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Effects of Improving Forest Road Standards on Shortening the Arrival Time of Ground-based Firefighting Teams Accessing to the Forest Fires

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Abstract

In fighting against forest fires, it is crucial for the ground-based firefighting team to reach a fire area in critical response time in which the chance of controlling the fires is significantly high. Road networks are the key infrastructures that provide access to the forest areas for the protection of forest resources. In order to benefit from this important function of roads, especially in forested areas with high natural forest fire risk, they should be built in with adequate technical road standards since the low standards limit the fire truck speed that increases the arrival time of the firefighting team to the fire areas. Most of the forest roads in Turkey are Type-B secondary forest roads with low technical road standards (road width, curve radius, surface materials) that limit the speed of fire trucks. This paper aimed to evaluate the potential contribution of improving the standards of Type-B secondary forest roads in terms of increasing accessible forested areas in critical response time in the case of forest fire occurrence. The study area was Kahramanmaraş Forestry Enterprise Directorate (FED), where forests are sensitive to forest fires at the first degree. In the solution process, firstly, accessible forest areas by the firefighting teams located in the study area (six teams) according to the critical response time were determined by considering the existing road network in the study area. In the second scenario, the possible increase in the accessible forest areas with improved forest road standards and increased travel speed in forest roads was investigated. The results indicated that the areas that can be reached promptly by the firefighting teams in critical response time were 21% and 44% for considering existing roads and improved roads in the whole study area. On the other hand, the accessible forested areas in critical response time increased from 17% to 36% when standards of the forest roads were improved. It is indicated that improving road standards has a significant value to contribute the efficiency of firefighting activities if the practitioners implemented presented methodology.

Keywords: Forest roads, road standards, forest fires, firefighting, critical response time

1. Introduction

Wildfires are one of the vital disasters that affect the forest ecosystem particularly in forests with high natural forest fire risk. Besides, they threaten human life and cause serious property losses. In Turkey, large forest lands are annually affected by the forest fires, causing severe losses from an economic, environmental, and social aspects (Karabulut et al., 2013). The sustainability of forest resources are adversely affected by the forest fires which result in environmental impacts on forest ecosystems (Bilici, 2009).

For effective fighting against forest fires, the ground-based firefighting teams must arrive the fire scenes and start firefighting within the critical response time which is defined as the time when the probability of extinguishing forest fires rises significantly (Keramitsoglou et al., 2004). Therefore, it is important to determine the areas that the firefighting team can reach in critical response time. The critical response time is computed based on the fire sensitivity level of the forested areas (Akay et al., 2018).

The firefighting teams need to be positioned in the right locations in order to arrive the fire scenes promptly by using the shortest route. Since the firefighting teams are mostly carried to fire areas by fire-trucks, the accessible forests from a firefighting station within the critical response time can be determined based on the road length and design speed. About 66% of the forest roads in Turkey are classified as Type-B secondary forest roads, which have low standards and limited design speed (GDF, 2012). Type-B roads require major annual repairs due to the lack of adequate road standards. One way to expand the accessible forest areas that can be reached from a point within a specified time period is to improve the road standards increasing the design speed and eventually reducing travel time eventually. Thus, improving the road standards and efficiency of firefighting activities should be evaluated together in the most appropriate way.

The decision support systems integrated with Geographical Information Systems (GIS) improve the effectiveness of fire management tasks such as planning, managing, and decision making (Burgan et al., 1998; Sampson et al., 2000; Kucuk and Unal, 2005). Previous studies investigated the integration of decision support systems with GIS techniques for solving vehicle routing problems (Manussaridis et al., 2007; Keenan, 2008). In some researches, vehicle routing was explored in real-time that allows for routes to be updated dynamically as a vehicle travels along a road network (Ichoua, 2000; Gendreau et al., 2001; Ghiani et al., 2003).

Previous studies suggested that increasing the design speed on current forest roads with low standards could increase firefighting response capabilities. However, no study has been encountered in the literature dealing with the effects of improving forest road standards on the efficiency of firefighting activities. In this study, GIS-based network analysis was used to evaluate the effects of improving road standards on accessible forest areas by the ground-based firefighting team according to the critical response time. The study was implemented in Kahramanmaraş FED consisting of forests with high natural fire sensitivity. The Network Analyst tools of ArcGIS software was employed to determine the accessible forest areas by considering the existing and improved forest roads.

2. Material and Methods
2.1. Study Area

The study was implemented in Kahramanmaraş FED which covers 10 Forestry Enterprise Chiefs (FECs) (Figure 1). The geographical location of the study area is 38.06 N - 36.70 E and 37.18 N - 37.07 E. The study area is approximately 597,083 ha with approximately 45% covered by forest areas. In the FED, 44% of the forest area is a productive forest while the rest is degraded one. The forest areas are generally located in the transition region between the Mediterranean and the continental climate. The forested areas in Kahramanmaraş FED are classified as first-degree fire sensitive forests. There are six firefighting teams in the FED.

2.2. GIS Database Generation

In order to determine accessible forests in the critical response time using the GIS-based network analysis, digital data layers of land use types and road network were generated. In this process, 1:25000 scale topographic and forest management maps obtained from Kahramanmaraş FED in 2018 were used as base maps in ArcGIS software. The land use map of the study area was produced based on the forest management maps. Then, a new data layer of forest areas was produced by reclassifying the land use map using ArcGIS.
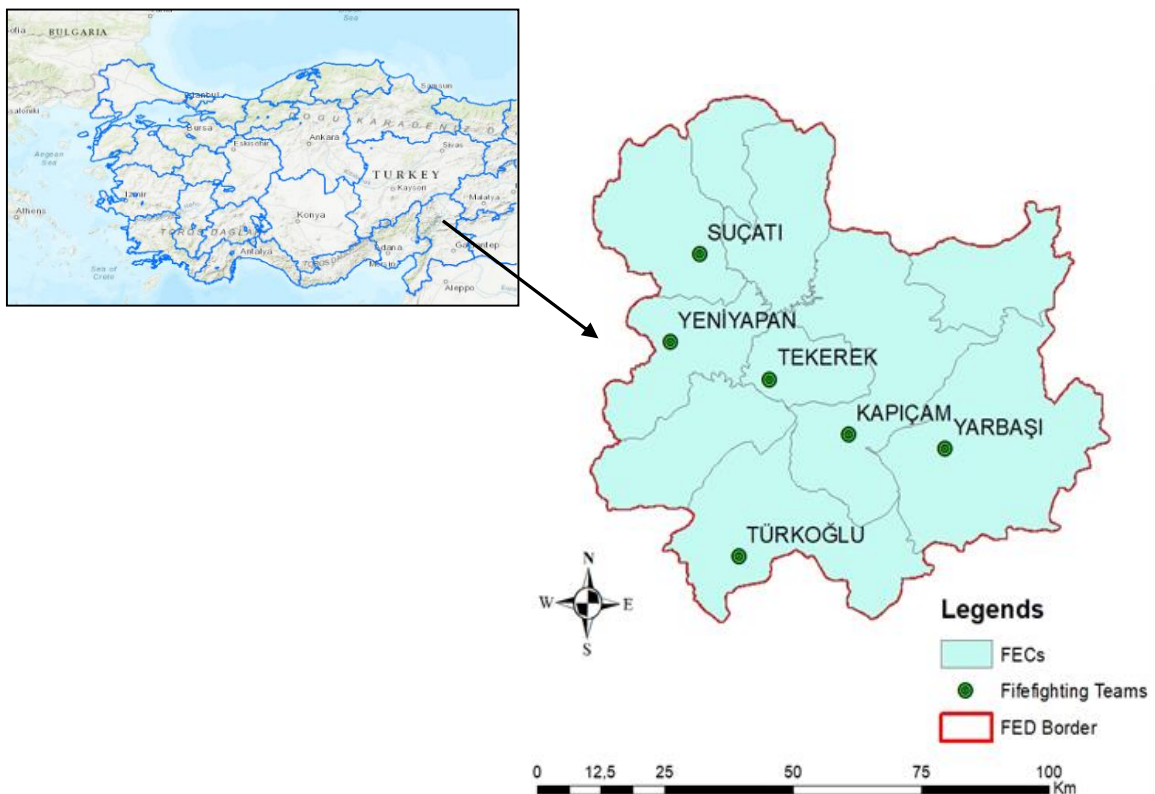

Figure 1. Study area

The average travel time of the fire trucks (carrying firefighting teams) for each road section was computed and included into the attribute table of the road network layer. The travel time was computed as a function of road length and average truck speed, which can vary based on

road types and status. The road types in the study area were asphalt, gravel, and forest roads (Type-B), while the road status was classified as good, average and poor. The vehicle speed information recommended by some previous studies (Bilici, 2009; Akay et al., 2012) and the

Traffic Inspection Branch Directorate (TIBD, 2010) have been taken into account. In the light of this information, the average fire truck speed for the road types is indicated in the Table 1.

Table 1. Average fire truck speed (km/hour) by road type and road status

Road Type	Road Status		
	Good	Medium	Poor
Asphalt Road	60	50	40
Gravel Road	50	40	30
Forest Road	30	25	20

The accessible forested areas in critical response time considering improved forest roads (subject to road improvement construction and road surface construction) were determined in the second scenario. In this scenario, the average vehicle speed for improved forest roads was estimated as 40 km/hr, which is the average travel speed of a fire truck on a forest road with improved surface material (Akay et al., 2012). Then, travel time for each road section was computed using the Equation I, and inserted into the attribute table of the road network map (Şakar, 2010):

$$t = \frac{l}{v} 60 \tag{1}$$

t : travel time (minutes)
l : road length (km)
v: average speed of fire truck (km/hour)

2.3. Network Analysis

The potential contribution of improving the standards of Type-B secondary forest roads in terms of increasing accessible forested areas in critical response time was evaluated with network analysis approach. In the solution process, firstly, accessible forest areas by the firefighting team according to the critical response time were determined by considering the existing road network in the study area. In the second scenario, the possible increase in the accessible forest areas was investigated for the forest roads with improved standards with high travel speed.

One of the most common methods used in the determination of an optimum route is network analysis where various parameters such as length, cost, and time are assigned to the road sections (Zhan, 1997). In this study, the network analysis based on "The New Service Area" method of the "Network Analyst" tool in ArcGIS was used to evaluate accessible forested areas in the critical response time for both scenarios. According to the forest fire sensitivity map of Turkey, developed by the General Directorate of Forestry (GDF), Kahramanmaraş FED is covered with first degree fire sensitive forest areas where critical response time is defined as 20 minutes (GDF, 2008).

In the application of New Service Area method, the locations of the firefighting teams were considered as service area points while the forest areas that can be reached within the critical response time were service areas. Then, the forest areas accessed within the critical response time were determined for both scenarios. Finally, the additional forest areas that can be reached by improving the road standards were determined by eliminating the accessible forested areas in the first scenario from the accessible forested areas in the second scenario.

3. Results and Discussion
3.1. GIS Database

The total road length was 15496.5 km in which about 51.5% was forest road (Type-B), 41.7% was gravel road, and 6.7% was asphalt road (Figure 2). It was found that the road type with the highest number of road section was gravel road, followed by the forest road and asphalt road. About 62.6% of the road network was in a good condition and 29.1% was in an average condition while the rest was in poor condition. In the case of road types, 100% of the asphalt roads, about 63.8% of the gravel roads, and 56.7% of the forest roads were in a good condition, indicating that they can provide reliable trafficking (Table 2).
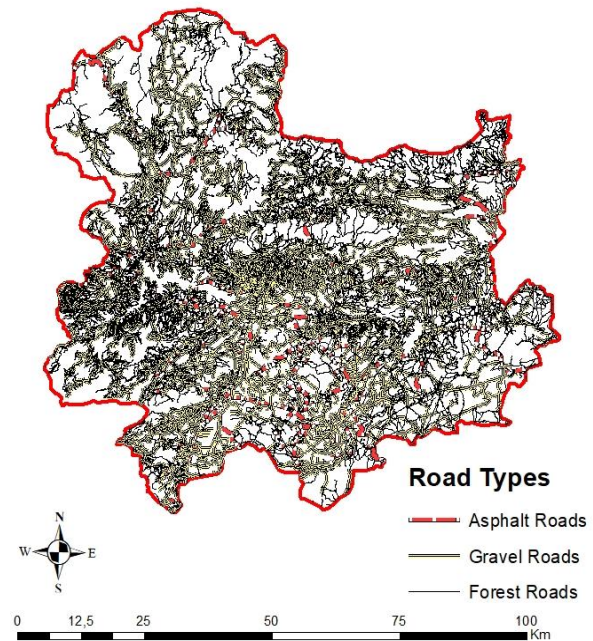

Figure 2. Road network map

The results indicated that the number of land use types in the study area was eighteen (Figure 3). The largest land use class was the high forests (42.09%), followed by the agricultural lands (35.19%) (Table 3). The land use types including high forest, coppice forest, forest soil, erosion, nursery, and afforestation areas were reclassified as forest lands. After running reclassification, the total forest area was about 60.17% of the study area.

Table 2. Road network statistics within the study area

Road Type	Number of Road Sections	Road Lengths (km)	Road Status (km)		
			Good	Average	Poor
Asphalt	2862.0	1044.9	1044.9	-	-
Gravel	17507.0	6464.2	4121.3	1190.9	1152.0
Forest Road	13526.0	7987.4	4532.3	3320.1	135.0
Total	33895.0	15496.5	9698.5	4511.0	1287.0

Land Use Types

High Forest	Stoney	Residence	Forest Soil-Stoney
Coppice Forest	Sand	Depot	Forest Soil-Agriculture
Forest Soil	Swamp	Mine	Forest Soil-Erosion
Erosion	Water	Agriculture	
Nursery	Rangeland	Afforestation	
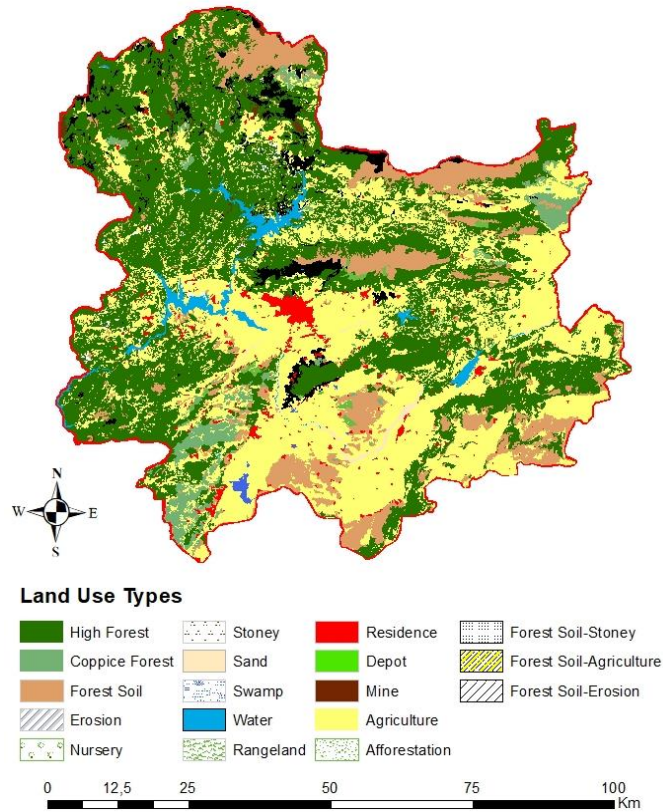
Figure 3. Land use type map

Table 3. Areal distribution of land use types

Land Use Types	Area (%)
High Forest	42.09
Agriculture	35.19
Forest Soil	11.52
Coppice Forest	3.04
Residence	1.89
Forest Soil-Stoney	1.88
Water	1.73
Forest Soil-Erosion	0.99
Sand	0.48
Afforestation	0.35
Stoney	0.35
Swamp	0.18
Forest Soil-Agriculture	0.17
Erosion	0.13
Rangeland	0.01
Depot	0.003
Nursery	0.002
Mine	0.001

3.2. Network Analysis

The areas that can be reached by the firefighting teams within a critical response time were determine by using New Service Area method. Because the study area consisted of the areas sensitive to the forest fires at the first degree, the buffer areas reached through the road network within 20 minutes were investigated. Firstly, accessible forest areas by the firefighting team were determined by considering the existing road network, and then the possible increase in the accessible forest areas was investigated for the forest roads with improved standards in the second scenario.

The results indicated that about 21% of the total study area could be reached by the firefighting team within the critical response time in the first scenario, while accessible areas increased up to 44% in the second scenario (Figure 4). It was found that the firefighting teams can reach about 17% of the forest areas in 20 minutes, considering the existing road network. On the other hand, about 36% of the forest areas could be reached by firefighting teams considering the forest roads with improved standards (Figure 5).

In a study conducted by Podolskaia et al. (2019), the transport network model was used to estimate traveling time and distance to a forest fire. A map of the ground fire protection zone was produced to evaluate the 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 a similar study conducted by Podolskaia et al. (2020), road data sources were evaluated for the regional forest fire management and it was suggested that the road datasets should be maintained and updated correctly. The results also indicated that within the accessible areas in critical response time, total forest roads subject to improvements were 3627.30 km in the study area (Figure 6). The added accessible forests in critical response time can be taken into account to estimate potential economic outcomes of improving road standards. The economic value of the accessible forests could be potentially saved from the forest fires by improving road standards can be estimated considering wood-based forest products. In this process, the costs of improving road standards should also be computed based on the cost of road improvement and their technical maintenance costs. Even though improving road standards might result in some additional costs at the road construction stage, maintenance and repair costs may considerably decrease in the long term (Akay et al., 2021).
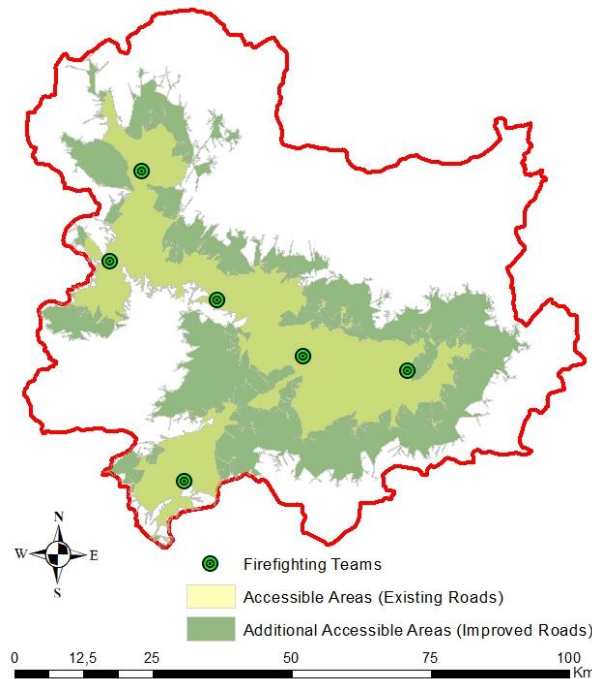

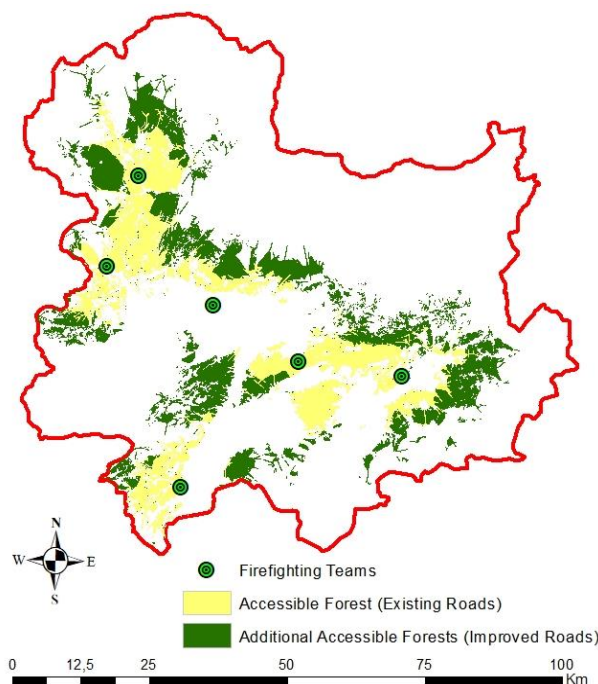Figure 4. Accessible areas in two scenarios

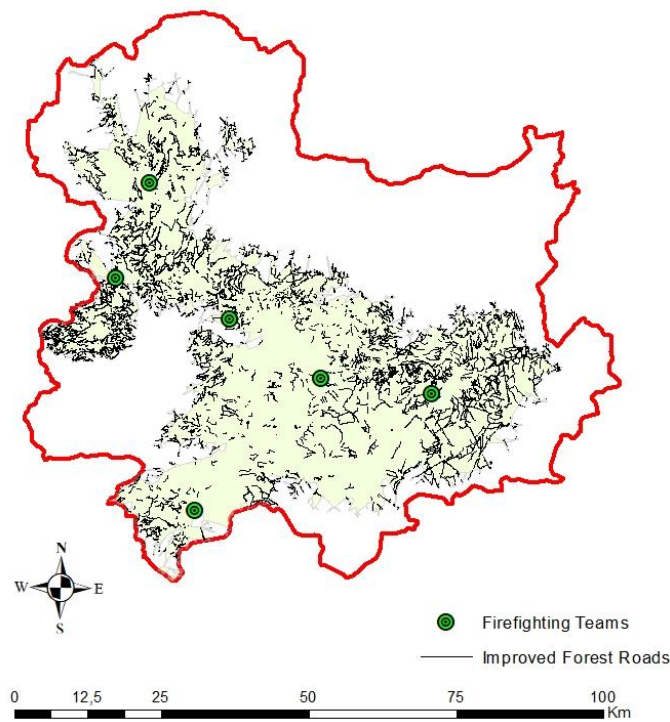Figure 5. Accessible forest areas in two scenarios

Figure 6. Forest roads need to be improved in the study area

Conclusions

Wildfires are inevitable events that seriously damage forests, negatively affect the sustainability of forest resources, and result in biological and ecological impacts on forest ecosystems. In order to minimize the biological and ecological impacts of forest fires on forest ecosystems, the important for firefighting team must reach fire scene as quickly as possible through on-ground transportation. Optimizing the locations of the firefighting team, building new roads, and increasing the design speed on current roads could increase firefighting response capabilities. In this study, GIS techniques were used to assist the forest fire managers to conduct effective firefighting activities by utilizing forest roads with improved standards.

The results of sample application conducted in Kahramanmaraş FED indicated that accessible forest areas by the ground-based firefighting teams in the case improved forest roads were more than two times of the accessible forest areas when considering existing road standards. Thus, increasing the design speed on current roads would minimize the arrival time of firefighting teams to the fire and increase the accessible forest areas in critical response time. It would also increase the capabilities of firefighting teams. In future studies, the economic outcomes of improving road standards should be estimated by computing the costs of improving road standards and the economic value of the forests that are potentially saved from the forest fires after improving road standards. Besides, the effects of optimizing the locations of the firefighting teams and constructing new roads on the arrival time of the firefighting teams to fire scenes should be evaluated especially in the fire-sensitive forest areas.

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