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Determination of fire susceptible areas and location selection of fire stations by geographical analytical method

Sayed Payamuddin Danish [1], Mevlut Uyan *[2], Mehmet Ertaş [2]

[1]*Konya Technical University, Graduate Education Institute, Konya, Türkiye*
[2]*Konya Technical University, Vocational School of Technical Sciences, Konya, Türkiye*

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Abstract

Fire is one of the biggest disasters that can jeopardize people's life and property safety. In the event of a fire, any delay in firefighting response can result in serious injury or death. First responders need experience, good equipment, communication and teamwork for emergency response. Today, effective response for all emergency teams is achieved through good planning, risk management, comprehensive training and preparation. GIS technology is a powerful tool to improve all aspects of fire brigade systems. This study involves a series of spatial analyses of data for the construction of fire stations in Kabul, Afghanistan, and the relocation of existing fire stations from unsuitable locations to locations where they can respond to fires in a shorter time. The aim of the study is to identify fire-prone areas in Kabul, identify suitable locations for fire stations and create access routes from fire stations to fire trucks.

1. Introduction

Fire incidents cause huge losses of life and property every year all over the world. Failure to provide the necessary coordination between the relevant units at the time of fire, uncertainty of the areas opens to fire, uncertainty of the roads leading to the fire zone, lack of coordination maps and maps indicating which area the fire station belongs to, various difficulties such as traffic density prevent fire prevention and timely intervention.

Due to the presence of worn-out and old buildings in the cities, rapid population growth and irrational growth, the security system of the city also needs to be developed to cover the whole city. The civil war in Afghanistan over the last four decades has destroyed much of its socio-economic infrastructure, one of which is the firefighting stations in Kabul. The difficulties in this regard cause serious problems for the residents of Kabul. It is clear that the current situation directly affects the process of emergency access to fire zones and the performance of the fire brigade in Kabul. Kabul is one of the busiest cities of the country and traffic congestion in this city is known as one of the main difficulties in the performance and actions of the fire brigade and other relevant units to immediately reach the fire zones.

In recent years, rapidly developing information technologies are also used in fire management. With the development of Geographical Information Systems (GIS), better results are obtained in the production of analytical maps. GIS offers very effective analysis possibilities for many disciplines that study spatial phenomena (Uyan and Dursun, 2021). Many spatial decisions problems lead to GIS-based multi-criteria decision analysis (Ertunç and Uyan, 2022). By analyzing large-scale data, GIS can answer spatial questions that can be used in analytical data on urban fires. One of the important factors in fire services in metropolises is the shortening of the time to reach the fire zone. GIS provides a valuable tool to study the spatial structure of transport networks (Sert et al. 2017). This issue should be carefully considered for fire stations and a sufficient number of fire stations should be established to provide fair services to all local residents. By using network methods, spatial analysis and GIS network analysis, possible fire locations and the best location for the fire station and the shortest route to the fire area can be determined.

GIS is a powerful information management system with a unique ability to collect, analyses and visualize location-based information. As most firefighting tasks are spatially based, GIS has emerged as an important

* **Corresponding Author**

(payamdanish@gmail.com) ORCID ID 0000-0002-0988-0804
*(muyan@ktun.edu.tr) ORCID ID 0000-0002-3415-6893
(mertas@ktun.edu.tr) ORCID ID 0000-0002-9458-3395

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component of information platforms built to support firefighting services. In this study, by using network analysis and spatial analysis with the help of GIS, important data were determined for the effective determination of possible fire points, firefighting stations and the areas covered by these stations in Kabul/Afghanistan.

2. Method

2.1. Study area

Kabul Province, located in the central part of Afghanistan, is surrounded by the provinces of Laghman in the east, Kapisa in the northeast, Logar in the south, Parwan in the northwest and Maidan Wardak in the southwest. Geographically, it lies between 34° 8′ 60″ and 34° 54′ 36″ north latitude and 68° 49′ 48″ and 69° 57′ 0″ east longitude. Administratively, Kabul is not only a province, but also a capital city and has 15 districts.

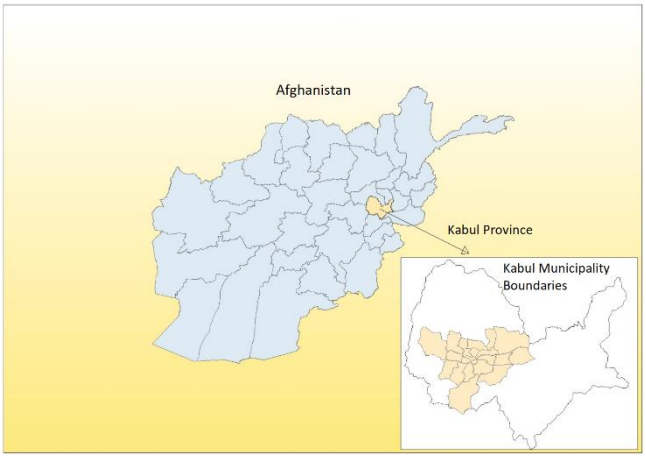


Figure 1. Afghanistan and Kabul city map

2.2. Methodology

The main objective of this study is to propose a model that supports the decision. Decision makers decide on the most suitable locations for fire stations. In this context, the following steps are followed:

- Problem/objective definition (site selection for fire stations)
- Considering the main technical tools to analyses the service area and the optimal route of the fire stations.
- Data collection, preparation and transfer to GIS software.
- Preparation of network analysis maps of roads to reach the fire scene by the shortest route.
- Preparation of density map for traffic congestion in Kabul.
- Proposing a site for new fire stations in Kabul.

In this research, two analytical methods were used to solve the above-mentioned problems.

1. Spatial Analysis
2. Density analysis
3. Network Analysis

3. Results

3.1. Density analysis

We converted our vector data into raster data to better visualize the region and the density of roads in Kabul. In Figure 2, we can better see the areas where traffic density is high and fire trucks cannot easily reach these areas. It is understood that the fire brigade should pay more attention to these areas in order to reach the fire scene immediately or at least normally in case of an accident. Some work has been done to cover these areas in the proposed part of the fire stations and the previous stations have been relocated to suitable places.

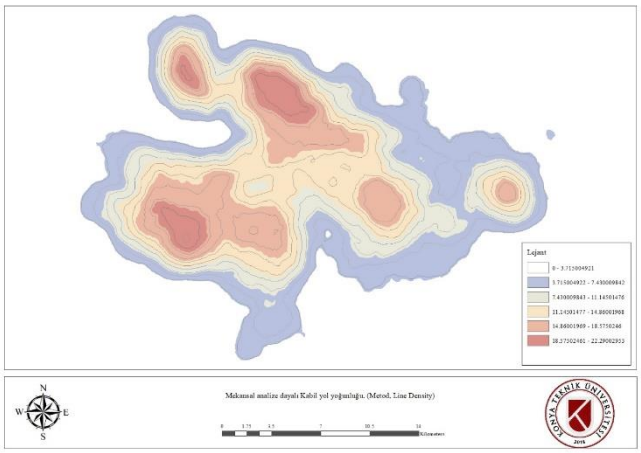


Figure 2. Road density map in Kabul

3.2. Network Analysis

Two methods were used in this research.

3.2.1. Closest facility

Finding the nearest fire station, the nearest police car to the scene, and the nearest shop to a customer's address are examples of nearest facility problems. Once you have found the nearest facilities, you can determine how many to find and whether to move towards or away from them. Once you have found the nearest facilities, you can show the best route to them, for example, you can pinpoint the nearest fire station for the scene. Or we can get help from two or more fire stations at the same time, which is the method used in this study. In the study, the closest and most suitable route from two fire stations to 25 possible fire points was determined.

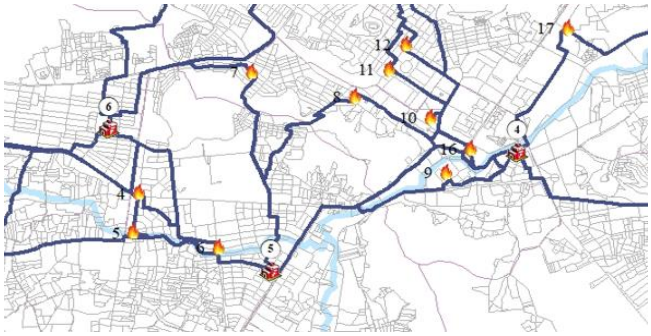


Figure 3. The closest and most convenient routes from the two existing fire stations to 25 possible fire points

3.2.2. Service areas

With this network analysis method, we can find service areas anywhere on the network. The network service area is the area covering all accessible streets, i.e. streets with a certain impedance. For example, the five-kilometer service area of a fire station includes all streets that can be reached within five kilometers of the fire station. Accessibility refers to the ease of travelling to a site. In Network Analyst, accessibility can be measured in terms of travel time, distance or any other impedance on the network. Accessibility assessments help answer basic questions such as which road is blocked by a fire truck or which house is covered by a station.

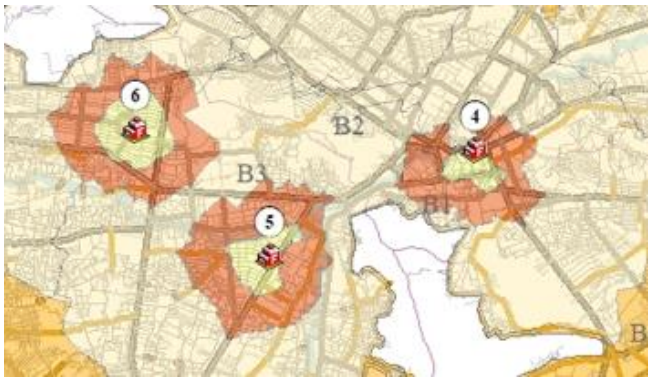


Figure 4. 5 km radius of some existing stations

There are currently six field fire stations in Kabul, but the area covered by each station is not known in advance. In case of fire, the Central Fire Brigade, after receiving information from the fire area, decides which field station to send to the fire area. For studies that consider existing stations, the definition of demand usually starts with an assessment of the effective response area for each of these stations using time or distance limits (Isa et al. 2016). It is clear that the six existing stations cannot cover all 22 districts of Kabul. With the possible locations of fires and fire stations in Kabul identified, the basic analysis of these points using the spatial and network analysis method will be described.

1. Two analyses were performed, one to find the closest facility to the incident and the other to find the shortest route to the incident.

2. For the first analysis, the location of the incident is as important as its location.

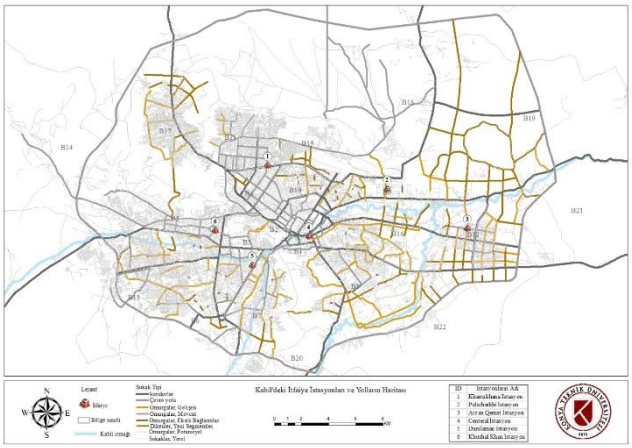


Figure 5. Location of six existing fire stations in Kabul

50 roads with a length of 257.34 kilometers were created with Closest facility for 6 stations. This is too long in terms of firefighting; therefore 5 new fire stations are proposed to cover the entire city of Kabul in a timely manner (Figure 5).

In Figure 6, 5 new stations are proposed in addition to the previous stations. These stations have been determined to reach the farthest points of Kabul city. In Figure 6, as in Figure 5, 50 routes are created from each station to the scene of the incident.

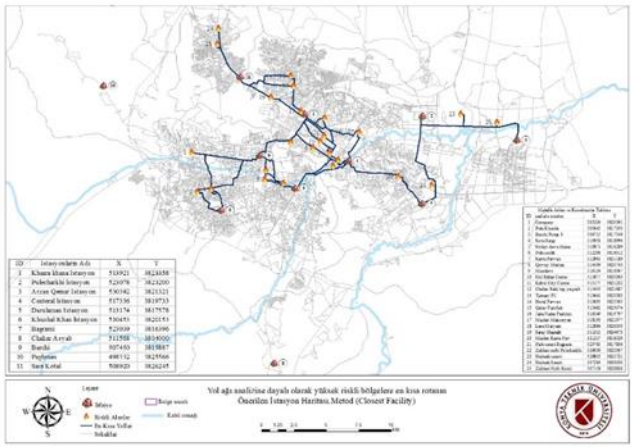


Figure 6. Location of six existing and 5 proposed fire stations in Kabul

50 roads with a length of 204.77 kilometers were created for 11 fire stations. The establishment of 5 new fire stations in Kabul reduced the total length of roads from 257 km to 204 km.

Service Area - for 6 stations

Route analysis can be used to find the optimal route between two locations, while service areas analysis can create a multigene around a point of interest covering all accessible locations and streets within a given km or driving time (Chen 2017). In this section, we tried to determine the areas covered by each existing fire station. The areas covered by each fire station were calculated for 1000 meters, 2000 meters, 5000 meters, 7500 meters.

Figure 7 shows that the coverage range of each station is between 1 km and 7.5 km. The existing areas covered by the six stations were calculated as 538.15 km^2 and subtracted from the total area of the municipal boundary, which is 1030.5 km^2. It is calculated that the existing stations cover 52.24% of the total area. 47.76% of Kabul city up to 7.5 km is not covered by firefighting.

Service Area - for 11 stations

Five new stations have been proposed for increased fire coverage in Kabul, two of which are located in District 20 and one in the most remote district, District 14. The coverage length of these stations is the same as the previous stations. All roads around the 11 stations are marked at distances of 1 km, 2 km, 5 km and 7.5 km.

The existing areas covered by the eleven stations were calculated as 815.49 km^2 and subtracted from the total area of the municipal boundary of 1030.5 km^2. It

was calculated that the existing and proposed stations cover 79.13% of the total area. 20.87% of Kabul city up to 7.5 km is not covered by firefighting. The majority of these areas are areas without an existing road network.

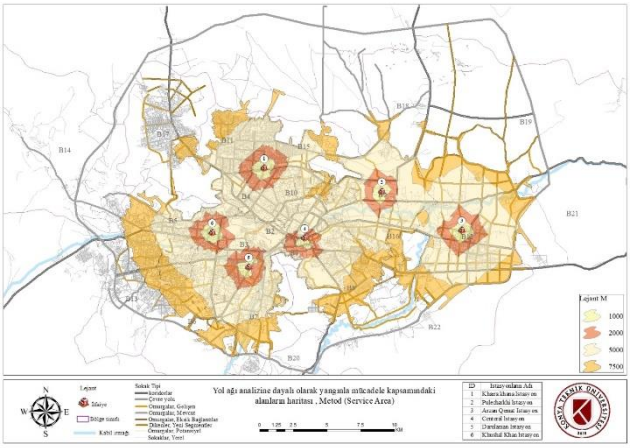
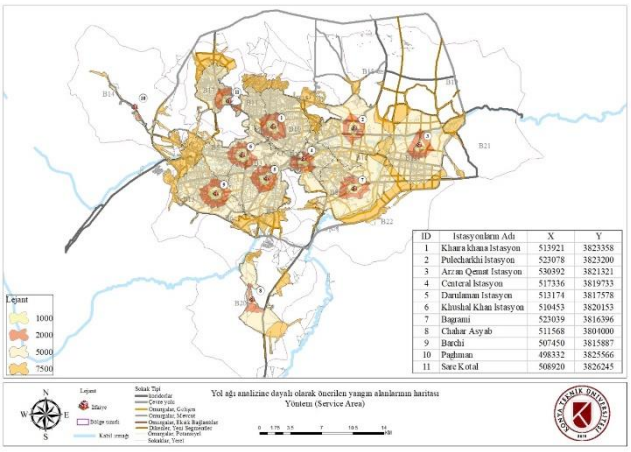


Figure 7. The areas covered by all roads around the six existing stations at distances of 1 km, 2 km, 5 km and 7.5 km



ID	İstasyonların Adı	X	Y
1	Khana khana İstasyon	513921	3823358
2	Pulecharkhi İstasyon	523078	3823200
3	Arzan Qemat İstasyon	530392	3821321
4	Cenferal İstasyon	517336	3819733
5	Darulaman İstasyon	513174	3817578
6	Khushal Khan İstasyon	510453	3820153
7	Bagrami	523039	3816396
8	Chahar Asyab	511568	3801000
9	Barchi	507450	3815887
10	Paghman	498332	3825566
11	Sare Kotal	508920	3826245

Figure 8. The areas covered by all roads around the existing and proposed 11 stations at distances of 1 km, 2 km, 5 km and 7.5 km

4. Conclusion

In this research, spatial analysis was used to determine important data for the effective determination of possible fire points, fire extinguishing stations and the areas covered by these stations.

In this study, it can be ensured that all people living in cities and neighbourhoods can benefit from fire brigade services in a fair manner in case of an accident. The spatial analysis tools provided by GIS provide the most reliable analyses for such studies. The results show that a GIS-based system can be effectively used to assist firefighters in managing fires and locating potential firefighters in a short time and assessing the location of existing firefighters.

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