



ASSESSMENT OF FIREFIGHTING TEAMS BY USING GIS-BASED NETWORK ANALYSIS METHOD: A CASE OF YAYLA FOREST IN TURKEY

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ABSTRACT: The forest areas located along the coastline of the Mediterranean region in Turkey are sensitive to forest fires in the first degree. According to the fire statistics, about 21000 hectares of forest areas are damaged by forest fires annually. In order to fight forest fires effectively, the firefighting teams should reach the fire location and start fire extinguishing activities within the critical response time. GIS-based network analysis method can be used to evaluate the performance of the firefighting teams in a specified area. In this study, the locations of three firefighting teams within and around Yayla Forest Enterprise Chief (FEC) in the city of Balıkesir in Turkey was evaluated using "Network Analyst" module of ArcGIS software. In the first step, the optimum routes which provided the fastest access from the locations of firefighting teams to the possible fire areas were determined by using "New Closest Facility" method under "Network Analyst" module. Then, "New Service Area" method under the same module was used to calculate how far the firefighting teams can reach in the study area within a specific critical response time. It was found that 16 out of 19 potential fire areas could be reached by the teams within the critical response time. In addition, 83% of the forest areas in Yayla FEC was found to be reachable by the firefighting teams within the critical response time. The results suggested that the locations of the firefighting teams were found to be suitable for effective firefighting activities in the study area.

Keywords: Firefighting teams, forest fire, forest roads, network analysis, shortest path.

CBS TABANLI AĞ ANALİZİ YÖNTEMİ KULLANILARAK YANGIN İLK MÜDAHALE EKİPLERİNİN DEĞERLENDİRİLMESİ

ÖZET: Ülkemizde Akdeniz bölgesinin kıyı şeridinde boyunca uzanan ormanlık alanlar orman yangınlarına birinci dereceden hassastır. Yangın istatistiklerine göre yılda yaklaşık 21000 hektar ormanlık alan orman yangınlarından zarar görmektedir. Orman yangınlarıyla etkin bir şekilde mücadele edebilmek için yangınla mücadelede görev alan ilk müdahale ekiplerinin yangın yerine ulaşması ve kritik müdahale süresi içerisinde yangın söndürme faaliyetlerine başlaması gerekmektedir. Belirli bir alanda yangınla mücadele ekiplerinin performansını değerlendirmek için CBS tabanlı ağ analizi yöntemi kullanılabilir. Bu çalışmada, Balıkesir ilinde yer alan Yayla Orman İşletme Şefliği sınırları içinde ve çevresinde bulunan üç yangın ilk müdahale ekibinin lokasyonları ArcGIS yazılımının "Network Analyst" modülü kullanılarak değerlendirilmiştir. İlk aşamada, ilk müdahale ekiplerinin lokasyonlarından olası yangın alanlarına en hızlı erişimi sağlayan optimum güzergahlar, "Network Analyst" modülü altında "New Closest Facility" yöntemi kullanılarak belirlenmiştir. Daha sonra, yangınla mücadele ekiplerinin kritik müdahale süresi içinde çalışma alanında ne kadar uzağa ulaşabileceğini hesaplamak için aynı modül altında "New Service Area" yöntemi kullanılmıştır. Ekipler tarafından kritik müdahale süresi içerisinde 19 potansiyel yangın alanından 16 alana ulaşılabilirdiği tespit edilmiştir. Ayrıca, çalışma alanındaki ormanlık alanların %83'üne yangınla mücadele ekipleri tarafından kritik müdahale süresi içerisinde ulaşılabilirdiği tespit edilmiştir. Sonuçlar, yangınla mücadele ekiplerinin konumlarının çalışma alanındaki etkili yangınla mücadele faaliyetleri için uygun olduğunu ortaya koymuştur.

Anahtar kelimeler: Yangın ilk müdahale ekipleri, orman yangını, orman yolları, ağ analizi, en kısa yol.

INTRODUCTION

In recent decades, rapid population growth and consumer demand have considerably increased the pressure on forests considered as one of the most important renewable natural resources. The most obvious reflections of this pressure on forest resources are illegal forest openings, excessive cuttings and forest fires (Ertuğrul, 2005). Among them, forest fires severely destroy forests, affect the sustainability of forest resources and cause significant disturb and ecological damages on forest ecosystems (Bilici, 2008). Besides, forest fires threat human life and cause serious property losses.

Mediterranean ecosystems are highly sensitive to forest fires due to the composition of plant species and dry climate in summer time (Demir et al., 2009). For the period of 2003-2012, it was reported that ratio of fire damaged areas was 6% in Greece, 5.6% in Italy, 4.2% in Spain, 1.2% in France, and 0.4% in Turkey (Eker & Abdurrahmanoğlu, 2018). In Turkey, 5.5 million ha of forest areas along the coast of Mediterranean region is highly sensitive to forest fires (CFE, 2008).

In order to fight forest fires effectively, the firefighting teams should reach the fire location and start fire extinguishing activities within the critical response time. The critical response time is defined as the time when the probability of extinguishing forest fires rises significantly (GDF, 2008). Therefore, it is important to determine the areas that can be reached in critical response time, which varies depending on the fire sensitivity levels of the forest areas. Table 1 indicates

critical response times estimated according to fire sensitivity degrees, based on long term statistical data collected during forest fire incidents in Turkey.

Table 1. Critical response time to forest fires by fire sensitivity level (GDF, 2008)

	Fire Sensitivity Degrees			
	I	II	III	IV and V
Critical Response Time	20 min	30 min	40 min	50 min

Since the firefighting teams are mostly transported to fire areas by fire-trucks, the accessible forests from a firefighting station within the critical response time can be determined based on the length and design speed of the road network. The computer-aided methods (i.e. network analysis, linear programming, dynamic programming, heuristic methods) can be used in the solution of such transportation problems in which the optimum route with the shortest travel time is determined among many alternative routes (Akay et al., 2012). In Turkey, firefighting teams are occasionally deployed to different regions to support the local firefighting teams in extinguishing of large fires. However, they may encounter serious problems while reaching the fire area since they are not familiar with the region or the road network. In such cases, the optimum route not only provides the fastest access, but also the reliable access to the fire areas.

In recent years, GIS-based decision support systems have been used in planning, managing, and decision making stages of fire management activities (Sampson et al., 2000; Kucuk et al., 2005). For firefighting activities, pre-fire precautionary measures, and post-fire operations, obtaining and analyzing information by using GIS-based systems are relatively easier, economic, and faster compared to traditional methods (Kucuk & Bilgili, 2006). Besides, network analysis based modules in GIS tools such as "Network Analyst" in ArcGIS software provide users with advanced methods to solve fire access problems (Akay & Sakar, 2009).

Dimopoulou & Giannikos (2004) developed a GIS-based decision support system to determine the fire fighting vehicles necessary to extinguish a fire. They assigned vehicle speed for different road types to investigate whether fire fighting vehicles arrive to the fire area in the critical time. The optimum locations for the fire fighting vehicles were also determined to maximize the efficiency of the firefighting activities. Keramitsoglou et al. (2004) developed a decision support system to assist fire managers in determining the optimum routes for fire fighting vehicles in Greece. They evaluated the specific decision variables such as road type, road condition, and population density within a routing algorithm.

Bonazountas et al. (2007) used GIS network analysis tools to calculate the arrival time of the ground-based firefighting team to a fire area for managing forest casualties. The access time including water re-charging cycles was determined based on a raster-based road network. In a study conducted by Podolskaia et al. (2019), travelling time and distance to a forest fire was estimated using the transport network model, generated by the Network Analyst tool in ArcGIS. A map of fire ground protection zone was produced to evaluate ground transport accessibility for three time periods (one, two and three hours). It was found that the forest fires are mostly located within the zones of one and two hour's availability.

In this study, the performance of the firefighting teams located in a sample FEC was evaluated using "Network Analyst" module of ArcGIS software. The solution process included two stages; 1) the fastest access from the locations of firefighting teams to the possible fire areas

were determined and 2) how far the firefighting teams can reach in the study area within a specific critical response time was determined.

MATERIALS AND METHODS

Study Area

The study was conducted in Yayla FEC located in the border of Dursunbey Forest Enterprise Directorate (FED) which is classified as the first degree fire-sensitive area. The dominant tree species in the area are Larch, Brutian pine, Oak and other deciduous trees. The study area is approximately 21 thousand hectares and 13.678 hectares are covered with forests. The study area is located between 39°32'31.21", 39°21'12.84" north latitudes and 28°39'30.05", 28°51'47.38" east longitudes (Figure 1).



Figure 1. Study area

Firefighting Teams and Potential Fire Areas

There are three firefighting teams (Yayla, Tarlabası, Reşadiye) in the study area. Among these teams, Tarlabası team and Reşadiye team are not within the boundaries of the Yayla FEC, however, they were considered in the network analysis because they are located very close to the boundaries of the study area. Within the scope of the study, potential fire areas need to be determined in order to plan the firefighting organization with GIS techniques. For this purpose, 19 forest fires that had occurred in the last 50 years were selected based on the data obtained from Dursunbey Forest Enterprise Directorate (Table 2). Then, locations of the firefighting teams and the previous forest fires were marked on the new data layer produced using the ArcCatalog module in ArcGIS.

Table 2. Forest fires occurred in the last 50 years in the study area

No	Burned Area (ha)	Cause of Fire	Year
1	13.0	Unknown	1973
2	1.2	Unknown	1983
3	4.0	Unknown	1985
4	0.2	Unknown	1991
5	0.5	Negligence and carelessness	1992
6	0.05	Negligence and carelessness	1993
7	0.1	Unknown	1994
8	0.02	Unknown	1995
9	0.005	Lightning	1995
10	0.2	Unknown	1995
11	0.01	Unknown	1996
12	0.03	Intentional	1998
13	1.0	Unknown	1999
14	0.1	Unknown	1999
15	0.1	Negligence and carelessness	2008
16	8.0	Negligence and carelessness	2009
17	0.2	Unknown	2014
18	0.06	Unknown	2015
19	108.0	Unknown	2016

Network Analysis Method

The road network map of the study area was developed based on the topographic maps and the field study. In order to determine the optimum route that allows fire trucks to reach the fire area in the shortest time possible, the average travel time of the fire truck spent on each road section was determined. Travel time was calculated depending on the length of the road section and the average speed of the fire truck. The average vehicle speed varies depending on the type and condition of the road. For this reason, the new fields including road length (km), road type, road condition (i.e. good, medium, and poor), fire truck speed (km/h) and travel time (minutes) were added in the attribute table of the road network layer.

Road section lengths were calculated using the Calculate Geometry tool in the attribute table. Road types are classified under five groups as the asphalt road, gravel road, forest road (B-Type secondary forest road), fire safety strip and tractor road. A number of field studies have been conducted in the study area to determine road conditions. In the determination of the average vehicle speeds, average speed information suggested by Traffic Control Branch Directorate (TCBD, 2010) and Bilici (2008) were taken into consideration. In light of this

information, the average fire truck speed was determined for each road section according to the type and condition of the road (Table 3).

Table 3. Average vehicle speeds (km/hour) for road types and road conditions

Road Conditions	Asphalt	Gravel	Forest Road	Fire Safety Strip	Tractor Road
Good	60	50	30	20	15
Medium	50	40	25	15	10
Poor	40	30	20	10	5

After determining the average vehicle speeds, the Field Calculator tool was used in the Attribute Table to assign vehicle speed information to each road section. For this purpose, “Pre-Logic VBA Script Code” was written in Visual Basic computer programming language using “If...Then...Elseif...Then” conditions. Finally, the travel time for each section was calculated using the Field Calculator tool in the attribute table using the following formula:

$$t_i = \frac{l_i}{v_i} 60 \quad (1)$$

t_i : total travel time for the section i (minutes)

l_i : length of the section i (km)

v_i : average fire truck speed for the section i (km/hour)

60: used to convert travel time from hour to minute

In order to implement the network analysis method with the help of Network Analysis plugin in ArcGIS, Personal Geodatabase was first produced in the ArcCatalog module. Then, the Network Dataset was developed by utilizing the road network data layer that contains the values (travel time) of each road segment that constitutes the road network in the study area. Finally, link (ND_Edges) and node (ND_Junctions) files were generated using Network Dataset. After completing the Network Dataset, the network analysis application was performed using “ArcMap” module in ArcGIS. In this application, New Closest Facility and New Service Area tools under Network Analyst were implemented separately.

New Closest Facility Tool

New Closest Facility tool was used to determine the optimum route between the firefighting teams and the potential fire areas in the study area (Akay et al., 2012). First of all, the optimum routes on which the firefighting teams can reach each fire area in the shortest time were determined. Then, the potential fire areas that can be reached by the firefighting teams within the critical response time were determined. In this method, the locations of the firefighting teams and fire areas can be automatically loaded from the relevant data layers to the system.

New Service Area Tool

The New Service Area tool was used to evaluate accessible and inaccessible forest areas by the firefighting teams within the critical response time. The New Service Area tool works similar to a GIS buffer analysis. A service area point is considered as a center point from which the road network can be reached in a user-defined total link value (Akay et al., 2012). In this study, the locations of the firefighting teams are considered as service area points and service area is the forest areas that can be reached within the total link value of critical response time. The

New Service Area Tool was applied considering the critical response time of 20 minutes because Yayla FEC consists of the first degree fire-sensitive areas.

RESULTS AND DISCUSSION

Data Layers

The total length of the road network in the study area was calculated as 400.4 km. The majority of these roads are forest roads (37.5%), followed by gravel roads (29.5%), tractor roads (13.5%), asphalt roads (12.8%), and fire safety strips (6%) (Table 4). The total number of sections produced in the generation of road network layer was determined as 271.

Table 4. Road network information

Road Type	Number of Sections	Length (km)	Ratio (%)	Length (km) regarding with Road Conditions		
				Good	Medium	Poor
Asphalt	29	51.2	12.8	49.0	2.2	0.0
Gravel	84	118.0	29.5	64.2	45.7	8.1
Forest road	94	150.2	37.5	45.5	29.8	74.9
Fire safety strip	15	27.0	6.7	12.7	9.3	5.0
Tractor road	49	54.0	13.5	22.2	27.8	4.0

The road network data layer over forest areas in the study area is shown in Figure 2. Considering the conditions of the road sections in the study area, 48.4% of the roads were classified as good, 28.7% as medium, and 23.0% as poor. All asphalt roads were considered to be in good condition in terms of traffic flow. When the gravel roads were taken into consideration, it was found that more than half of the roads were in good condition (54.4%), 38.7% were in medium and remaining roads were in poor condition (6.9%). For the forest roads, it was determined that 49.9% of the roads were poor, 30.3% were good and 19.84% were in medium conditions. A data layer representing the locations of the firefighting teams and potential fire areas is also generated in ArcGIS as shown in Figure 3.

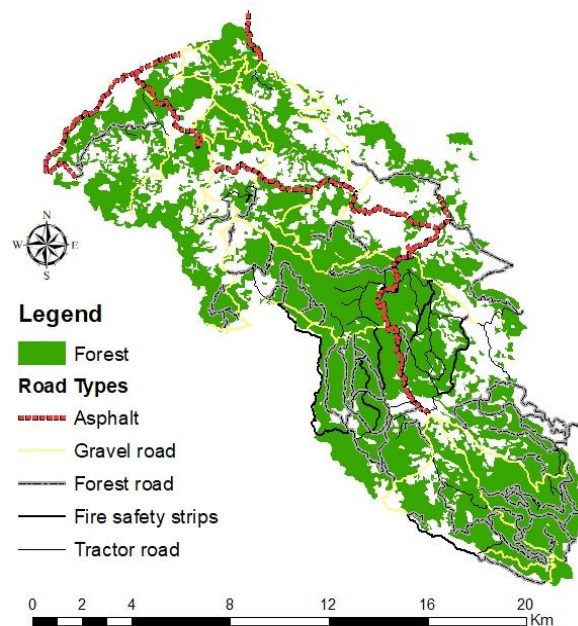


Figure 2. Road network data layer of the study area

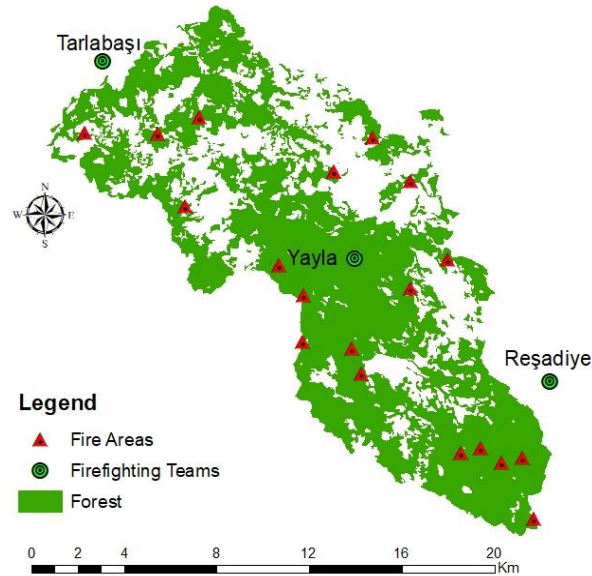


Figure 3. Firefighting teams and potential fire areas

Network Analysis

The Network Analysis application was carried out using two basic data layers produced in the Network Dataset. These data layers; the link data layer representing the travel time of each road section and the node data layer representing the intersection of these links. After generating network database, New Closest Facility and New Service Area tools were implemented separately.

New Closest Facility Results

Using the New Closest Facility Tool, the travel times of the firefighting teams to reach potential fire areas were determined. Figure 4 shows the optimum routes that ensure the minimum travel time to reach each fire area. As shown in Table 5, 11 out of 19 potential fire areas were reached by the Yayla Firefighting Team within the critical response time of 20 minutes. Of the remaining eight fire areas, four of them can be reached by the Tarlabası Firefighting Team and one fire by the Reşadiye Firefighting Team within the critical response time. Thus, only three of the 19 potential fire areas could not be reached by the firefighting teams within the critical response time. In a similar study conducted by Sakar (2010) in the Mediterranean city of Kahramanmaraş in Turkey, it was reported that seven out of 15 potential fire areas could not be reached by the firefighting teams. On the other hand, it was found that the Yayla Firefighting Team can reach these three fire areas (Fire 1, 13, and 14) in 21, 25, and 21 minutes, respectively. The results suggested that there is a close relationship between the travel time and road length, as well as between travel time and road types (Akay et al., 2012).

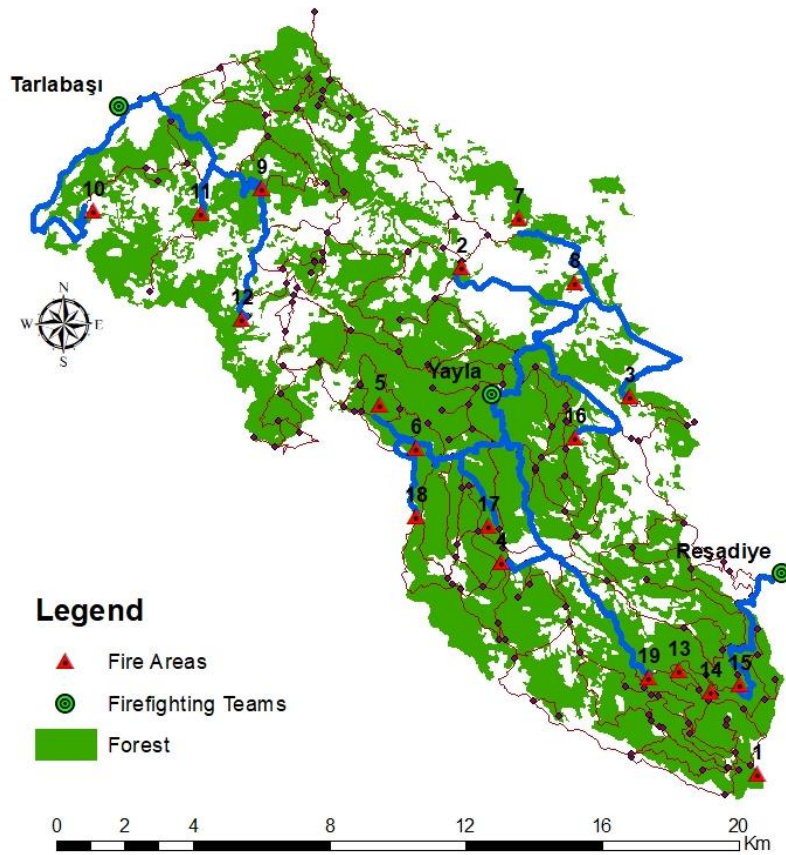


Figure 4. Optimum routes to the point of fire

Table 5. Total travel time (minutes) to reach fire areas

Fire Fighting Teams	Forest Fire Areas																		
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
Yayla	21	12	20	12	8	9	17	8	22	39	25	21	25	21	21	14	10	15	14
Tarlabası	54	22	39	45	38	40	27	28	14	12	13	19	58	55	55	39	46	48	48
Reşadiye	29	39	47	27	33	33	45	35	49	66	53	48	30	23	18	37	29	39	28

New Service Area Results

With the New Service Area Tool, the locations of the fire fighting teams were taken as the center and the forest areas that can be reached in the study area within the critical response time were determined. Thus, the areas where fire fighting teams could reach on the road network within a 20-minute period were identified (Figure 5). As a result of the New Service Area Tool application, it was found that 11346.39 hectares, which correspond to 83% of the forest areas within the area of the Yayla FEC, can be reached by the fire fighting teams within the critical response time. The Yayla Fire fighting Team can reach 63% of these areas while Tarlabası Fire fighting Team and Reşadiye Fire fighting Team can reach 17% and 3%, respectively. However, 2325.05 hectare of the study area, which corresponds to 17% of the forest areas, cannot be reached by any fire fighting teams within the critical response time of 20 minutes. Akay & Kılıç (2015) used GIS-based network analysis method to evaluate the efficiency of a fire fighting team located in Sarnıç FEC in the city of Bursa in Turkey. They found that 26.18% and 60.29% of the forest areas can be reached within a critical response time considering high and coppice forests, respectively.

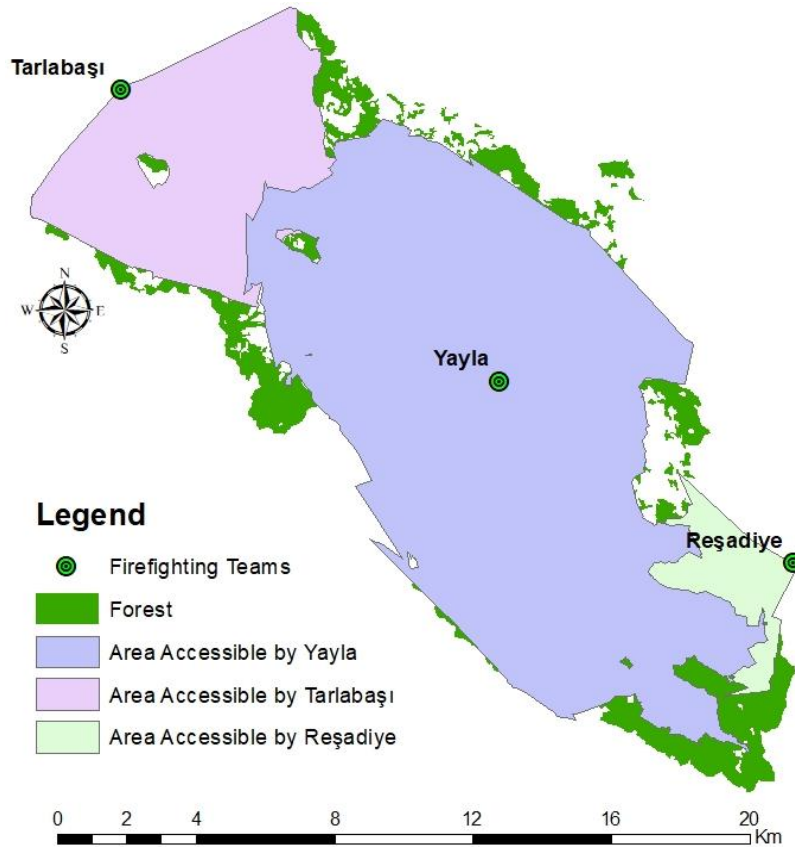


Figure 5. Areas reached by the firefighting teams within the critical response time

CONCLUSIONS

One of the important elements of the fight against forest fires is early detection and quick intervention. In order to achieve this goal, it is very important to locate the firefighting teams so that potential fires can be reached in considering critical response time. In this study, GIS-based network analysis method was used to evaluate the locations of firefighting teams in Yayla FEC which is categorized as the first degree fire-sensitive area. In the network analysis, the network database was generated by using the "ArcCatalog" module in ArcGIS software. Two analyzes were made on this database using the "Network Analyst" module. Firstly, the optimum routes which provide the fastest access to the possible fire areas (19 previous fire locations) from the firefighting teams were determined by using New Closest Facility Tool. Then, how far the firefighting teams can reach within the determined time limits from the location they are located were calculated by using New Service Area Tool. When the situation of the firefighting teams was examined, it was found that only three of the 19 potential fire areas could not be reached at the critical response time of 20 minutes. In addition, 83% of the forest areas that are in charge of the FEC were found to be reached with the firefighting teams during critical response time. The results were found to be sufficient for the firefighting in the study area to effectively fight forest fires and to use resources efficiently.

AUTHOR CONTRIBUTIONS

Abdullah E. Akay: Writing, editing and reviewing the manuscript, and supervising the study.
Abdullah Erdoğan: Obtaining information for the study area, organizing and analyzing data.
İnanç Taş: Building network database system and designing dataset.

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