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Visibility Analysis of Fire Watchtowers Using GIS: A Case Study in Dalaman State Forest Enterprise*

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Abstract

The determination of the forest fires locations as quickly as possible and accurately is very important for fighting forest fires. Therefore, fire watchtowers should be located on high peaks where watchtower staffs are able to watch most of the forested areas. In this study, Dalaman State Forest Enterprise was selected as first-degree fire-prone region, and visibility analysis has been performed to evaluate fire watchtowers network. Using Visibility Analysis technique of Geographic Information Systems (GIS), the location of each watchtower was evaluated separately and visible forested areas monitored by fire watchtowers were identified. Visibility analysis was conducted for 9 fire watchtowers which supervise the study area. In the study, forested areas observed by each individual watchtower and more than one watchtower, and also invisible forested areas were determined. The results showed that 47.2 % of forested area could be observed by fire watchtowers. In order to increase visibility percentage to more effective levels, new fire watchtowers should be established or inactive fire watchtowers could be moved to more suitable locations.

Keywords: Fire watchtower, Visibility analysis, Aegean region, GIS

1. Introduction

Forest fires are environmental events which have economic, social and ecological results. The forest fires occurred in Turkey every year cause loss of life and property and a high extinguishing cost. According to the recent fire statistics (from 1988 to 2016), the annual average number of forest fire is 2114 and that of burned forested area is 10615 ha. In Turkey, about 35% of total forested areas are sensitive to forest fires at first-degree, 23% at second-degree, and 22% at third-degree (Bilgili and Küçük, 2001). Also, when the burned forested areas are considered, the Antalya Regional Forest Directorate has the highest rate (25%). Thereafter, İzmir (10%) and Muğla (9%) have higher rates, respectively in terms of the burned areas (GDF, 2015).

The early detection of forest fires and exactly determination of the fire location are crucial to minimize the impacts of forest fires (Fern et al., 2008). In order to fight quickly and effectively against to forest fires, it must be intervened to fire as quickly as possible. Despite the use of modern techniques such as aerial vehicles and remote sensing data to detect forest fire (Yuan et al., 2015; Millan-Garcia et al., 2012; Şahin and İnce, 2009), the most commonly used method is fire detection by human surveillance from fire watchtowers. Fire watchtowers are built to monitor forest fires and used for communication during forest fires. Fire watchtowers should be built on high peaks leading to monitor large parts of forested areas.

Many different models are proposed for visibility analysis of watchtower. Küçük et al. (2017) utilized a visibility analysis in a network of fire watchtowers operating in the Boyabat State Forest Enterprise in Turkey. They reported that inactive watchtower should be removed from the network and replaced with new ones. So, the percentage of visible areas in current fire watchtower network will be increased from 73% to 81%. Pompa-García et al. (2010) improved visibility analysis by integrating a digital elevation model and a vegetation cover map. They suggested that one of the current fire watchtowers' place should be changed and built a new watchtower, which would increase the all visibility effectiveness from 43% to 81%.

Korale et al. (2009) determined the fire risk zones leading to move watchtower to a suggested suitable sites or take watchtower away using GIS and Remote Sensing. Akay et al. (2011) and Akbulak and Özdemir (2008) mapped visible and invisible areas by visibility analysis using GIS techniques.

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The purpose of this study is to determine the effectiveness of the fire watchtowers using visibility analysis. It is anticipated that building a new fire watchtower on required spots and removing or relocating existing fire watchtowers with low visibility will improve the effectiveness of the fire watchtowers in Dalaman State Forest Enterprise.

2. Material and Methods

2.1. Study Area

This study was conducted in the Dalaman State Forest Enterprise, located at 36° 35' 02"- 37° 03' 32" north latitude and 28° 35' 56" - 29° 11' 07" east longitude (Figure 1). According to the forest management plans, Dalaman State Forest Enterprise covers an area of 88052.0 ha in which 57770.8 ha is forested. The dominant tree species of the study area are *Pinus brutia, Pinus nigra* and *Cedrus libani*. The fire sensitive tree species in the region increase the risks of forest fires. In fact, Dalaman State Forest Enterprise is placed among first degree fire-sensitive regions because of its fire sensitive vegetation and dry climate. To reduce hazard of forest fires, 3 fire watchtowers which managed by enterprise, are used for early detection of fires. Besides, Dalaman State Forest Enterprise is surrounded by another 6 fire watchtowers, therefore; total of 9 watchtowers were considered during visibility analysis. The information about fire watchtowers are given in Table 1.

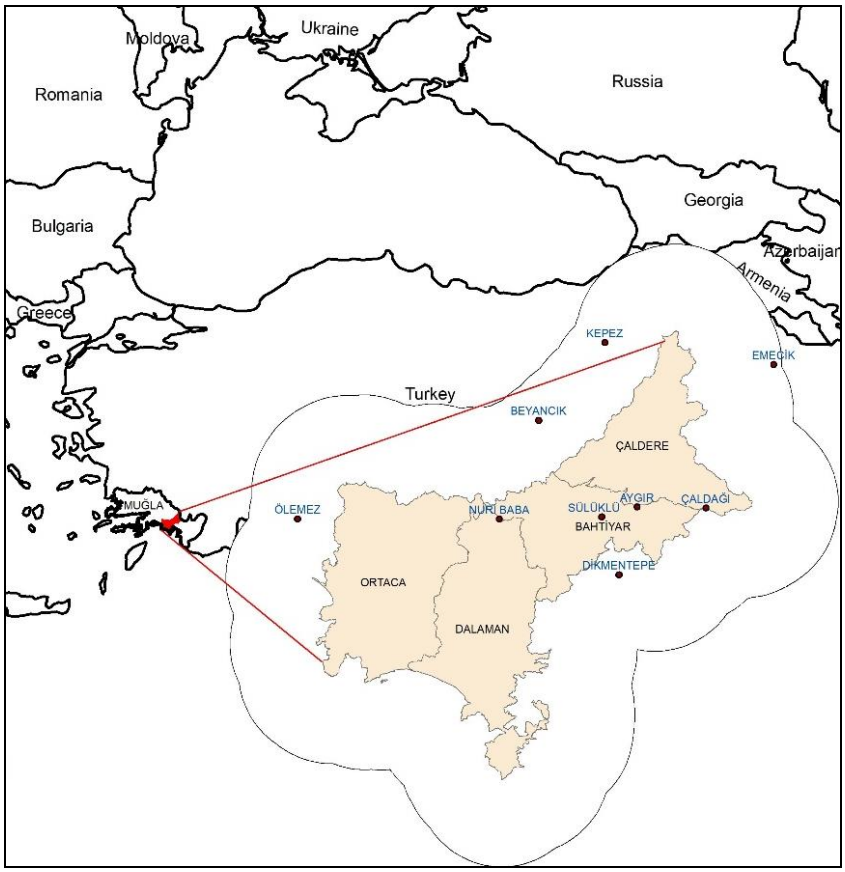

Figure 1. Location of study area

Table 1. Details of fire watchtowers

ID	Fire Watchtower	Forest District	UTM Coordinates		Status	Elevation(m)
			X	Y		
1	Emecik	Çameli	696855	4098826	Active	1496
2	Nuribaba	Dalaman	664910	4081042	Active	883
3	Aygır	Bahtiyar	680968	4082431	Active	1440
4	Dikmentepe	Göcek	678830	4074629	Active	1104
5	Çaldağı	Üzümlü	688973	4082293	Active	2177
6	Beyancık	Akköprü	669497	4092420	Active	1130
7	Kepez	Karaçam	677199	4101351	Active	1446
8	Sülüklü	Bahtiyar	676838	4081275	Inactive	1038
9	Ölemez	Sultaniye	641423	4081063	Active	953

2.2. Data Preparation

The first digital data which is necessary for visibility analysis is digital elevation model (DEM). In forested areas, it is very important to have DEM data with high accuracy, which reduces time and costs in forestry activities. In this study a high resolution (12.5 meters) DEM data from ALOS/PALSAR DEM Data source was used (URL 1). The ALOS satellite system uses radar images to produce medium and high resolution (30 and 12.5 meters) DEMs (ASF, 2015).

The high resolution DEM data has good success limitations for scientific use and access to this data is free of charge (Bignone and Umakawa, 2008; Trisakti and Julzarika, 2011). Forest stand type maps obtained from Dalaman State Forest Enterprise were digitized and added to the database in raster format. Later, using the "Reclassify" feature in the ArcGIS v10.1 software, the land use types in the study area were grouped as forest (65.61%), farmland (23.18%), settlement (5%), water (3.40%), and other land use (2.81%) under 5 classes (Table 2).

A point layer called “Towers” was added to the database to facilitate the visibility analyses. Data in this particular layer represents the locations of fire watchtowers and parameters for visibility analysis (Table 3).

Table 2. Information about land use class

Land use	Area	
	(ha)	(%)
Forest	57770.8	65.6
Farmland	20406.6	23.2
Settlement	4402.2	5.0
Water	2996.3	3.4
Other land use	2476.1	2.8
Total	88052.0	100

2.3. Visibility Analysis

In ArcGIS v10.1 (with a 3D analysis module), visibility analysis was conducted to determine observable places from each watchtower. Vector maps (classification map and point data) and DEMs of the study area were prepared as base layers.

In ArcGIS v10.1, visibility analysis was performed using "Observer Points" feature. For this purpose the point layer that contains sight properties of fire watchtowers, and DEM data were used. The point layer contains tower height, visible fire smoke height, sight distance, vertical angle and horizontal angle information.

Table 3. The necessary fire watchtowers data for visibility analysis

Watchtower	Tower height (m)	Smoke height (m)	Sight distance (km)	Horizontal angle (Degree)	Vertical upper angle (Degree)	Vertical lower angle (Degree)
Aygır	6	100	10	360	90	-90
Sülüklü	6	100	10	360	90	-90
Nuribaba	9	100	10	360	90	-90
Ölemez	6	100	10	360	90	-90
Çaldağı	6	100	10	360	90	-90
Dikmentepe	6	100	10	360	90	-90
Beyancık	6	100	10	360	90	-90
Emecik	6	100	10	360	90	-90
Kepez	6	100	10	360	90	-90

Tower heights data has been obtained from Dalaman State Forest Enterprise. The visible fire smoke height was set at 100 m so that not only the direct flames but also the smoke rising from the ground can be seen during the fire. The horizontal view angle is considered to be 360º so that the entire study area can be scanned from the fire watchtowers. And lastly, vertical view angle was set at upper 90 and lower -90 degree.

Forested areas that can be seen from the fire watchtowers were determined at the last stage of the study. For this purpose, visible areas determined by visibility analysis were intersected with data layer that showing land use classes. According to the results of the visibility analysis of the study area, visible areas are shown on Figure 2 and areas can be seen by each tower given at Table 4 separately.

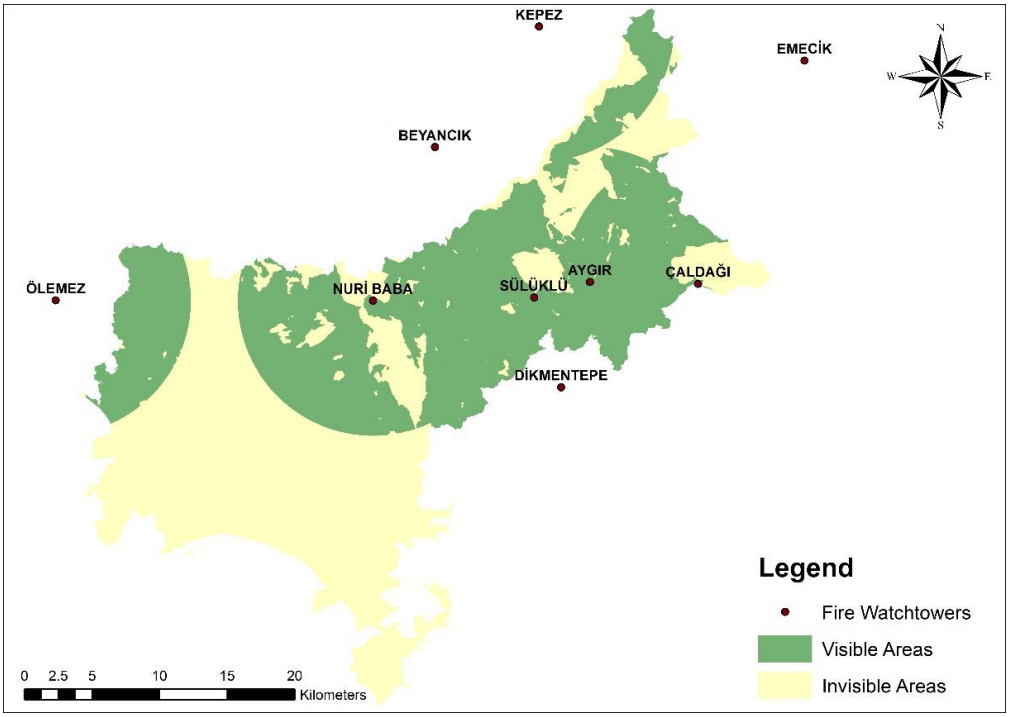

Figure 2. Visibility map of fire watchtowers

Table 4. Visible areas monitored by fire watchtowers

Watchtower	Total area		Visible forested area	
	(ha)	(%)	(ha)	(%)
Aygır	1026.8	1.2	929.1	1.6
Sülüklü	1551.5	1.8	1181.4	2.0
Nuri Baba	11277.6	12.8	5902.9	10.2
Ölemez	5831.1	6.6	897.1	1.6
Çaldağı	3322.6	3.8	2877.2	5.0
Dikmentepe	1239.7	1.4	1000.0	1.7
Beyancık	1042.0	1.2	778.8	1.4
Emecik	22.3	0.01	22.3	0.01
Kepez	2841.8	3.2	2661.6	4.6
More than one	15084.3	17.1	12190.0	21.1
Invisible	44812.3	50.9	29330.5	50.8
Total	88052.0	100.0	57770.9	100.0

3. Results and Discussion

In visibility analysis, we used horizontally 10 km scanning radius that is widely accepted distance for rough terrain for detecting the smoke under optimal weather conditions (GDF, 1995). According to visibility analysis, different radius distances are used in various studies. In the USA, radius from 13 to 32 km have been used. While in a large part of the western USA, where visibility is good, a radius of 24 km is accepted, in the south and south-east, where visibility is poorer, a 10 to 13 km radius is most often used (Davis 1959). Variable distances up to 18 km were used in Canada (Artsybashev, 1984). In Spain, 6 to 8 km scanning radius is accepted for the worst conditions despite 30 to 40 km scanning radius is used for optimal situations. In Portugal effective detection radius is accepted for poor conditions and good conditions as 13 km and 20 km, respectively (Rego and Catry, 2006). As a general acceptance, values of 10 km for rough terrain and 20 km for flat terrain are widely used (Ruiz 2000; Küçük et al. 2017).

Although there are 3 fire watchtowers (Aygır, Nuri Baba, Sülüklü) within the boundaries of Dalaman State Forest Enterprise, total of 9 fire watchtowers can observe the study area. As a result of the visibility analysis obtained from these 9 fire watchtowers, we

determine forested areas observed by each individual watchtower and more than one watchtower, and also invisible forested areas. The forested areas monitored by Aygır, Sülüklü, Nuri Baba, Ölemez, Çaldağı, Dikmentepe, Beyancık, Emecik and Kepez fire watchtowers have been identified as 929.1, 1181.4, 5902.9, 897.1, 2877.2, 1000.0, 778.8, 22.3 and 2661.6 ha respectively (Table 4.). The forested areas observed by more than one watchtower and invisible forested areas have been found as 12190.0 and 29330.5 ha, respectively. Results of visibility analysis indicated that 49.1% of the total area and 49.2% of forested area could be monitored by fire watchtowers (Figure 3). Sülüklü fire watchtower was removed in 2017. Due to the removal of Sülüklü fire watchtower, visible forested areas decreased from 49.2% to 47.2%. According to this result, removal decision of Sülüklü fire watchtower can be accepted as suitable for actual situation.

This results shows that the actual visible area percentage is not enough for predetermination forest fires effectively because at least 70% of the scanned area must be visible for rough terrain (GDF 1995).

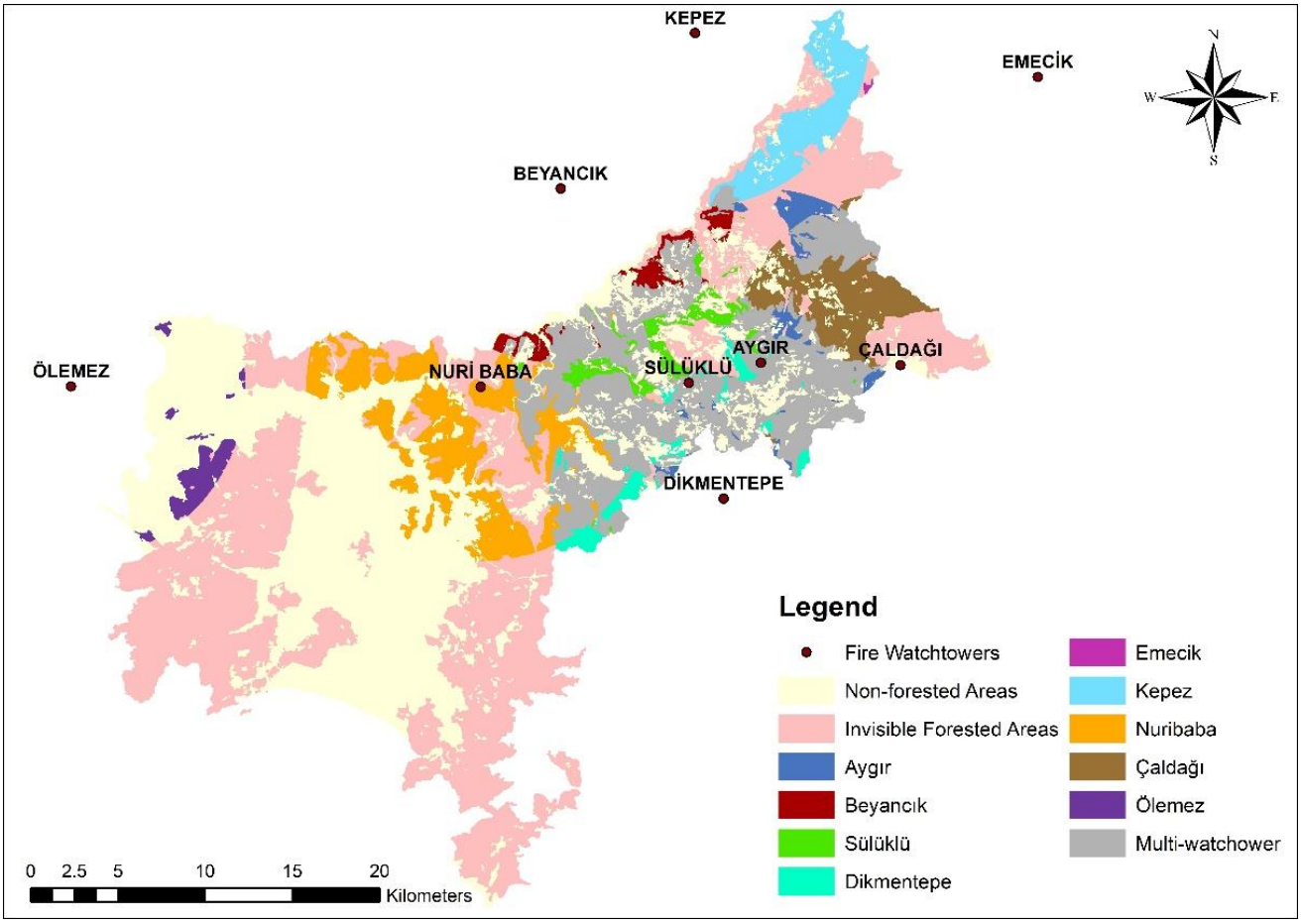

Figure 3. Visible forested areas seen by one or more fire watchtowers

4. Conclusions

In this study, a visibility analysis was conducted in order to determine visible and invisible forested areas from forest fire watchtowers. Dalaman State Forest Enterprise in Turkey's South Aegean Region which is first-degree fire-prone region selected as the study area. 65.6% of Dalaman State Forest Enterprise is covered with forested areas that contains *Pinus brutia*, *Pinus nigra* and *Cedrus libani.*

Visibility analysis was conducted for 9 fire watchtowers which supervise the study area. It can be clearly seen that 49.1% of the total area is visible, while 47.2% of the forested areas are visible when Sülüklü fire watchtower was eliminated. Also, while some areas can only be monitored by one fire watchtower, some areas can be seen by two or more watchtowers. On the other hand, at least 70% of the scanned area must be visible for rough terrain for effective monitoring (GDF, 1995). In order to increase visible forested areas from 47.2 % to 70 %, a new fire watchtower can be located in the south-western region of the study area. Thus, the visible forested areas will rise to appropriate levels.

In Turkey, 35% of total forested areas are sensitive to forest fires at first-degree, but a visibility analysis for all over these areas has not been conducted. In an area where the forest fire risk is so high, the locations of the fire watchtowers must be promptly examined. Furthermore, visibility analysis of areas that sensitive to forest fires should be performed including all the existing fire watchtowers around the perimeter.

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