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Using GIS-based Network Analysis to Evaluate the Accessible Forest Areas Considering Forest Fires: The Case of Sarajevo*

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Abstract

The forest fire is one of the greatest environmental disasters in forest ecosystems. In order to effectively fight against forest fires, the ground team needs to access fire areas immediately and start firefighting within critical response time. Therefore, it is important to evaluate the forest areas where the ground team can reach in critical response time. In this study, the GIS-based network analysis method was used to evaluate the capabilities of the ground team to arrive at forest areas promptly, considering the forested areas in Canton Sarajevo in Bosnia and Herzegovina. In the solution process, the effectiveness of establishing new fire stations (20) was evaluated by comparing the results obtained in the case where only the former stations (12) were taken into account. The optimal route and associated response times of firefighting teams to potential fire areas were generated considering the previously occurred forest fires (58 fires) in the region. The results indicated that about 18% of the forested areas were accessible considering the former fire station while accessible forest areas increased up to 45% considering the new stations. When analyzing the previously occurred forest fires, it was found that 33 fires were reached in the critical response time considering former fire stations. On the other hand, the accessible forest fires increased up to 56 fires for the case of new fire stations in the region.

Keywords: Forest fires, GIS, Network Analysis, Fire stations, Fire teams

1. Introduction

Forest fires are one of the most important abiotic factors that damage the sustainability of forests. A significant number of human resources and budgets are allocated for the fight against forest fires. In addition to the forest damages, these fires can also cause loss of life and property in nearby settlements. Forest fires can be defined as fires that partially or entirely burn all flammable materials (trees, standing death trees, leaning logs, grass, leaves, dry trees and branches, etc.) in the forest ecosystem and tend to spread quickly due to the open environment (Eroglu, 2009). Starting a fire requires three elements, combustible material, oxygen, and temperature.

There are three types of forest fires; cover fire, canopy fire and ground fire. Cover fire and canopy fire are mostly encountered among the fire types (Çanakcıoğlu, 1993). The causes of forest fires are grouped as accident, negligence and carelessness, intention, lightning and unknown cause. The correct estimation of the factors affecting the fire ensures successful results in firefighting activities. The most important factors affecting fire are combustible materials, weather conditions and topographic conditions (Şakar, 2010).

Forest fires are common in Bosnia and Herzegovina in spite of the fact that this area is not of high risk in Europe. There are two critical periods of fires: spring (March-April) and summer (July-August), although forest fires occasionally may appear all over the year. Local people cause spring fires by burning weeds, and other plants remains when they clean their land next to forests. The reason for summer fires is mainly related to the visitors, and the damage rates are far higher than spring ones (Uščuplić, 2001).

The precautions before and after the fire must be determined in advance to perform the firefighting process safely. Planning the fight against forest fires, a comprehensive and complex process, is important in terms of the precautions to be taken in the early response to the fire. The main goal is the protection of forests. In order to prevent forest fires, communication between the forest service and the public, necessary training and determination of importance should be provided (Çanakçıoğlu, 1993). Fire response teams are groups of workers equipped with the necessary tools and materials to control and extinguish a fire. Fire response teams fighting against forest fires are divided into five groups: initial response team, ready force team, mobile team,

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fire-truck team and aerial team (helicopter, plane) (Akay and Kılıc, 2015).

The initial response team starts the first fight against forest fires. The locations of the initial response team depend on the degree of fire sensitivity, the number of access roads available in the forest, the availability of necessary sources such as water and electricity. In order to be able to respond effectively to forest fires, the time of transportation of the initial response team to the fire area by road should not exceed the critical response time. The critical response time varies depending on the fire sensitivity of the burned area (GDF, 2008). The fire sensitivity rate of a region is determined by the number of fires in that region, the ratio of the burned area to the area of the forest management unit and the fire constant (Mol, 1994). The concept of fire sensitivity has been developed in order to be able to rank forests for fire sensitivity and to show the status of forests with known sensitivity rate compared to other forest lands (Küçük and Ünal, 2005).

It is more effective and economical to quickly access and analyze the necessary information for the work to be done before, during and after the fire using GIS technology (Küçük and Bilgili, 2006). Akay et al. (2009) implemented a GIS-based decision support system using the network analysis method in order to determine the optimum route for the ground crew fighting forest fires to reach the fire areas as soon as possible. Akay et al. (2014) used the Network 2001 program to determine the optimum road route to reach the fire area promptly. In the study, a database consisting of various data layers was developed using the ArcGIS program. In order to provide access to areas that could not be reached during the critical response time, alternatives have been put forward such as improving the existing road networks, improving their technical standards, and increasing the average speed of transportation.

In this study, it is aimed to determine the forested areas that can be reached by the initial response team in Canton Sarajevo during the critical response time by using the GIS-based network analysis method. In the solution process, the effectiveness of the new initial response teams suggested in the study area was evaluated. Additionally, the optimal routes to potential fire areas were generated considering the previous forest fires between 2016 and 2022 in the region.

2. Material and methods

2.1. Study Area

The study area is located within the border of Canton Sarajevo in Bosnia and Herzegovina. The total area is about 127000 hectares in which 70254 ha is covered with forests and public enterprise "Sarajevo-forest" d.o.o. Sarajevo manages this area. The city of Sarajevo is located in a valley at an average altitude of 520-750 m, and it is surrounded by mountains Trebević 1629 m, Igman 1647 m, Bjelašnica 2067 m and Treskavica 2088 m. On 24% of the total analyzed area, a steep terrain slope was recorded, limiting factor for road construction and firefighting activities. An additional problem for access to forest areas is mined forest areas from the last war (Figure 1).

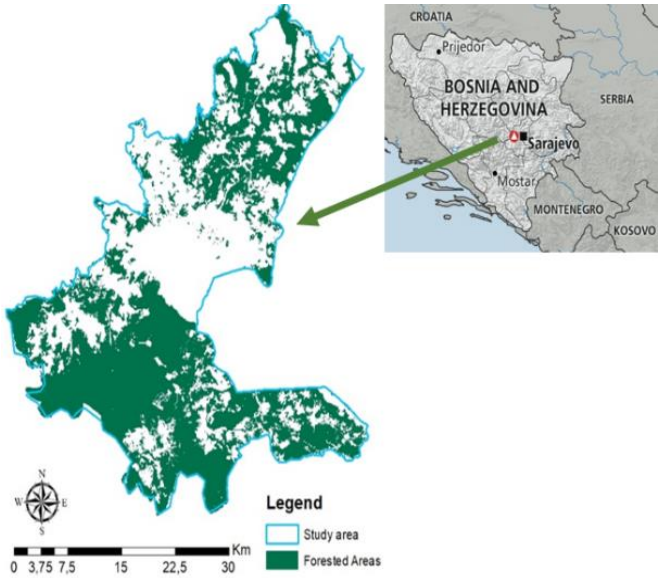

Figure 1. Study area

In Sarajevo, the summers are warm and mostly clear, and the winters are very cold, snowy, and partly cloudy. The average temperature typically varies from 10.9°C to 11.7°C. The hottest month is July, with an average temperature between 20 and 23,5°C but the maximum daily temperature goes up to 38,5°C. The area is affected by the mid-European continental climate from the North and the Mediterranean climate from the South. The main species are European beech, Silver fir, European spruce, Scots and Black pine, Oak, and European hornbeam. The forests in the study area are estimated as second degree sensitive to forest fire, meaning the critical response time is 30 minutes (GDF, 2008).

2.2. GIS Database

The GIS database was generated to perform the network analysis in the ArcGIS program. The road network, forest map, locations of the fire stations, and previous fires data were obtained from the Forest Management Department. The map of the road network is indicated in Figure 2. In the study area, there is a total of 20 fire stations where 8 of which were relatively new. The location of the fire stations and previous fires are shown in Figure 3.

2.3. Network Analysis

In order to conduct network analysis, first a network database needs to be generated in ArcCatalog module of ArcGIS. This database was based on the average travel time of fire truck on each road section in the road network layer. Travel time can be calculated depending on the length of the road and the average speed of the vehicle. The average vehicle speed varies according to the road types.

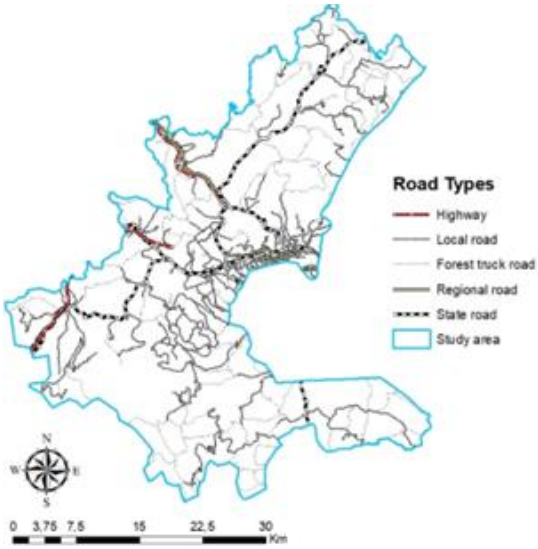

Figure 2. Road network map

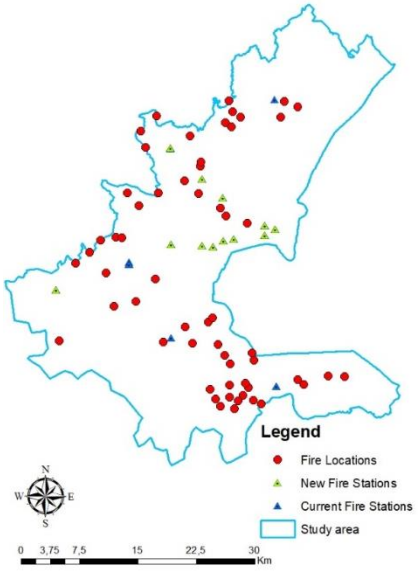

Figure 3. Fire stations and fire locations

The fields titled length (km), road type, vehicle speed (km/hour) and travel time (minutes) are generated for each road section in the "Attribute Table" of the road data layer. Path lengths were calculated using the "Calculate Geometry" tool in the Attribute Table. Road types are classified under five groups as highway, state road, regional road, local road, and forest truck road depending on the current information of the study area. Based on the information obtained from Highway Department and local authorities, Average fire truck speeds according to road types are given in Table 1.

Table 1. Average fire truck speed based on road types

Road Types	Average Speed (km/h)
Highway	80
State road	60
Regional road	60
Local road	50
Forest truck road	30

Finally, the transportation time for each section was calculated using the Field Calculator tool in the Attribute Table by using the following formula:

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

t_i : Total travel time for section i (minutes)
l_i : The length of section i (km)
v_i : The average vehicle speed for section i (km/h)
60 : Used to convert the transportation time from hours to minutes

After the Network Dataset was generated, the network analysis was carried out using the "ArcMap" module in ArcGIS program. In this analysis, the "New Service Area" and "New Closest Facility" methods, which are under the "Network Analyst" extension, were applied separately.

2.3.1. New Service Area

In order to increase the effectiveness of the fight against forest fires, it is important that the initial response team, an essential element in the firefighting organization, reach the fire area in the critical response time. For this purpose, the "New Service Area" has been applied for this study. In the "New Service Area" method, which is similar to the "Buffer Analysis" method as its working principle, a service point determined on the network system is determined as the starting point and the regions within a total link value (travel time) suggested by the user are determined on the network system. This study aimed to determine the forest areas that can be reached within the critical response time based on the location of the current initial response team with the New Service Area method. The critical response time varies depending on the fire sensitivity of the burned area. The New Service Area method was applied considering the critical response time of 30 minutes, since the study area was determined as 2nd degree fire sensitive areas.

2.3.2. New Closest Facility

The "New Closest Facility" method aimed to determine the optimum route between the potential fire areas in the study area and the initial response team. First, the routes where the existing initial response team can reach each fire area in the shortest time were determined. In this method, the positions of initial response teams and fire areas can be automatically uploaded to the system from the relevant data layers.

3. Results and Discussion

3.1. Accessible Forest Areas

Network analysis was carried out using two primary data layers generated in the ArcGIS. These data layers are the link data layer representing the road sections in the road network, considering the transportation times,

and the node data layer representing the intersections of these links (Figure 4). By adding the "New Service Area", the forest areas reached in the study area during the critical response time were determined by centered on the positions of the initial response teams. Firstly, forest areas that could be reached by 12 former initial response teams on the road network within 30 minutes were identified. Then, taking into account the new initial response teams, the forest areas where 20 initial response teams could be reached were determined (Figure 5). The results showed that former initial response teams reached 18% of total forest area during the critical response time.

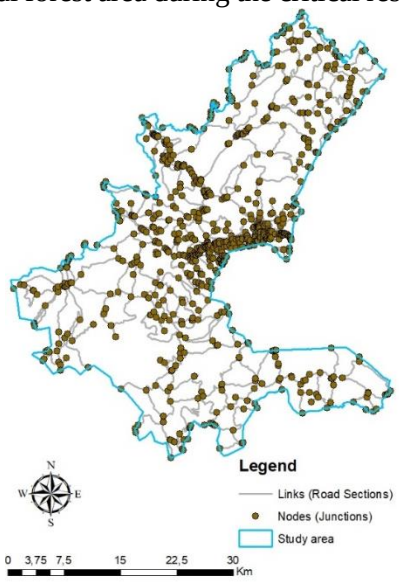

Figure 4. Link and node data layers in Network Dataset

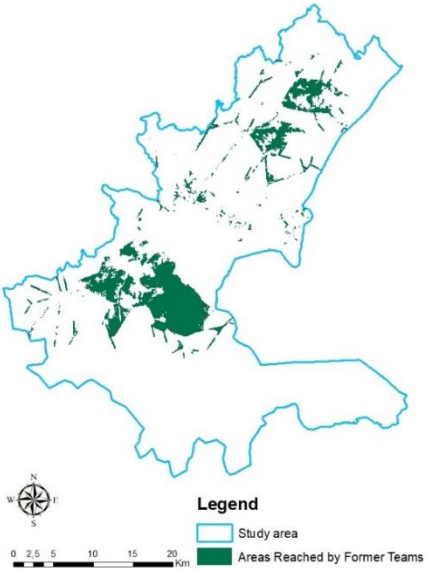

Figure 5. The forest areas reached by the previous initial response teams

When the new initial response teams were taken into account, the ratio of accessible forest areas increased to 45% (Figure 6). In a similar study where locations of the initial response teams were evaluated in the city of Tirana in Albania, Haska et al. (2021) reported that 27% of the forest areas in the study area was accessed within the critical response time considering the current the response teams while accessible areas increased up to 65% with the additional response teams.

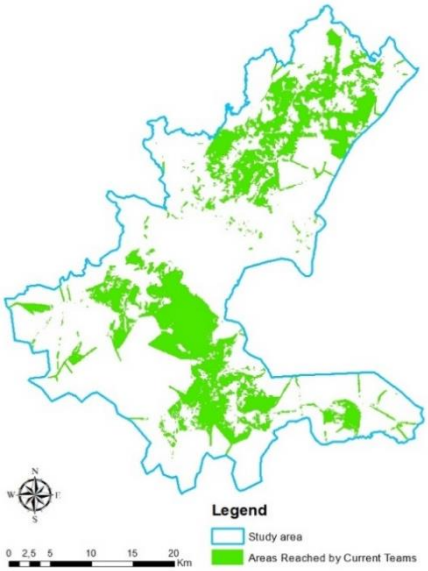

Figure 6. The forest areas reached by the current initial response teams

3.2. Accessible Fire Locations

After implementing the "New Closest Facility", it was found that 33 previous fire areas were reached in the critical response time (30 minutes) considering former initial response teams (12 teams) (Figure 7). It was found that initial response team located in the fire station number 8 could reach 12 forest fire areas within the shortest arrival time.

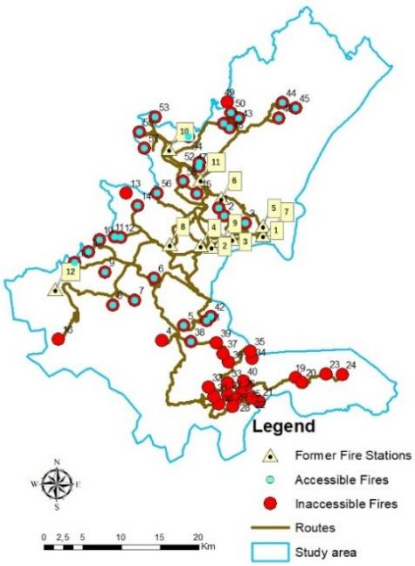

Figure 7. Accessible fire areas by the initial response teams in the former fire stations

From the second run of the analysis, where all of the current initial response teams (20 teams) were considered, accessible fire areas increased up to 56 fire among 58 previous fires (Figure 8). Therefore, including 8 new fire stations allowed initial response teams to reach almost all of the potential fires in the study area, except fire area number 13 and 49 (Table 2). When 8 additional new fire stations established in the study area, initial response team located in the fire station number 15 was able to reach 19 forest fire areas within the shortest arrival time.

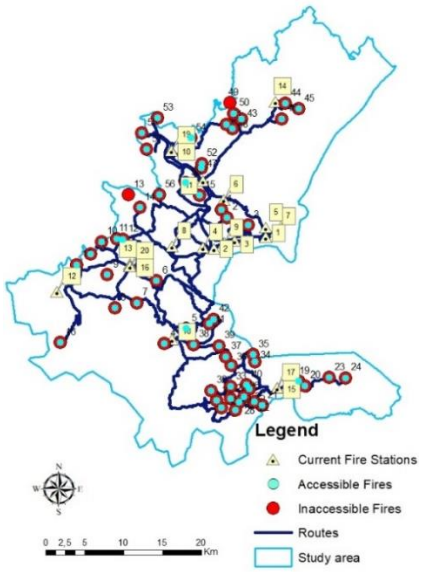

Figure 8. Accessible fire areas by the initial response teams in the current fire stations

It was also found that initial response team located in fire station number 8 provided the shortest arrival time to only two fire areas (14 and 56). The rest of the fire areas accessed by the teams from fire station number 8 were accessed by the teams from the other stations. A previous study conducted by Akay et al. (2012) indicated that increasing the number of teams in a specified area would increase the number of accessible potential forest fires within the critical response time. Besides, the firefighting teams need to be established in suitable locations in order to reach the fires as quickly as possible by using the shortest route.

Table 2. Arrival times of the initial response teams to the previous fire areas for two cases

I. Case (Former Fire Stations)			II. Case (Current Fire Stations)					
Fire Stations	Fire Areas	Time (min)	Fire Stations	Fire Areas	Time (min)	Fire Stations	Fire Areas	Time (min)
2	1	10.13	2	1	10.13	15	35	17.11
2	2	10.61	3	2	10.24	15	36	15.51
3	3	5.82	3	3	5.82	18	37	14.07
4	5	23.32	18	4	2.08	18	38	3.76
8	6	16.91	18	5	7.53	18	39	11.41
8	7	17.44	13	6	9.76	15	40	9.48
8	8	13.48	13	7	9.46	18	41	13.77
8	9	14.64	13	8	5.50	18	42	12.27
8	10	16.49	20	9	6.03	14	43	10.56
8	11	11.77	20	10	7.88	14	44	2.86
8	12	10.15	20	11	6.24	14	45	4.77
8	14	9.76	20	12	7.86	14	46	6.70
11	15	11.20	8	14	9.76	11	47	1.87
8	17	17.48	11	15	11.20	14	48	14.35
8	18	21.44	13	16	25.93	14	50	13.82
8	38	29.19	20	17	8.88	19	51	14.65
4	41	21.78	20	18	12.83	11	52	2.04
4	42	23.29	15	19	3.38	10	53	4.46
11	43	11.43	15	20	4.83	10	54	2.98
11	44	17.45	15	21	9.52	19	55	8.13
11	45	19.36	15	22	6.21	8	56	15.42
11	46	16.38	15	23	10.05	19	57	10.59
11	47	1.87	15	24	13.91	11	58	6.58
11	48	15.22	15	25	7.58			
11	50	14.68	15	26	9.04			
10	51	14.68	15	27	16.95			
11	52	2.04	15	28	10.38			
10	53	4.46	15	29	12.16			
10	54	2.98	15	30	18.77			
10	55	8.16	15	31	19.48			
8	56	15.42	15	32	17.36			
10	57	10.63	15	33	13.43			
11	58	6.58	15	34	17.11			

4. Conclusions

To minimize the ecological effects of forest fires on forest ecosystems, firefighters need to reach the fire areas by ground transportation in critical response time. In this paper, the GIS-based network analysis method was used to assist practitioners in conducting effective firefighting activities by assessing of accessible forest areas by the initial response teams. The study was implemented in Canton Sarajevo in Bosnia and Herzegovina where there are 12 former and 8 newly established fire stations. In the study, previous forest fires between 2016 and 2022 were evaluated in the assessment of initial response teams in the study area. It was found that approximately 18% of the forest areas were accessible considering the former fire station, while it was 45% considering the new stations. It was also found that 33 fire areas were reached in the critical response time, considering the former fire stations. On the other hand, almost the forest fire areas (56) were accessible in case of considering new fire stations. The results from the analysis indicated that establishing new stations for the teams can increase the capabilities initial response teams. Besides, building new roads can assist forest managers in fighting against forest fires. The computer-based approaches presented in previous studies where GIS applications, optimization techniques, and multi-criteria decision making methods were facilitated can be used in designing and planning of forest road networks in fire sensitive areas (Najafi and Richards, 2013; Tampekis et al., 2015; Laschi et al., 2016; Grigolato et al., 2017). Improving the technical standards of the existing forest roads will also help to expand the accessible forest areas within the critical response time, as the average speed of fire trucks would be higher in high standard roads.

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