

# Visibility analysis of fire lookout towers in the Boyabat State Forest Enterprise in Turkey

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**Abstract** For a successful fire suppression, it is essential to detect and intervene forest fires as early as possible. Fire lookout towers are crucial assets in detecting forest fires, in addition to other technological advancements. In this study, we performed a visibility analysis on a network of fire lookout towers currently operating in a relatively fire-prone region in Turkey's Western Black Sea region. Some of these towers had not been functioning properly; it was proposed that these be taken out of the grid and replaced with new ones. The percentage of visible areas under the current network of fire lookout towers was 73%; it could rise to 81% with the addition of newly proposed towers. This study was the first research to conduct a visibility analysis of current and newly proposed fire lookout towers in the Western Black Sea region and focus on its forest fire problem.

**Keywords** Forest fires · Fire management · Fire lookout tower · Geographic information system · Visibility analysis

## Introduction

Fires have been shaping landscapes across the world. Consequently, many researchers have focused their efforts on the subject. The methods and ways have increasingly been explored to combat the wild and man-made fires. Fires pose great financial, ecological, and social threats; those in fire-prone areas take them especially seriously. Control measures are constantly renewed and updated to minimize fire damage (Kucuk et al. 2015).

Success in fighting forest fires involves more than merely taking the necessary measures on time and using resources efficiently and economically (Cumming 2005; Holmes and Calkin 2013). It is crucially important to utilize new technologies in all phases of fire management (Saglam et al. 2008; Quince 2009). Detecting fires on time and reporting them to fire command centers play an important role in the success of fire control and suppression efforts (Chandler et al. 1983; Hirsch and Martell 1996; Budd et al. 1997; Aricak et al. 2014a; Yavuz et al. 2015). Reducing the severity of loss associated with wildfire is highly dependent on measures such as fire prevention, detection, and firefighting. When fire prevention fails, firefighting strategies must be initiated, but this can only happen following the early detection. The best way of reducing firefighting costs and fire losses is therefore early detection, rapid

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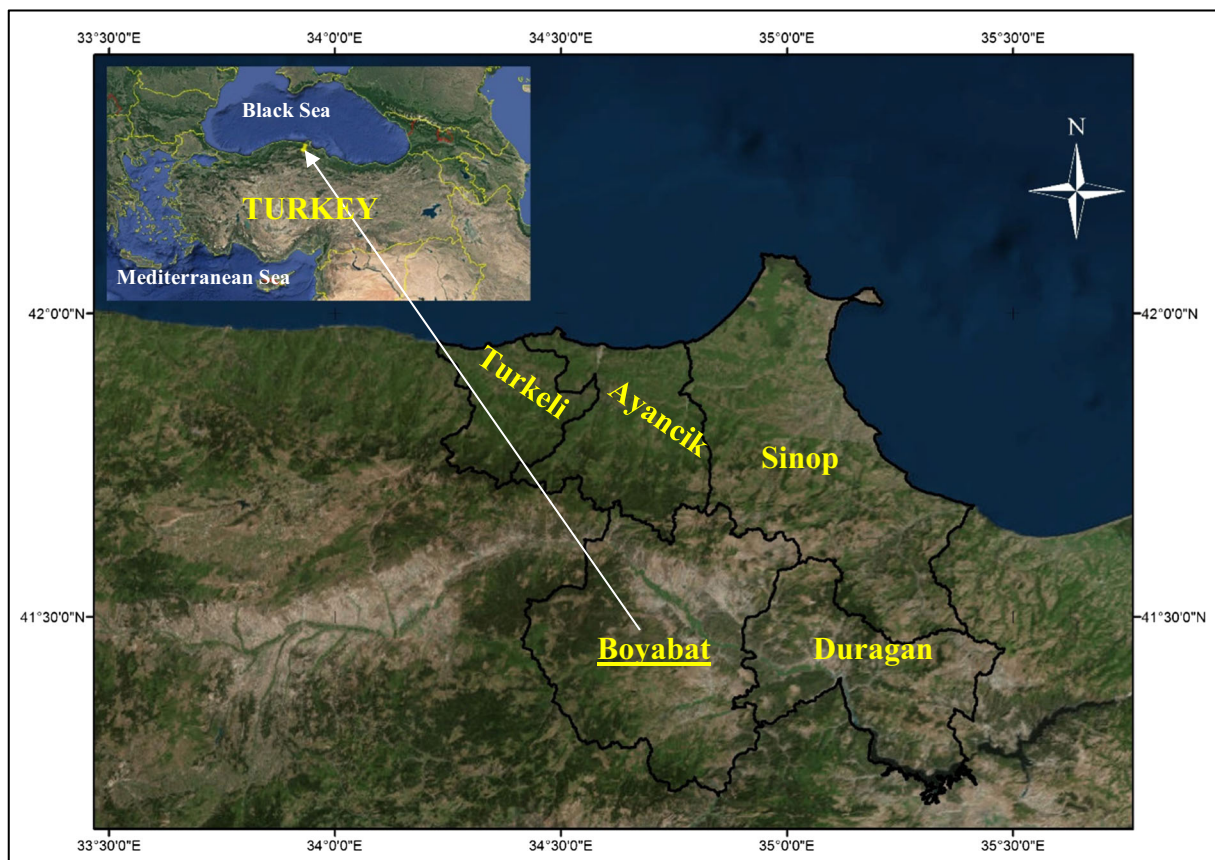
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deployment of resources, and extinguishment (Rego and Catry 2006). Several techniques are used to detect forest fires (Matthews et al. 2010; Yavuz and Saglam 2012; Schroeder et al. 2014; Yuan et al. 2015; Cruz et al. 2016). Unlike traditional fire lookout towers, which are only useful for detecting fires, remote sensors and aerial detectors provide useful information on weather, topography, and fuel conditions in firefighting strategies (Bilgili and Kucuk 2002; Kucuk and Bilgili 2006). At this point, the positioning of the imaging sensors and the areas they survey are rather important factors, because as the area observed by any one sensor gets larger, so many different elements are integrated to the scene; the ability of the sensors not discerning the real threat from the false alarm gets higher as well (Fernandez-B et al. 2012). Although the Turkish Forest Service has still not fully embraced the idea, Lidar technology has also provided some cutting edge insights to the problem of early detection (Utkin et al. 2003; Utkin et al. 2004).

Discovery time is certainly a very important component of the overall time spent between fire ignition and

firefighting; however, it is very difficult to evaluate the discovery time as, in reality, no information is generally available before the fire is detected. Since the majority of the forest fires are detected by the human eye, studies have started to take the accuracy and limitations of visual detection into account, because studies have shown that there is a close link between fire detection and the visibility of the smoke column (Rego and Catry 2006). Traditionally, forest fires were detected via human surveillance at strategically situated fire lookout towers in many parts of the world (Buck 1938; Byram and Jemison 1948; Mees 1976; Berni et al. 2008). The fact that a fire is visible to a person with normal vision does not necessarily mean that an observer will definitely detect it. A number of variables that affect detection by human observers are quality of eyesight, searching techniques, attention and concentration, position, conditions, and equipment aids (Davis 1959). Visibility and detection should also include personal factors associated with the observer.

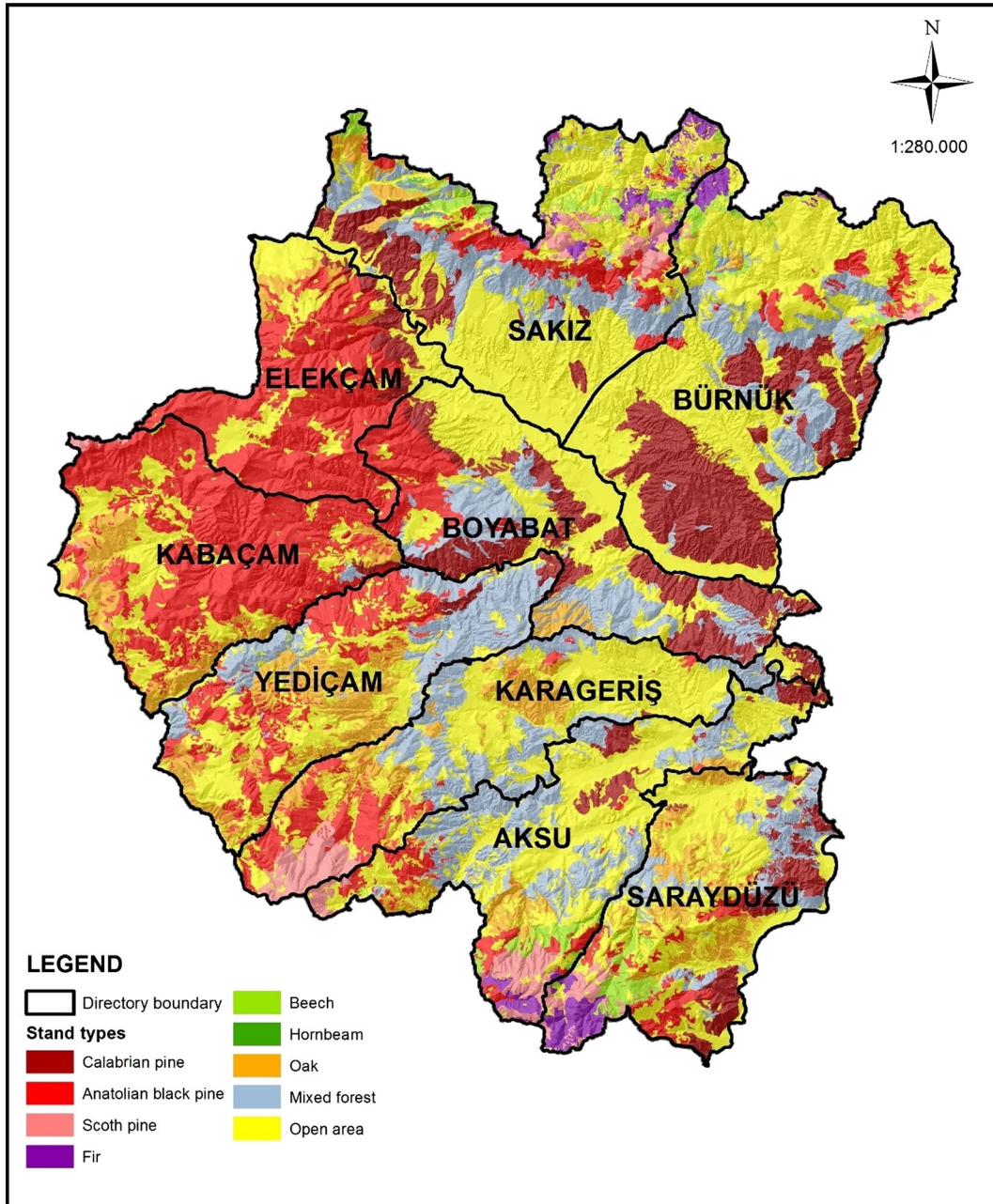


**Fig. 1** Location of the study area on Turkey

**Table 1** The distribution of main stand types in the Boyabat Forest Enterprise

Stand types	Area (ha)
<i>Pinus brutia</i> + <i>Pinus nigra</i> (sensitive to fire)	52,306
Other species	48,473
Total forest area	100,779

It is important to build fire lookout towers in strategic positions in regions where frequent fires are a problem (Maloy and Dean 2001; Fan et al. 2010; Singh et al. 2014). Fire lookout towers have provided early detection of fires, and facilitated the efforts to prevent their spread (Rego and Catry 2006; Garcia et al. 2010; Sivrikaya et al. 2014). Intervention capacity is positively linked to the early detection of the forest fire(s) and the



**Fig. 2** Stand types within the study area

words reaching the stationed field crews. The Fire Department within The Turkish Forest Service primarily observes forest fires with a network of strategically placed forest fire lookout towers; this is the main type of fire detection in many countries. In Turkey, fire lookout towers remain the principal system of organized detection with a network of 776 observation points, generally operating 24 h a day during the fire season by two people from early June to the end of September. Also, smoke detecting sensors and thermal cameras are secured on the fire lookout towers situated along the Mediterranean and Aegean coastline forests uninterruptedly during the fire season (General Directory of Forestry (GDF 2014). Initial results showed that the percentage of correct fire detection through this newly introduced hardware was rather high unless there was a heavy haze or fog obscuring the line of sight for the sensors. They are fully integrated into the fire management system. Whenever the system is triggered by any of the detection means, all fire intervention tools such as personnel, as well as terrestrial and aerial vehicles, are individually evaluated through the system and the most conveniently situated ones are immediately forwarded to the area.

The Fire Fighting Department has installed and manned the fire lookout towers to determine ignition points and alert the control centers to fires in their very early stages; this minimizes the fire damage and costs of extinguishing (Garcia et al. 2010). Fire lookout towers' flexibility to quickly convey correct and up-to-date information to fire control centers makes them an invaluable hardware against forest fires. Maximizing the capacities of fire lookout tower groups decreases the losses resulting from fire damage. One can determine whether or not a group of fire lookout towers is providing enough coverage for a given forest area via spatial analysis in a geographic information system (GIS) (Catry et al. 2007; Singh et al. 2014). Factors such as distance, topography, air transparency, time of day, and the existence of other detection systems all play important roles in determining the efficiency of fire lookout towers, and thus should be considered equally important when planning an integrated system for fire detection. This is especially relevant, for example, whenever decisions are made to determine whether existing towers should be decommissioned, or new towers are to be established (Brown and Davis 1973; Catry et al. 2007).

**Table 2** Fire danger classifications based on slope percentage

Slope class	Classification code	Fire danger
35<	1	Extreme
15–35	2	High
5–15	3	Moderate
0–5	4	Low
Open area	5	Open area

Visibility analyses of Turkish forest fire lookout towers were relatively rare. In a previous study, researchers conducted a visibility analysis of 14 lookout towers serving the Gelibolu peninsula, northwestern Turkey. They used GIS to determine that 73% of this forest land was visible from these towers (Akbulak and Özdemir 2008). In a Kemalpaşa study, researchers determined that 52% of forest area was visible (Askin 2004; Akay et al. 2012). Another study was conducted by Sivrikaya et al. (2014) in south central Turkey.

Although it extends along the Black Sea coast, and has, historically, been regarded as a very wet and humid region, the Black Sea region has recently experienced many large forest fires and extensive fire damage (Kucuk et al. 2008a; Aricak et al. 2014b). The conifer forests of the Boyabat State Forest Enterprise have large areas of Calabrian pine (aka red pine locally) (*Pinus brutia*) and Anatolian pine (*Pinus nigra*); thus, this region has recently been reevaluated as being a high forest fire-risk area.

Prior to the implementation of GIS technology, the Forest Service detected forest fires in the Boyabat State Forest Enterprise with a network of fire lookout towers. The Enterprise has identified a need to scrutinize the effectiveness of the fire lookout towers (in their current locations) because the response times were much longer than what an effective firefighting strategy dictates. Therefore, it was the objective of this particular study to investigate the overall effectiveness of forest fire

**Table 3** Fire danger classifications based on aspect class

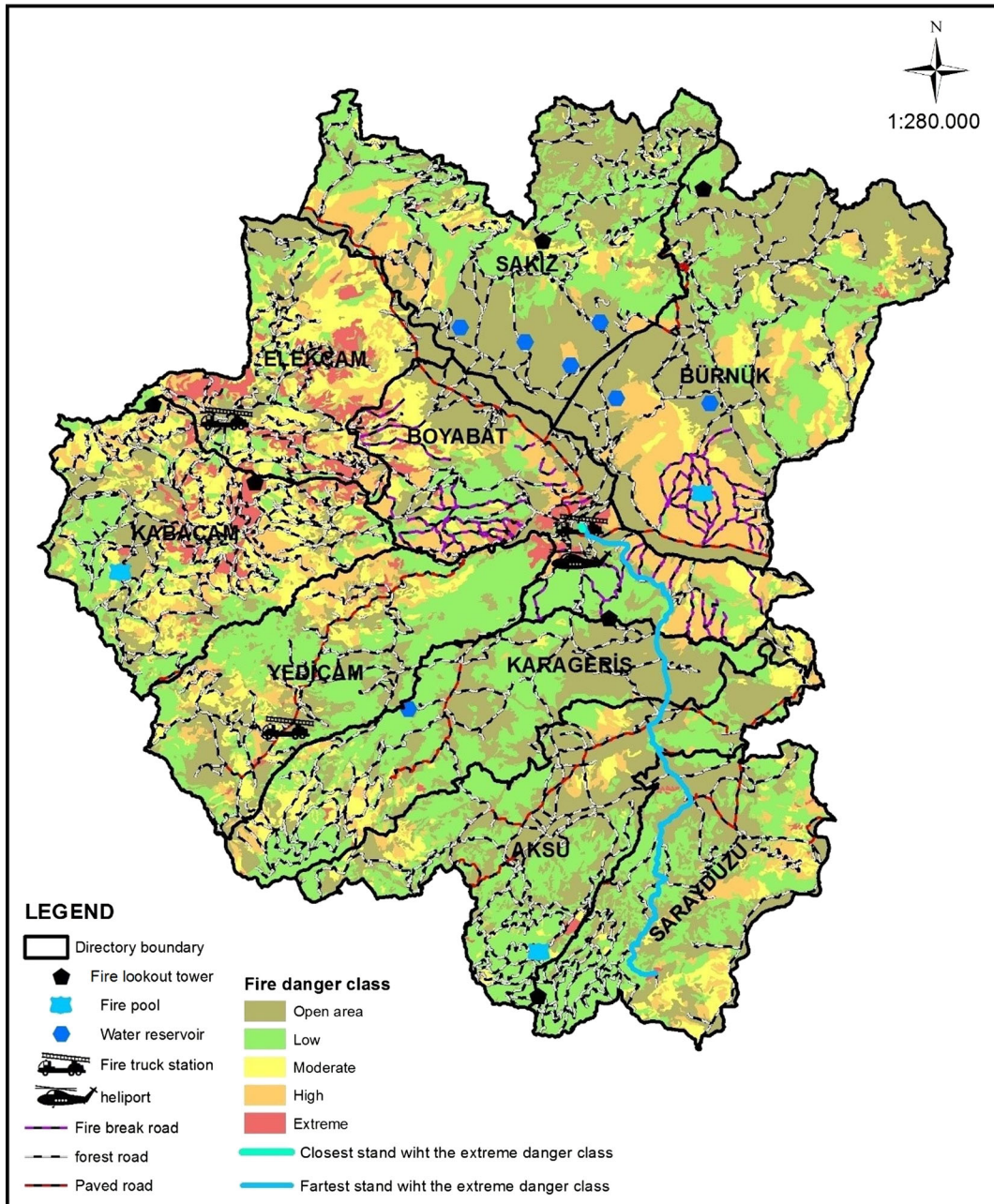
Aspect class	Class code	Danger class
South-southwest	1	Extreme
Southeast	2	High
East, northeast, west, and northwest	3	Moderate
North	4	Low
Open area	5	Open area

lookout towers in Boyabat State Forest Enterprise, employing the visibility analysis and to make suggestions if new fire lookout towers are needed to increase the effectiveness or to decommission the inactive one(s) to better man the firefighting scenarios. It was the first research to conduct a visibility analysis in the Western Black Sea region, focusing this area’s forest fire problem.

**Materials and methods**

**Description of the study area**

This study was conducted in the Boyabat State Forest Enterprise, located at 41° 12’ 12”–41° 41’ 22” north latitude and 34° 13’ 30”–35° 01’ 48” east longitude (Fig. 1). Average elevation of the region is 350 m asl;



**Fig. 3** Fire organization map, relevant to all resources

average slope is 62%. This area has Mediterranean-like climatic conditions. It has rather high temperatures in the summer and fairly low ones in the winter. According to meteorological data collected from 1950 to 2010, its lowest and highest temperatures were  $-16$  and  $45$  °C, respectively; its overall average temperature was  $13$  °C. Relative humidity was 59%; its annual total precipitation average was  $515$  kg m<sup>-2</sup>. In the Boyabat State Forest Enterprise, average wind speed was  $0.9$  m min<sup>-1</sup>. July, August, and September are the hottest months of the year; January and February are the coldest (General Directory of Meteorology (GDM 2015)).

The Boyabat State Forest Enterprise covers an area of 166,354 ha; 100,779 ha is forested and the rest is open. The dominant tree species are Calabrian pine, Anatolian black pine, Scots pine, fir, beech, oak, and hornbeam. Calabrian pine (*P. brutia*) and Anatolian black pine (*P. nigra*) forests, which are highly critical for forest fires, comprise 53,306 ha (53%) of the forested area (Table 1, Fig. 2). *Pinus brutia* and *P. nigra* species compose the two major conifer forest types of importance to fire managers and are the two most widely distributed conifers in Turkey (Kucuk et al. 2008b).

The Boyabat State Forest Enterprise is placed among second-degree fire-prone regions because of its vegetation composition. The Enterprise has six fire lookout towers, one heliport, one bulldozer, one trailer, three fire truck positioning locations, five fire trucks, three four-wheel drive initial attack trucks, three fire pools, and seven water reservoirs.

### Mapping procedures

In this study, 23 vectorized topographical maps were used, scaled to 1/25,000, with 10-m contour intervals. These maps were produced by the General Directory of Forestry. These maps formed the basis for additional intermediary layers (such as slope, aspect, and view shed analysis maps), which many researchers have used as basic parameters for modeling fire risk (Guettouche et al. 2011). These vectorized maps were used to generate a triangulated irregular network (TIN) for each map; then, it was converted to digital elevation model (DEM) for analysis. While generating the slope map, it was categorized slope classes by considering fire danger classes, which were categorized in five classes (Table 2). Fire danger class was determined based on species composition, stages of stand development, stand crown closure, and topographic features such as aspect

and slope. The following steps were taken in the process. First, each variable class was assigned a fire danger rating (extreme, high, moderate, low, and open area) according to the danger of each class. Second, each fire danger class was rated on a scale from 1 to 5. Third, all variables were then integrated through GIS (Saglam et al. 2008).

A 1/25000-scaled national quad map, generating a DEM, was used to create aspect classes corresponding to a particular stand type in the study area, so a danger classification depending upon aspect classes was established (Table 3).

A fire organization map was formulated (Topaloglu 2013) from the coordinates of the fire lookout towers, fire pools, water reservoir, heliport, and fire truck positioning locations in the Enterprise. In fire lookout tower visibility analysis, these maps were used as a base layer to identify forest fire danger classes (Fig. 3).

### Visibility analysis of fire lookout towers and mapping

The Boyabat Forest Enterprise has six fire lookout towers. The coordinates of these towers are recorded in a database. In ArcGIS (with a 3D analysis module), visibility analysis was conducted to determine observable places from each lookout tower. Prior to the analysis, vectorized maps, TINs, and DEMs of the study area were prepared as base layers. After completing the visibility analysis, the stand map, classified according to fire danger and visibility layer, was intersected; thus, visible, invisible, and beyond-range available fuels and area-wise acreages were determined. A point layer called “radar” was added to the database to facilitate the visibility analyses. Data in this particular layer rep-

**Table 4** The parameters and descriptions of the “radar” layer

Parameters	Description
Coordinate	x and y coordinates of the lookout towers
Spot	Elevation above sea level
Offset A	Height of the observation platform
Offset B	Height of smoke to be observed
Azimuth 1	The start of the horizontal scanning angle
Azimuth 2	The end of the horizontal scanning angle
Vert 1	The start of the vertical scanning angle
Vert 2	The end of the vertical scanning angle
Radius 1	Scanned area inner radius (blind area)
Radius 2	Scanned area outer radius (area to be scanned)

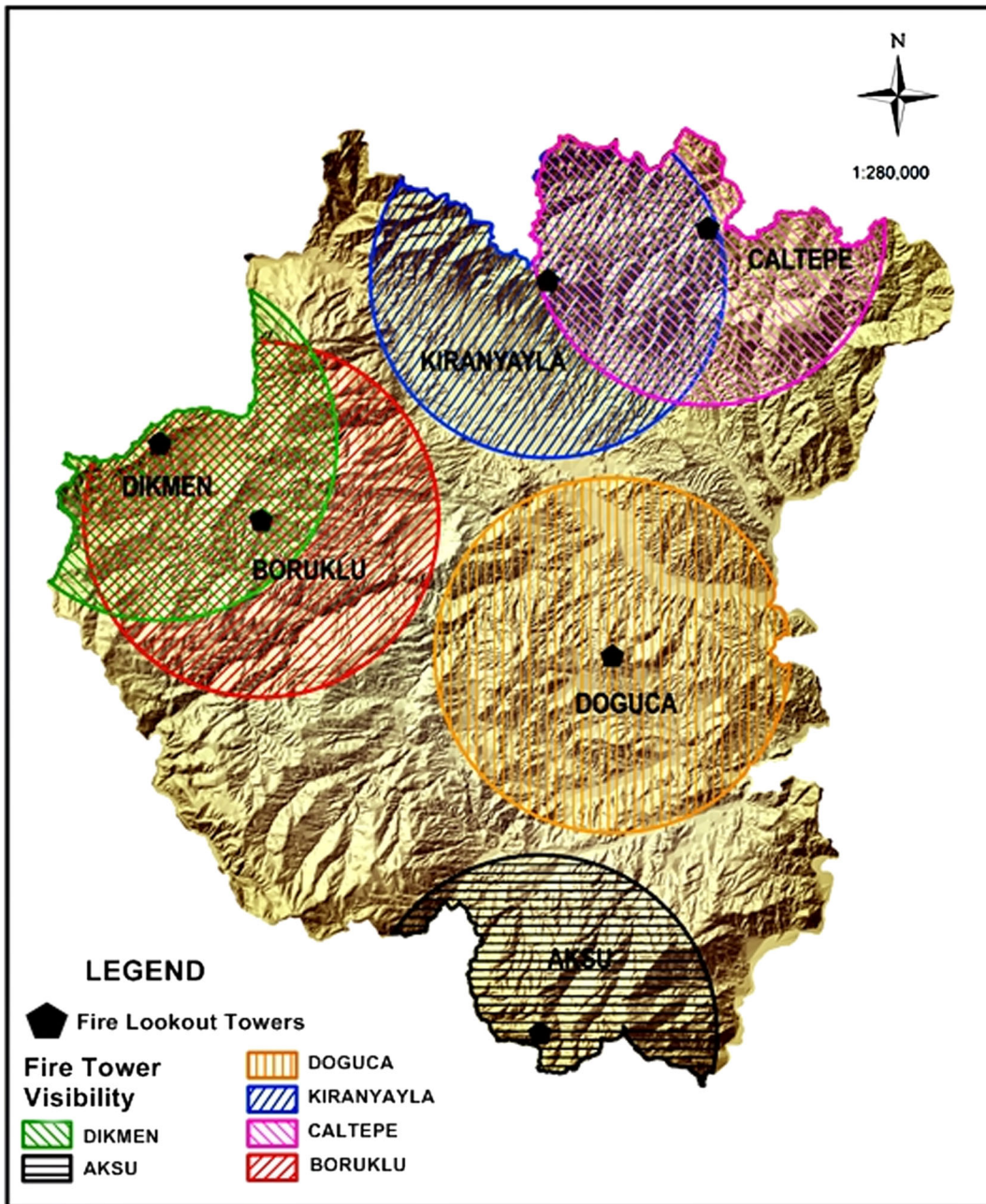


Fig. 4 A visibility map of current fire lookout towers

resented the locations of fire lookout towers. The parameters and their descriptions are given in Table 4.

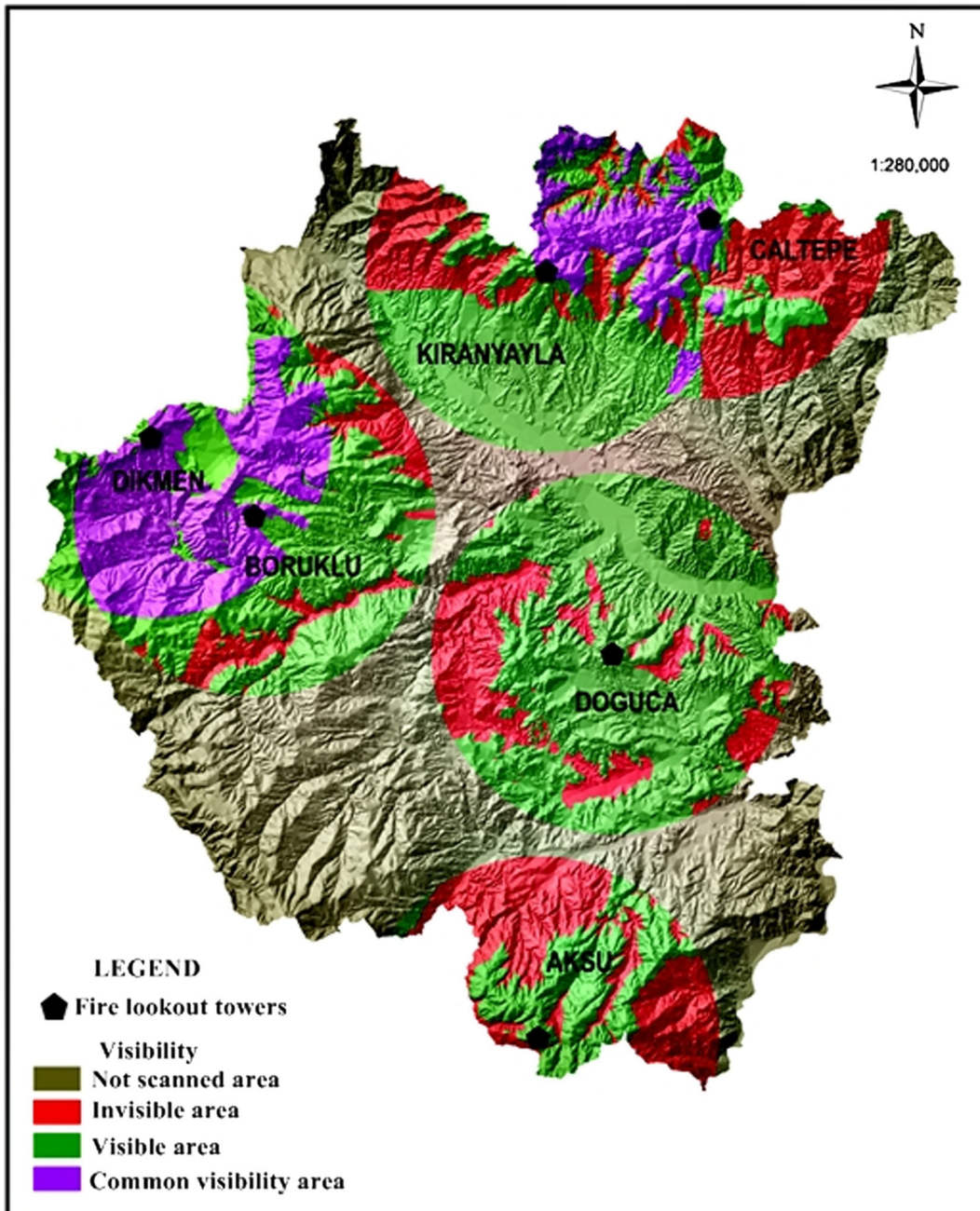
While determining the potential locations for the new fire lookout towers, criteria such as maximum viewable area from such a vantage point and easy accessibility to the location were taken into account. The radial sighting distances between the stationary point and the objects to be detected and any other relevant variables were

Table 5 The observable area acreage of the Enterprise’s six current lookout towers (ha)

Visibility analysis of six fire towers (ha)			
Scanned area	109,702	Visible area	79,676
Not scanned area	56,652	Invisible area	30,026
Total	166,354	Total	109,702

qualitatively or quantitatively sampled. Radar layer was also added as a parameter. A 6-m height was accepted for each observation platform (offset A). A 100-m height was chosen for each platform (offset B); observers could see the not only flames coming from the ground but also the rising smoke (GDF 1995). The horizontal scanning angle (Azimuth 1, 2) ranged from

$0^{\circ}$  to  $359^{\circ}$ . The vertical scanning angles of  $90^{\circ}$  in “Vert 1” and  $-90^{\circ}$  in “Vert 2” (according to the horizon) were entered. A scanned area internal radius for the lookout towers (which are presumed to do circular scanning) was assumed to be 3 m for blind areas and 10,000 m for areas to be scanned. These figures were entered into the database because they were the accepted distances to



**Fig. 5** A visibility analysis map of the current six fire lookout towers



realize smoke and its origins for observations done without visual aids and with binoculars under optimal visibility conditions (GDF 1995). An effective detection radius was reported to be around 13.4 km (Rego and Catry 2006). The detection distance was accomplished on the “radar” layer with the 3D Analyst > Surface Analysis > Viewshed function. With the help of the

DEM, the visibility of the areas as observed from the lookout fire towers was determined.

After completing visibility analysis, the scanning area for each lookout tower was drawn. Then, using the “Buffer” function in ArcGIS, a 10,000-m buffer zone was established over each fire lookout tower layer. This zone was a layer that displayed the areas that could

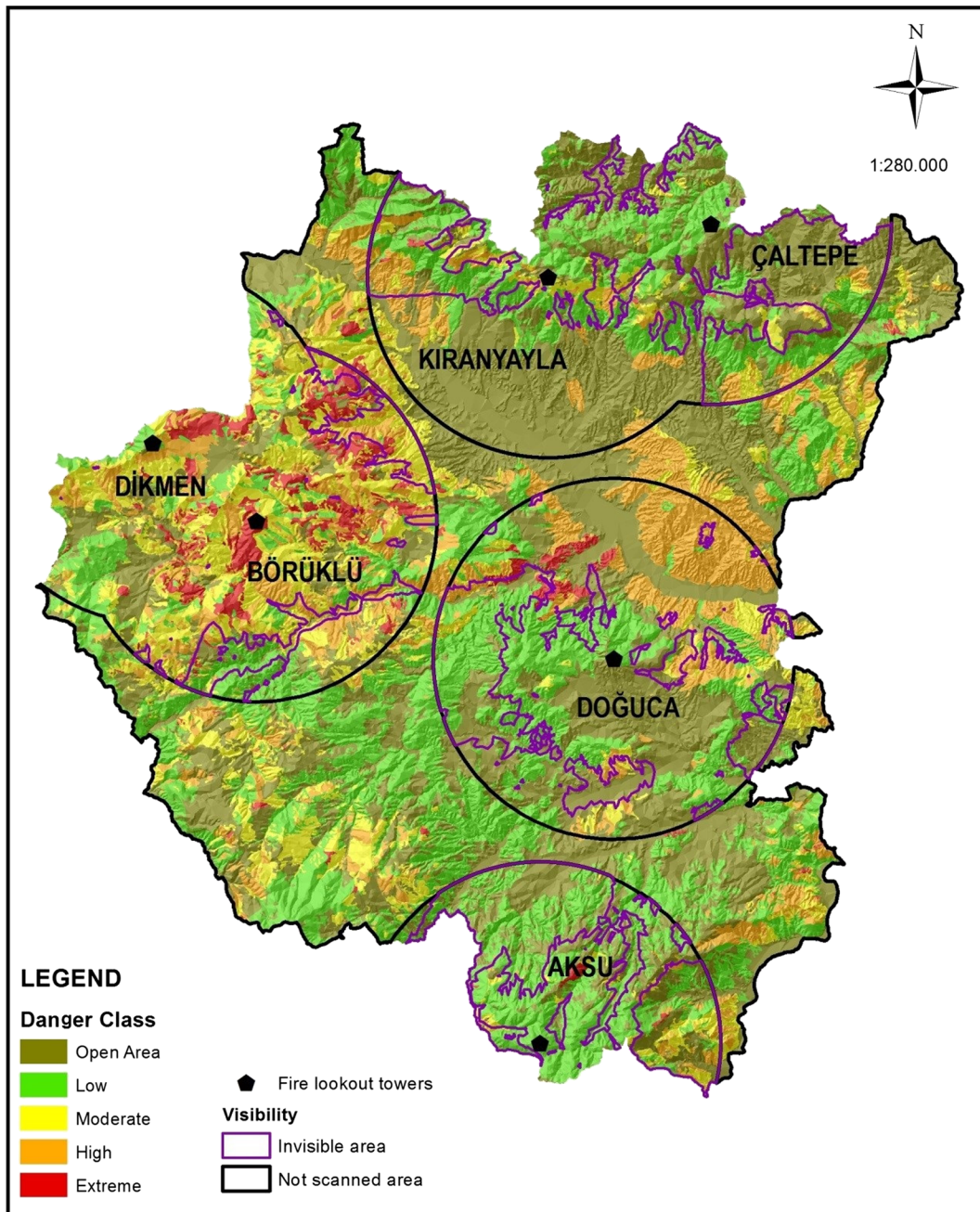


Fig. 6 A visibility analysis of the fire danger map

be scanned (or not) within each lookout tower's operational area. In the visibility analysis map, the abovementioned data and procedures identified the "visible," "invisible," "not scanable," and "commonly scanned areas." These were then added to the database as a separate layer. Thus, it could interact with each layer of the database and be used for further inspection.

It was determined what portion of the stand types categorized as "fire danger" was observable (or not) through fire lookout towers. With this information, it was possible to evaluate the maximum effective visible areas observable by more than one tower and question each tower's current location with regard to fire danger, functionality, and tower integrity.

For those areas that could not be scanned or observed from any of the current fire lookout towers, we recommended new fire lookout tower locations based on scan radius, need for observation, distance to the nearest operational tower, and the density and accumulation of combustible materials. To determine the best spots for additional fire lookout towers, we analyzed the data of surrounding vantage points and took combustible material into account. At the same time, a guaranteed 70% visibility test was performed (GDF 1995) for each tower (both operational and newly proposed).

After completing a visibility analysis of two newly proposed fire lookout towers in Zeytinlik Tepesi and Kiziltepe, we generated a new "visible area" layer. A new visibility analysis was performed that included two proposed fire lookout towers and eliminated three older ones and compared this to previous visibility analyses. In a visibility analysis, which took the entire study area into account (to see what difference the proposed new fire lookout towers provided for the area), the changes were evaluated within the new fire lookout towers' observable scanning areas. This comparison displayed

the difference in terms of the visibility of combustible materials to materialize the aerial changes, as well as acreage gain or loss, observable through the maps. This procedure was repeated for each remaining and proposed fire lookout tower within the full extent of the study area and compared these results to previous analyses. The suitability of the newly proposed fire lookout towers was also questioned.

## Result and discussion

A horizontal 10-km scanning radius was used in the visibility analysis of the fire lookout towers in this study; it is the widely accepted distance for detecting the smoke under optimal weather conditions (GDF 1995). Such a distance varies, depending upon the weather conditions during the fire season, air quality, and the performance of the observer(s). There are some relevant studies in which various distances were done. In Portugal, 10- to 20-km distances were used in two different studies. In the south and southeast USA, where visibility was poorer, 10- to 13-km radiuses were the most commonly preferred distances (Davis 1959; Brown and Davis 1973). Variable distances up to 18 km were tried in Canada (Artsybashev 1984). In Spain, the visibility distance of a fire lookout observer with normal vision was established as 6–8 km for the worst conditions and as 30–40 km for the optimal ones. As a common practice, values ranging from 10 and 20 km were used for rough terrain and flat areas, respectively.

### Visibility analysis of present fire lookout towers

Figure 4 shows the locations of six operational fire lookout towers inside the administrative boundaries of

**Table 6** An area-wide (ha) representation of the visibility analyses of six fire towers, depending on fire danger categories

Visible area		Invisible area		Area, not to be scanned	
Danger class	Area	Danger class	Area	Danger class	Area
Extreme	4555	Extreme	420	Extreme	415
High	11,633	High	2938	High	7257
Moderate	10,658	Moderate	2946	Moderate	7493
Low	21,060	Low	11,929	Low	19,475
Open area	31,770	Open area	11,793	Open area	22,012
Total	79,676	Total	30,026	Total	56,652

many forest directorates within the Boyabat Forest Enterprise. The scan areas given in the figures for each fire lookout tower prove that the observations done on the towers are not solely limited to the administrative boundaries of the enterprises in which they are located. These figures show that overlapping areas are observable by more than one tower. This is a topographical

effect; this figure only shows projections of towers on a flat surface. This display is the manifestation of hastily made decisions; little detailed analysis was done before selecting these locations. Table 5 shows the acreage and percentage of “visible” and “invisible” areas.

Boyabat Forest Enterprise had 166,354 ha forest area, 109,702 ha (66%) of which can be scanned;

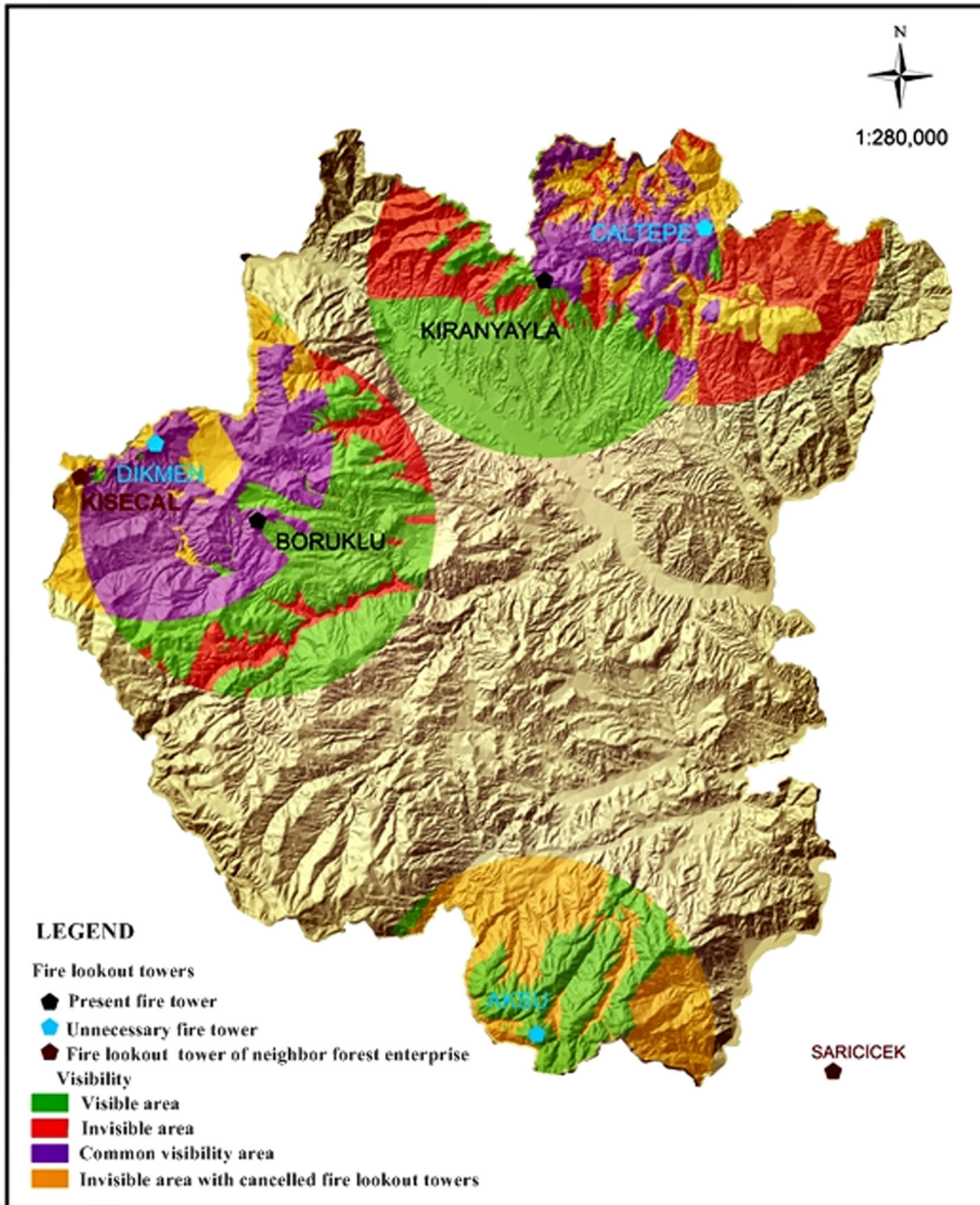
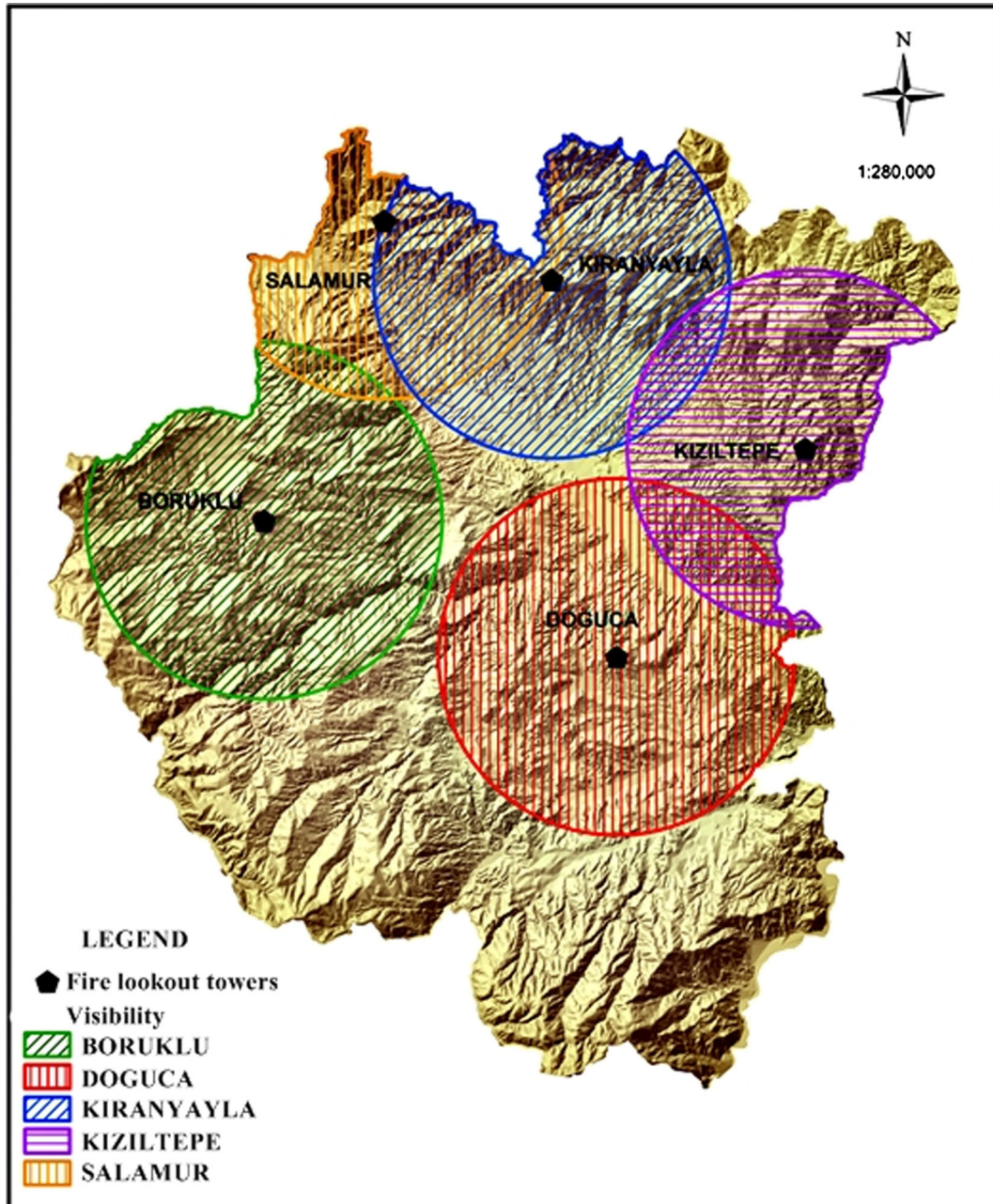


Fig. 7 The visibility statuses of the potentially eliminated fire lookout towers

79,676 ha (73%) of the scanned area can be observed from the fire lookout towers (Fig. 5).

Topaloglu's (2013) fire danger map was intersected with a visibility map to evaluate the suitability of current fire lookout towers (Fig. 6). By comparing the visibilities of fire-sensitive areas (Table 6) and the towers' present locations, we found better tower locations.

A total of 5390 ha forest area was located inside extreme fire danger class (Table 6). According to the results of visibility analyses, the present towers can see only 4555 ha (85%) of these stands in the extreme fire danger class and 21,829 ha (53%) of stands in the high fire danger class. In the unscanned area (beyond the visibility of all towers), 415 ha (8%) of stands were in



**Fig. 8** The areas to be surveyed by the remaining and newly proposed fire lookout towers

the extreme fire danger class; 7275 ha (33%) were in the high fire danger class.

Visibility analysis for present and recommended fire lookout towers

An area-wise comparison of the visibility analysis of the present fire lookout towers and the fire danger map was

made. Twenty-seven percent of the forest was in the extreme and high fire danger classes, 21% was in the moderate class, and 52% was in the low fire danger class. The areas that cannot be scanned or seen were also evaluated; 27,218 ha was in the extreme and high fire danger classes; 41% of this acreage (11,030 ha) was inside stands that could not be scanned or seen.

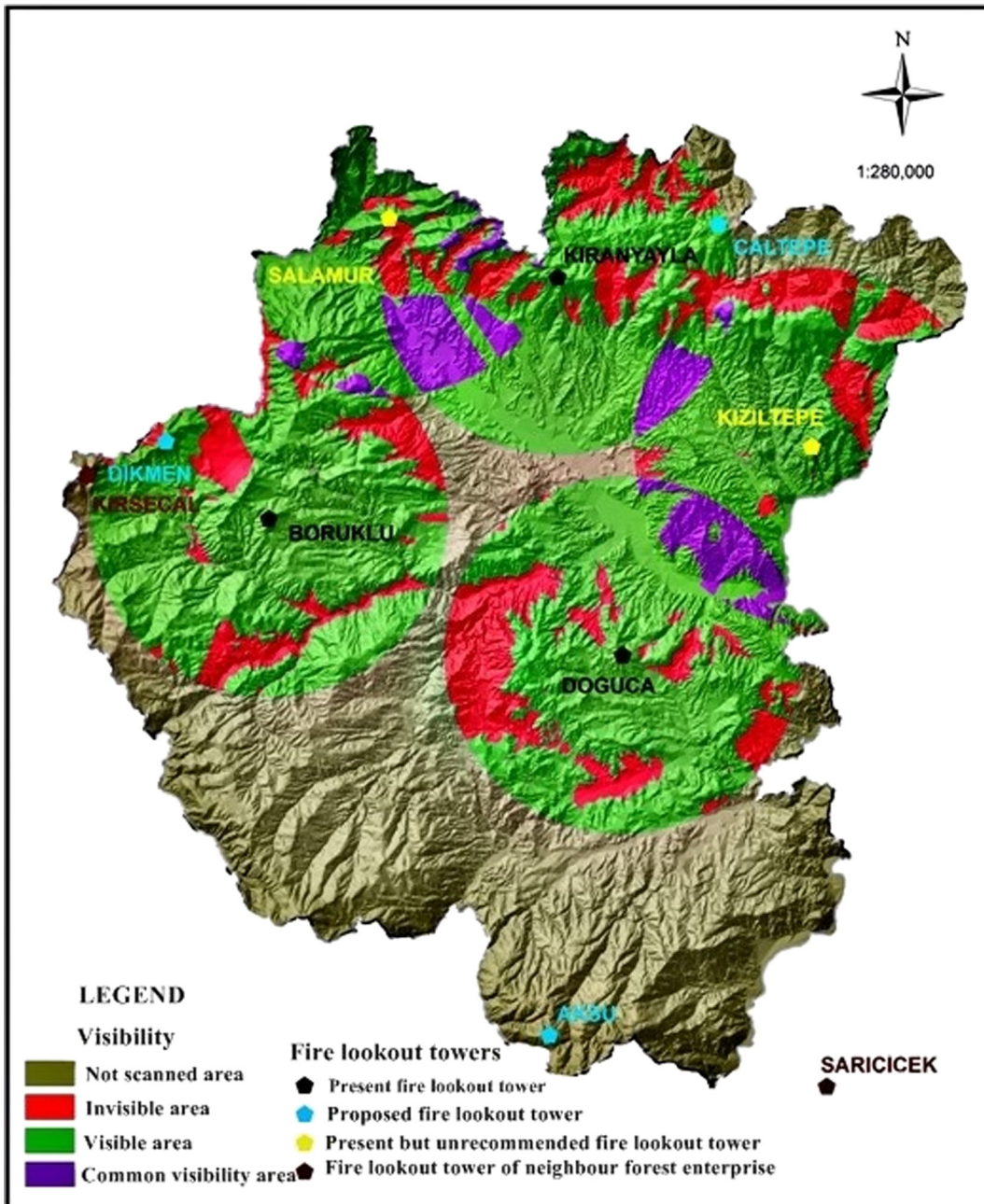


Fig. 9 The results of visibility analyses for the remaining and newly proposed fire lookout towers

**Table 7** A visibility analysis of current and newly proposed towers (ha)

Scanned area	106,560	Visible area	85,878
Not scanned area	59,794	Invisible area	20,682
Total	166,354	Total	159,829

When the recorded fire data for this particular area was investigated, the number of fires was 62 (54 surface fires, 8 crown fires), and the total burned area was 136 ha from 2006 to 2016 in the Boyabat State Forest Enterprise. On average, six fires occurred annually, and the annual burned area was 12.3 ha. The average burned area for each fire was 14 ha in Turkey. In terms of the relationship between the number of fires and the burned area for the duration of the above period, the areas affected were rather low in acreage. It could be explained that the strong fire organization for the area was well established and formulated. The largest burned area was 48 ha in the extreme fire danger class.

When the types of stands in the study area were evaluated separately, it was found that the acreage of stands that could be seen from more than one tower was 17,282 ha. The Dikmen and Boruklu fire lookout towers scanned a combined area of 30,376 ha; 11,694 ha was visible from both towers. Since a large portion of the Dikmen fire lookout tower's scan area is also scanned by a tower in the neighboring Taskopru State Forest Enterprise (the Kisecal fire lookout tower), manning and operating this tower was deemed unnecessary to both enterprises. Several authors reported similar visibility analysis results (Sivrikaya et al. 2014).

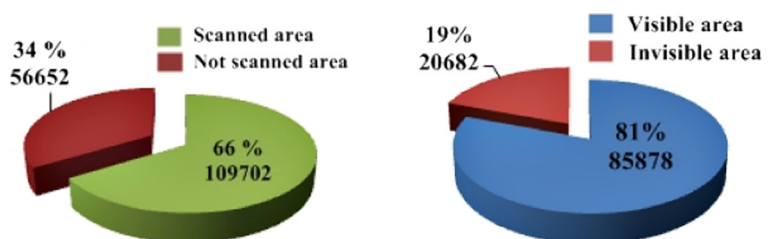
The Kiranyayla and Caltepe fire lookout towers scanned a combined area of 34,415 ha; 5588 ha of this was visible from both towers. The fire danger of the stands scanned by Caltepe was rather low; this scanning area includes many predominantly open areas. It was recommended that this fire lookout tower be taken out of the network. On the other hand, in the visibility

analysis of the Aksu fire lookout tower, it was found that it did not meet its performance criteria (70% of the scanned area must be visible) (GDF 1995). It can scan 8946 ha of the area but only see 52% (4678 ha) of it. The area that is supposed to be scanned and seen by the Aksu fire lookout tower is heavily dominated by fire-susceptible *P. brutia* which can be seen from the Saricicek fire lookout tower in the neighboring Vezirkopru State Forest Enterprise. The Aksu fire lookout tower was found to be unfit for its task.

When the current visibility analysis map and a fire danger map were intersected, it was seen that Dikmen, Caltepe, and Aksu fire lookout towers were not needed anymore. The areas negatively affected by this new scenario were 3435, 4546, and 13,707 ha, respectively (Fig. 7).

New fire lookout towers, Salamur and Kiziltepe, have been proposed to fill the gap (areas left unscanned and unseen) that would result from the elimination of the three currently unsatisfactory towers. A new visibility analysis as well as these two new lookout tower locations are provided in Fig. 8.

*Salamur fire lookout tower* By simultaneously taking into account the visibility analysis of the present towers and the fire danger map (Fig. 9), some unseen areas were determined that harbored serious fire danger in the northwest area of the Enterprise. The unscanned parts of this area are rather small. The unseen areas, on the other hand, are visible from the Kiranyayla fire lookout tower; however, they are blocked by topographical obstacles. With a contour map, the visibility of each possible location within this region was checked and was identified to be highly promising locations. Depending on the results we obtained from this analysis, it was determined that Salamur Tepesi (with an elevation of 1110 m) is the strongest candidate for a new lookout tower. This study which positions fire lookout towers in strategic locations is imperative for effective fire monitoring (Fan et al. 2010; Singh et al. 2014).

**Fig. 10** The visibility statuses of the remaining and newly proposed towers in the study area (ha)

**Table 8** A comparison of remaining and updated fire tower network visibility analyses (ha)

Visibility	Present tower	With recommend tower	Change
Scanned area	109,702	106,560	-3142
Area not to be scanned	56,652	59,794	+3142
Total	166,354	166,354	
Scanned area	79,676	85,878	+6202
Area not to be scanned	30,026	20,682	-9344
Total	109,702	106,560	

*Kiziltepe fire lookout tower* The procedure was repeated to help determine the location of the first tower and discovered unseen areas with high fire danger in the eastern section of the Enterprise. This region, which included young and highly fire-prone stands, is not visible from the Caltepe lookout tower; it could not be scanned from any other towers. A location search for this region was performed, and Kiziltepe (with an elevation of 765 m) was determined as the best spot. We evaluated the remaining and newly proposed towers in the fire organization together and performed a new overall visibility analysis for the entire Enterprise (Fig. 9). Table 7 shows visibility analysis and the remaining and newly proposed towers.

In this study, following the comparison between the relocation of the remaining fire lookout towers and the newly proposed ones, the areas scanned were 64 and 81% of the entire study area, respectively (Fig. 10). The results of the final evaluation to previous results were compared to one another (Table 8). The overall scanned area decreased by 2% (3142 ha). The visible area was 73% of the scanned area in the previous analysis; it

increased to 81% (79,676 ha) in the final analysis. The addition of newly proposed fire lookout towers decreased the amount of unscanned areas by 6% (9344 ha).

In the visibility analysis of the new scenario for the overall effectiveness of all functioning fire lookout towers, the addition of the newly proposed towers and the elimination of poorly functioning towers in terms of fire danger were also evaluated. It was noticed that 4426 ha (82%) of the 5390-ha forest stands was in the extreme fire danger class, while 14,727 ha (67%) of the 21,828-ha forest stands was in the high fire danger class (Table 9). The visibility analyses of the present and updated fire lookout towers (depending on fire danger class) are shown in Table 10.

In the comparison of visibility analyses (including the remaining three and newly proposed two fire lookout towers), it was found that area-wise decreases of 129 ha (2.8%) for the extreme fire danger class and 1732 ha (10%) for the low fire danger class were attained. An increase in the amount of 3094 ha (27%) for the high fire danger class and 1689 ha (16%) for the moderate fire danger class was identified.

When the fire organization map was evaluated, and the distance analysis was performed, the distance between the farthest fire truck and the extreme fire danger area was 14 km, the average arrival time in this case was 16 min, and the closest fire truck’s distance to engage with the fire was 0.2 km. The average time for a fire truck to reach the nearest water reservoir was 4 min. Besides, fire brake roads were constructed within the high and the extreme fire danger areas (Fig. 3). As a result, the fire organization formulated for this area was capable to intervene any fires within the boundaries of the enterprise in the fastest time possible.

**Table 9** An area-wide (ha) representation of the visibility analyses of present and updated fire tower networks, depending on their fire danger categories

Visible area		Invisible area		Area, not to be scanned	
Danger class	Area	Danger class	Area	Danger class	Area
Extreme	4426	Extreme	631	Extreme	333
High	14,727	High	2688	High	4414
Moderate	12,347	Moderate	2810	Moderate	5939
Low	20,876	Low	6896	Low	24,693
Open area	33,502	Open area	7656	Open area	24,415
Total	85,878	Total	20,681	Total	59,794

**Table 10** A comparison of the visibility analyses of present and updated fire tower networks, depending on their fire danger categories (ha)

Fire danger class	Present towers	With proposed towers	Difference
Extreme	4555	4426	-129
High	11,633	14,727	+3094
Moderate	10,658	12,347	+1689
Low	21,060	20,876	-184
Open area	31,770	33,502	+1732

Fire risk mapping and partial fire lookout tower visibility analysis were the subjects of Sivrikaya et al. (2014). Solely fire lookout tower visibility analysis was carried out by Askin (2004), Akbulak and Özdemir (2008), and Akay et al. (2012), and all these studies were done in the Mediterranean and Aegean regions of Turkey. Our study, on the other hand, dealt with both fire risk mapping and fire lookout tower visibility. For effective visibility, we also performed spatial analysis so tower locations were precisely determined. Finally, this was the first such study in the Western Black Sea region of Turkey.

## Conclusion

The information and feedback obtained from the fire lookout towers, related to early detection, conveying information to fire control centers and initial attack, controlling the fire, and minimizing the adverse effects of the fires, play a crucial role in combating forest fires. This assertion was substantiated in this study with the aforementioned sequence of analyses. The percentage of previous visible areas under the actual fire lookout towers setting was 73%, and this was raised to 81% with the addition of newly proposed fire lookout towers. A sound model was created in this study to elaborate the effectiveness of such undertaking. Although no noticeable gain was attained as a result of the procedure outlined in this paper, the visibility analysis employed proved that it had great potential while selecting new fire lookout tower locations for any potential site or forest land with high fire risk.

In Turkey and in many other parts of the world, a significant portion of the forest fire detection has still been handled by observers stationed on fixed lookout

positions in spite of the alternatives and the increasing maintenance cost. Therefore, it is important to fully understand the capacities of the system in order to fully use, complement, or replace it with other systems.

The results affirmed the long accepted fact that GIS is a useful and fundamental tool for evaluating fire lookout towers, understanding their capabilities, and determining new locations for fire lookout towers. In this study, it was revealed that some towers in the current setting were unnecessary; however, some additional ones still need to be constructed. It will be possible to assess “visible,” “invisible,” “scanned,” and “unscanned” areas based upon fire danger classes. The data produced in this study will help forest managers in their combats against forest fires. Similar studies must be conducted in all fire-prone regions of Turkey.

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