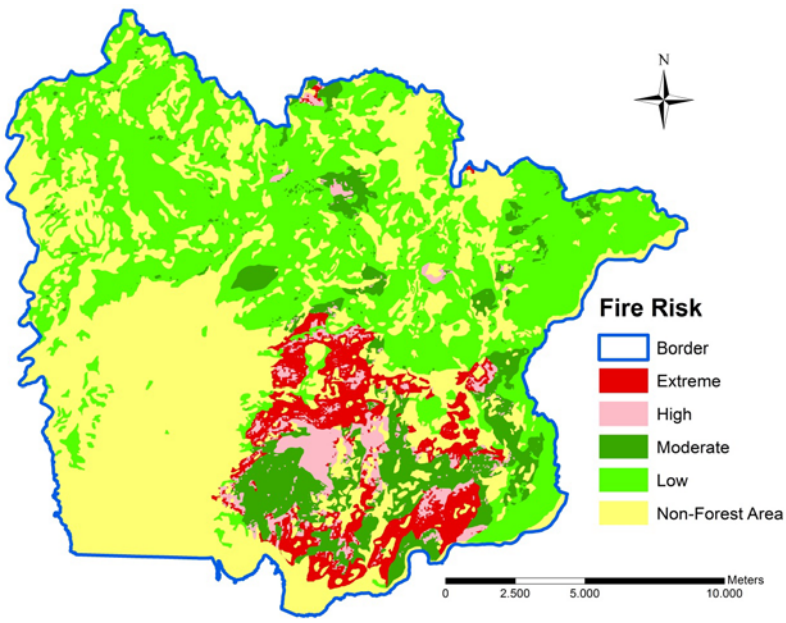

Fig. 2. Fire risk maps.

Table 3. Fire risk areas in each variable.

Fire risk class	Vegetation variables			Topography		Human factors		FRI
	SC	CC	DS	S	IS	SA	R	
Low	581.1	12,076.8	14,716.5	263.2	1,814.2	1,519.0	1,936.6	12,140.5
Moderate	12,076.8	1,226.5	635.1	4,842.1	8,061.7	2,651.4	2,306.7	2,984.1
High		2,042.7	565.7	10,705.0	2,428.8	4,368.9	2,554.9	1,219.3
Extreme	5,827.1	3,139.0	2,567.8	2,674.6	6,180.3	7,110.9	2,836.9	2,141.2

location of the fire tower. The view shed analysis tool was applied considering the criteria of fire tower height, visual cover, and maximum visualization range. Fire tower height, visual cover, and maximum visualization range are 7 m, 3,600 m and 10 km, respectively. Visibility of the tower was determined and the total visible area was analyzed. Then, the fire risk map was overlaid with visibility analysis map in GIS. Finally, an alternative fire tower was proposed for observation of invisible areas in the study area.

Table 4. Visibility analysis results of fire towers.

Towers	Visible area		Invisible area	
	Area (ha)	%	Area (ha)	%
Bereket	6,843.5	37.0	11,641.5	63.0
Karlıtepe	7,455.0	40.3	11,030.0	59.7
Visible both Bereket and Karlıtepe Tower	1,016.8	5.5		
Total visible area	13,281.8	71.8	5,203.2	28.1

Results and Discussion

According to the forest cover type map, the study area was 32,624.0 ha, and 18,485.0 ha (56% of the total study area) was forested area. The fire risk map was generated considering vegetation variables (stand composition, development stage, stand crown closure), topography (slope and insolation) and human factors (distance from road and distance from settlement and agriculture land) in Yeşilova Forestry Enterprise (Fig. 2). The map in Fig. 2 showed fire risk and the estimation of total area that could possibly be affected by fires. Results indicated that more than half of the total forested area (65.7%) was classified as low category, followed by moderate category (16.1%), extreme category (11.6%), and high category (6.6%) in fire risk map.

Table 3 presented fire risk areas in each fire risk category in some variables such as crown closure, species composition, development stage, slope, insolation, distance from road, and distance from settlement and agricultural land (Fig. 3). Results indicated that more than half of the total forested area (65.3%) was classified as moderate category, followed by extreme category (31.5%) and low category (3.1%) in species composition. According to the development stage, 79.6% of forest area was classified as low category, followed by extreme category (13.9%), moderate category (3.4%), and high category (3.1%). 65.3% of forested area was in low category, followed by extreme category (17.0%), high category (11.1%), and moderate category (6.6%) in crown closure. As an overall fire risk category in vegetation variables, half of the forest area (49.4%) was classified as low category, followed by moderate category (25.1%), extreme category (20.8%), and high category (4.7%) in vegetation variables.

A broad level analysis showed that more than half of the forest area (57.9%) was classified as high category followed by extreme category (14.5%) in terms of slope and insolation. Other remarkable changes were determined in human factors. About 73% of forested area in distance from settlement and agriculture land, and 56% of forested area in distance from road were determined as extreme and high category, respectively. When we evaluated vegetation variable, topography and human factor, human factors have more fire risk than other variables.

There is only one fire tower in Yeşilova forest planning unit, located in Bereket hill to detect and prevent forest fires. Visibility condition of the existing fire tower was analyzed by the view shed tool in ArcGIS, and the visible and invisible areas were determined (Fig. 4). According to visibility analysis, Karlıtepe Hill forest tower has limited visibility conditions. Visibility area observed from the existing towers was only 37% of forest areas (6,843.5 ha) (Table 4). The rest was invisible and most of the invisible areas were covered by susceptible pine forest in terms of fire risk. The existing fire tower was not adequate for monitoring all of the study area.

According to visibility analysis, new fire towers should be constructed for completely observing overall study areas. Therefore, we proposed a new fire tower that should be constructed in the northwest part of the study area. Determining a proposed fire tower in an invisible area, elevation of alternative fire tower and its visible capability were taken into account. New fire tower locations were suggested in the Karlıtepe Hill for monitoring whole study areas or diminishing invisible areas. According to visibility analysis, Karlıtepe fire tower has 40% of forest area. When we evaluated both fire towers in the Karlıtepe and Bereket hill, most of the study area (71.8%) becomes visible for effectively detecting and interfering in fires. The sooner we interfere with fires, the more successful we are in suppressing them (Fig. 5).

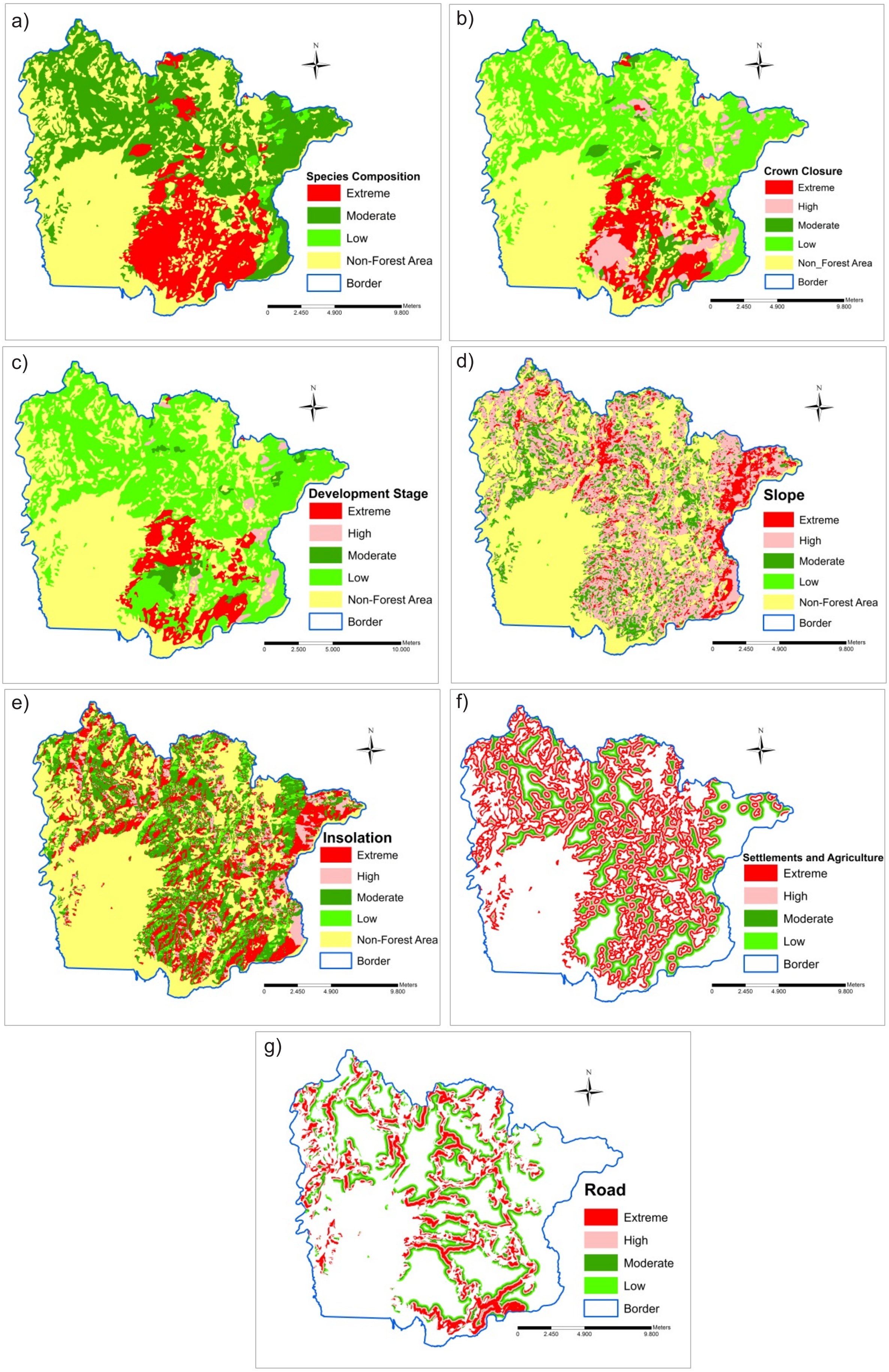

Fig. 3. Fire risk maps in each variable a) species composition, b) crown closure, c) development stage, d) slope, e) insolation, f) distance from settlements and agriculture land, and g) distance from road.

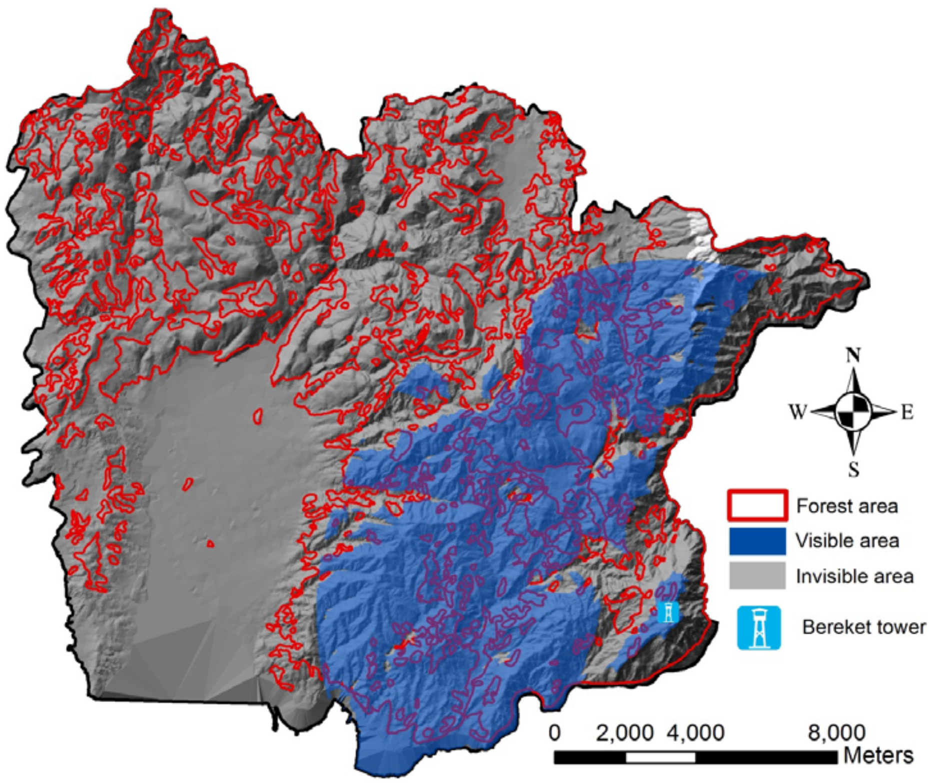

Fig. 4. Visibility analysis of existing fire tower (Bereket Tower).

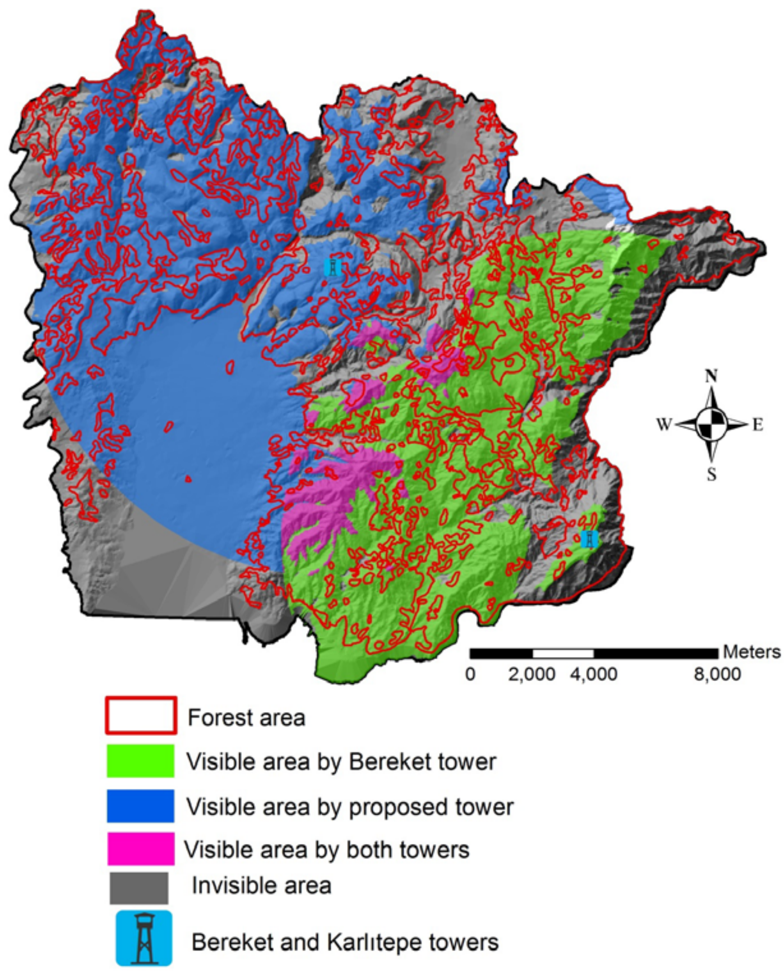

Fig. 5. Visibility analysis of existing fire tower (Bereket Tower) and proposed fire tower (Karlıtepe Tower).

Conclusions

Forest fire risk is primarily influenced by topography, vegetation variables and anthropogenic factors. Fire risk index was evaluated by using some factors such as species composition, development stage, crown closure, slope, insolation, distance from settlement and agriculture land, and distance from road. Determining fire risk index, each variable class was assigned a fire risk rating (extreme, high, moderate, or low) according to the risk potential of each class.

Fire risk map and fire tower location were evaluated together. According to visibility analysis, existing fire tower was not capable of monitoring the entire study area. It is important to point out that fire tower visibility effectiveness in the forest area is 37% and it is not sufficient for effectively detecting and interfering with fires. This should be improved in the near future for effectively monitoring a forest ecosystem. Because, 11,641.5 hectares remain unmonitored, (63% of the forest area), corresponding mainly with forest stands of high economic and environmental potential. Therefore, new fire tower locations were determined based on the fire risk map. 37 and 40.3% of the forest area are directly visible to Karlıtepe and Bereket, respectively, and 5.5% of the forest area is visible from both towers.

According to results, GIS is a useful and fundamental tool for fire risk maps, evaluating fire towers, their visible capability, and determining new locations of fire towers. A fire risk map and visibility analysis for fire towers have been proposed as a tool for effective fire management planning and providing broad-scale information to spatially fire potential areas when making decisions about how to protect the Mediterranean forest ecosystems in Turkey. Preparing fire management plans, fire risk maps, fire-fighting teams and fire tower locations should be evaluated together.

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