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Investigation of Waste Fires and Spatial Accessibility of Fire Stations in Izmir, Turkey

Atık Yangınlarının ve İtfaiye İstasyonlarının Mekânsal Erişilebilirliğinin İncelenmesi, İzmir, Türkiye

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ÖZ

Doğal nedenler veya insan faaliyetleri sonucu meydana gelen yangınlara zamanında müdahale edilmemesi büyük felaketlere neden olmaktadır. Yangın olaylarına hızlı müdahale, can ve mal kaybını önemli ölçüde azaltabileceğinden, itfaiye servisleri etkili bir şekilde yönetilmelidir. Coğrafi Bilgi Sistemleri (CBS), mekânsal analiz kabiliyeti sayesinde itfaiye servislerinin yangın yönetim politikalarının belirlemesinde oldukça etkilidir. Bu çalışmada yangınların büyük çoğunluğunu oluşturan atık yangınlarına odaklanılmıştır. 2018-2021 yılları arasında İzmir'de meydana gelen yangınlar, CBS kullanılarak analiz edilmiştir. İlk olarak yangın olayları zamansal ve mekânsal olarak incelenmiştir. Tüm yangınlar ve çöp yangınları ayrı ayrı analiz edilerek yangın yoğunluğu haritaları Inverse Distance Weighted (IDW) metoduyla oluşturulmuştur. İtfaiye istasyonlarının mahallere mekânsal erişilebilirlikleri konum tahsis analizi ile belirlenmiştir. Sonuç olarak yangın vakalarının yoğun olduğu ilçeler ve zaman aralıkları belirlenmiştir. Ayrıca, çalışma alanındaki tüm mahallelerin hizmet alabilmesi için gerekli minimum sürenin 62 dakika olduğu tespit edilmiştir. İtfaiye istasyonlarının mahallere erişilebilirliği 5, 10, 15, 20, 25, 30, ve 62 dakikalık zaman aralıkları için analiz edilmiştir. Sonuçlar, her bir yangın istasyonunun, hizmet verebileceği nüfus miktarına bağlı performansının değerlendirilmesinde kullanılmıştır.

Anahtar Kelimeler: *Acil müdahale, CBS, Ağ analizi, Yangın yönetimi, Atık yönetimi*

ABSTRACT

Failure to respond in time to fires causes great disasters. Since the loss of life and property can be significantly reduced with rapid response to fire incidents, fire services should be managed properly. Geographic Information System (GIS) is very effective in determining fire management policies of fire services thanks to its spatial analysis capability. This study focused on waste fires, which constitute the majority of fires. The fires that occurred in Izmir between 2018 and 2021 were analyzed using GIS. First, spatiotemporal analysis of fire incidents was investigated. Fire density maps were created with the Inverse Distance Weighted (IDW) interpolation method by analyzing all fires and waste fires separately. The spatial accessibility of fire stations to neighborhoods was determined by location-allocation analysis. The minimum time required for all neighborhoods to receive service in the study area has been determined as 62 minutes. The accessibility of fire stations to neighborhoods was analyzed for time intervals of 5, 10, 15, 20, 25, 30, and 62 minutes. The results were used to evaluate performance of each fire station based on the amount of population they served.

Keywords: *Emergency response, GIS, Network analysis, Fire management, Waste management*

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1. INTRODUCTION:

Fires are natural disasters that cause climate change, harm human life and nature. It is necessary to analyze the fire sources well in order to prevent the damages caused by the fire. The sources of fires are based on different causes. One of these reasons is man-made fires, which are deliberate (Baltacı & Yıldırım, 2020; Esen & Avci, 2018; Özenen Kavlak et al., 2020). The majority of the fires that occurred in Izmir between 2018 and 2021 was human-induced waste fires (Figure 1). It is reported by Izmir Fire Department that waste fires generally occur in waste containers, agricultural lands, dumpsites (unregulated landfills), and industrial sites. It is important to intervene in fires early, to minimize the damage caused by the fire (Kaplan & Kuru, 2019).

Firefighters can play an active role in responding to fires when they reach the fire in a short time. Therefore, the accessibility to fires can be determined by spatial analysis methods (Wang et al., 2021). GIS-based network analysis often utilized in emergency management (Gunes & Kovel, 2000), waste management (Yalcinkaya, 2020; Yalcinkaya & Uzer, 2021; Yalçınkaya, 2020) and urban planning (Gönüllü Sütçüoğlu & Yalcinkaya, 2021; Kalayci Onac et al., 2020, 2021). The response time of the fire stations to emergency scenes is optimized by analyzing spatial data with the help of geographic information system technology (ESRI, 2012). GIS plays a major role in establishing a system that formulates the accessibility of fire stations to fire incidents (Kaplan & Kuru, 2019). Responding to incidents in the fastest way and determining the shortest route, to carry out analyzes such as the determination of service areas of emergency response vehicles is possible with the network analysis method (Geçen, 2019).

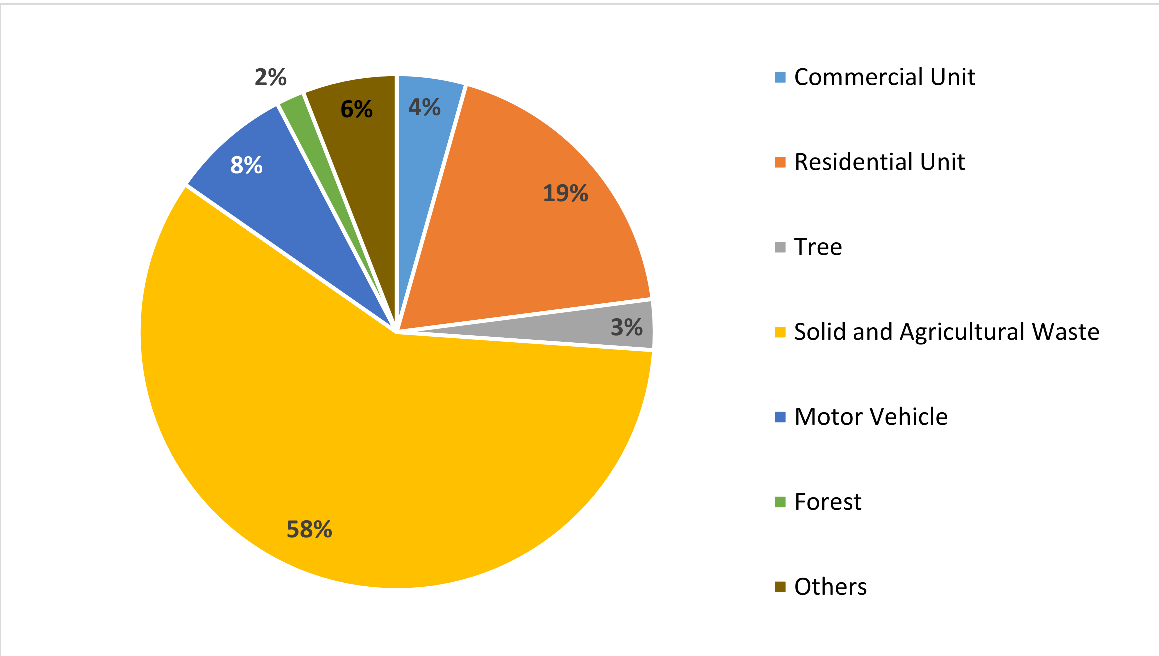

Figure 1. Types of fire incidents between 2018 and 2021 in Izmir (Izmir Fire Department, 2022).

Many works of literature have discussed the spatial accessibility of emergency response vehicles using the GIS network analysis method (Erkal & Değerliyurt, 2013; Nicoara & Haidu, 2014; Park et al., 2016; Sarı, 2017; Yin et al., 2021). Kaplan & Kuru (Kaplan & Kuru, 2019) spatially analyzed the fire data using the network analysis method. The areas served by the fire stations were determined by creating a database based on GIS, which facilitates the fire response process, and specifies the need for the fire station. In the study by Geçen (2019), the spatial accessibility of fire trucks to the scene in an emergency was investigated by using the network analysis method. The access times of the vehicles to the scene were determined. The places that cannot benefit from the fire service area have been identified, then the solutions have been presented. Kuku & Türk (2021) worked on the determination of the neighborhood where the fire station can serve within the 5-minute response time for the province of Trabzon. Also, the number of fire stations needed and suitable locations for the new stations were determined. Different analysis techniques were performed in modeling emergency response situations, besides network analysis. Singh et al. (2021) used the Euclidean Distance method together with the network analysis to evaluate the fire service areas and fill the service area gap. Sarı (2017) developed a GIS-based model which provides the shortest response time by assigning costs to streets based on obstacles they have such as speed bumps, traffic lights, parking status of the streets, railroad crossings and crossroads. Silalahi et al. (2020) created the Standard Deviational Ellipse model to analyze the distribution of spatial data alongside service area analysis. Akay & Şahin (2019) used the Analytic Hierarchy Process (AHP) as well as network analysis to find fire-sensitive areas. Wang et al. (2021) performed fire station optimization with a location-allocation model using points of interest data and multi-time traffic situation data. Modinpuroju & Prasad (2016) used location-allocation and service area analysis for rural road accessibility. Making spatial decisions and generating alternative models are effective in improving the existing firefighting systems by performing location-allocation and accessibility analyses (El Karim & Awawdeh, 2020).

This study aims to analyze waste fire incidents and the spatial accessibility of fire stations in Izmir. Waste fires constitute the majority of the fires occurred in Izmir between 2018 and 2021 (Izmir Fire Department, 2022). In this context, waste fires were evaluated spatiotemporally with the help of GIS. Fire density maps were created to intervene early during a fire incident and to minimize the post-fire damages. The spatial accessibility of the neighborhoods served by the fire stations was examined. The performances of fire stations were evaluated by taking into account the population served by each fire station.

2. MATERIALS AND METHODS:

The methodology includes the following steps: (1) collecting data and generating geodatabase, which includes spatial and non-spatial data; (2) generating fire density maps by examining fire incidents; (3) determining spatial accessibility of fire stations using location-allocation analysis. Figure 2 describes the stepwise methodology of the study.

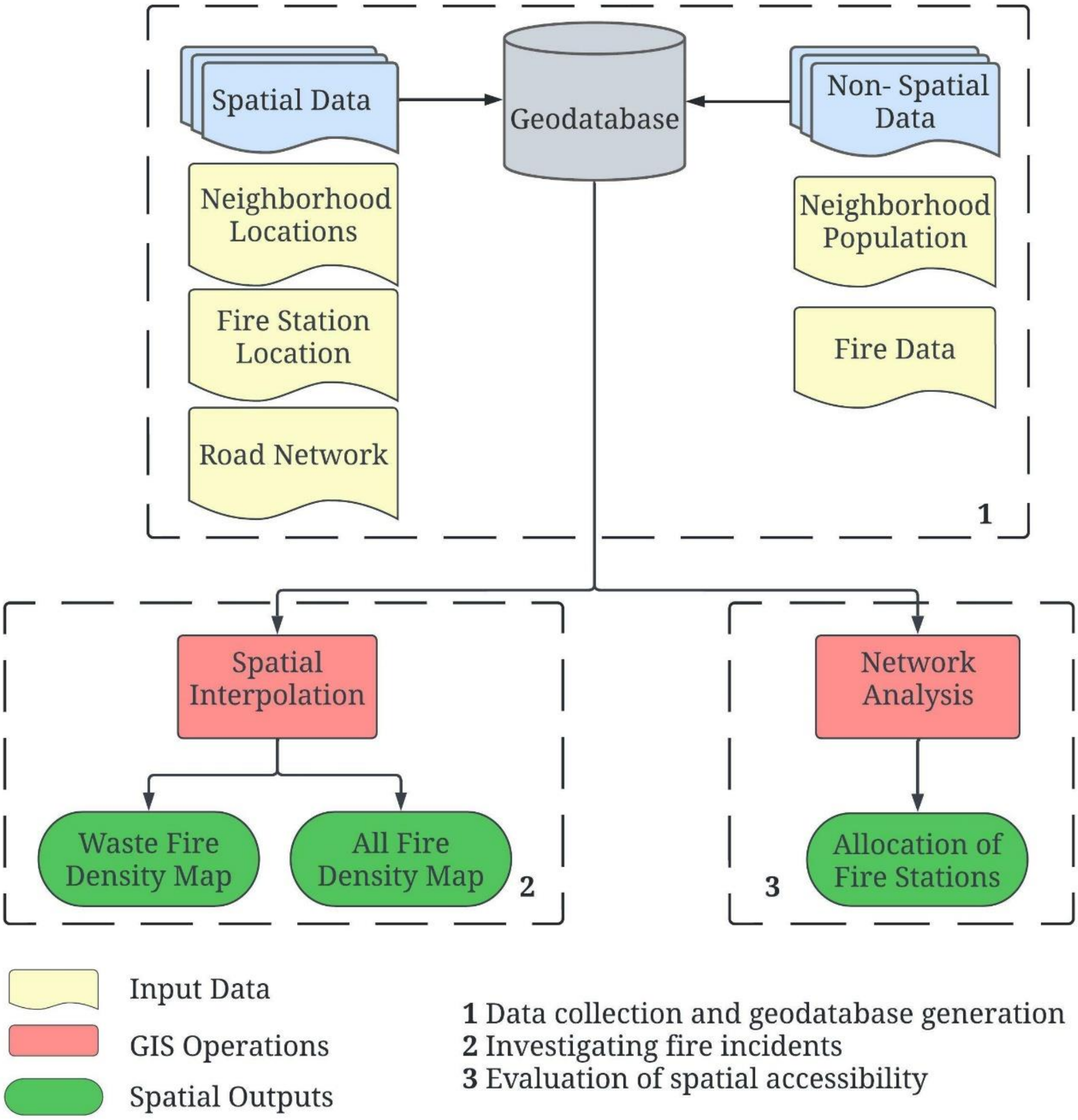

Figure 2. Stepwise methodology.

2.1. Study Area

The mainland Izmir (excluding the islands) was determined as the study area. The territory of the province lies between 37° 45' - 39° 15' north latitudes and 26° 15' - 28° 20' east longitudes. Izmir is located West of Turkey on the Aegean Sea. The length of the province in the north-south direction is approximately 200 km, its width in the east-west direction is approximately 180 km and its surface area is 12,012 km^2 (Izmir Governorship, 2022). It has a population of 4,279,647 in 30 districts and 1,295 neighborhoods, which makes it the third most populous city in Turkey after Istanbul and Ankara. Izmir Bay and its vicinity are the most densely populated areas. Izmir Fire Department, affiliated with Izmir Metropolitan Municipality, provides service to the city with a total of 61 locations: 56 stations, 4 stop points for forest fires and 1 sea search and rescue station (Izmir Fire Department, 2022). Figure 3 shows the study area, neighborhoods, and fire stations (with their ID numbers).

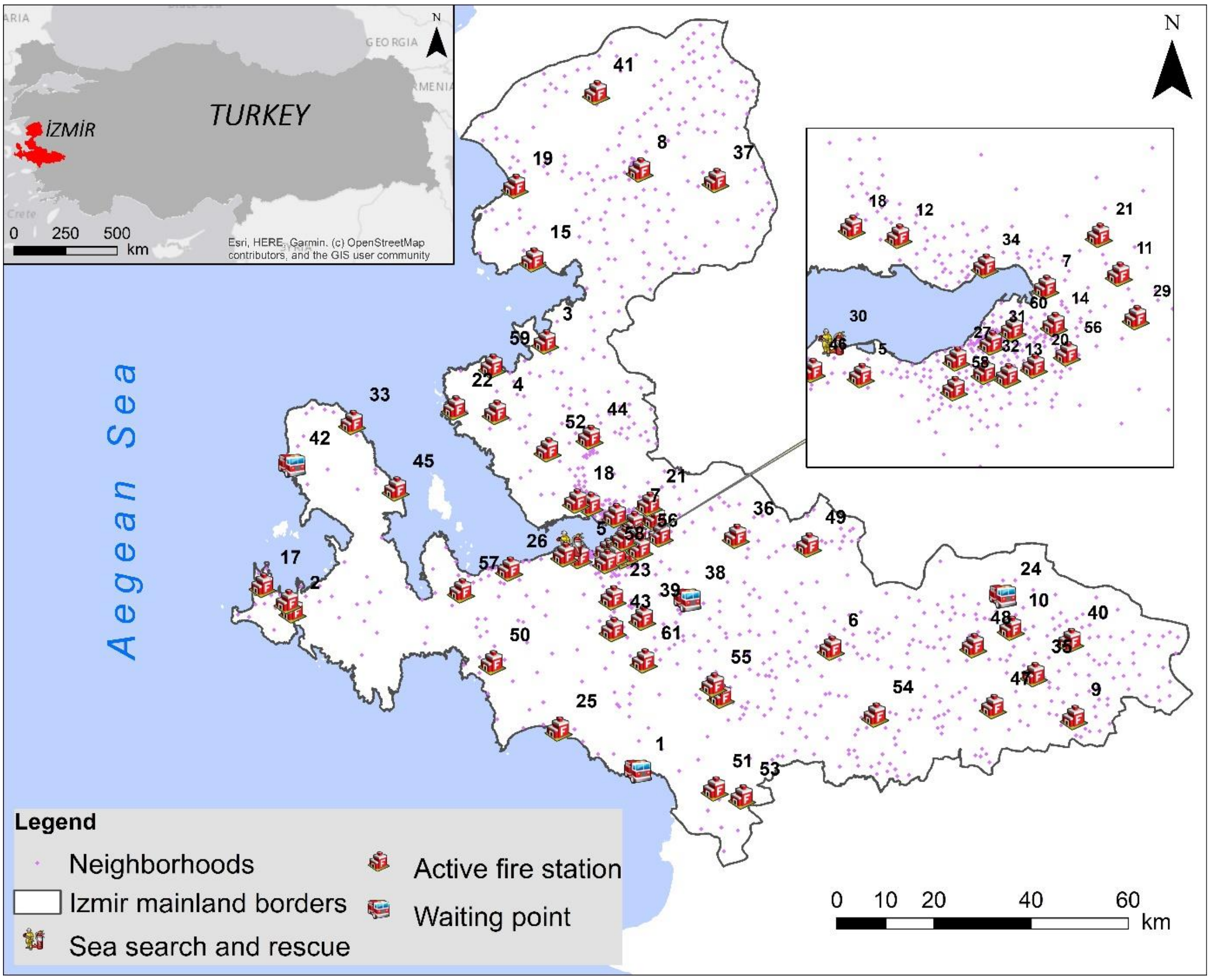

Figure 3. Study area.

2.2. Data Collection and Geodatabase Generation

The first step of the methodology is the collection of necessary data and the creation of an appropriate geodatabase. For this purpose, all spatial data were converted to WGS 1984 UTM (Universal Traverse Mercator) Zone 35 projected coordinate system, and a geodatabase was created in ArcGIS software. First of all, road classes that are not suitable for fire truck travel (path, bicycle road, etc.) are filtered in the Open Street Map (OSM) road data (OpenStreetMap, 2022). The road network dataset was created by arranging the speed limits for each road class according to the legal speed limits (General Directorate of Highways, 2022) that the vehicles must comply in Turkey. Neighborhood locations were generated using the Turkish Ministry of Interior's list of neighborhood names (Ministry of Interior, 2022), and then the current neighborhood populations (Turkish Statistical Institute, 2021) were added as an attribute. Fire station locations were generated using station addresses obtained from Izmir Fire Department (Izmir Fire Department, 2022). The station locations were confirmed with the help of Google Maps and Google Street View, and those that were inconsistent with the actual location were corrected. Fire response numbers between January 2018 and December 2021 were obtained from Izmir Metropolitan Municipality (Izmir Fire Department, 2022). This data includes the information on fire response numbers according to the fire type for each neighborhood in a monthly period.

2.3. Investigating Waste Fire Incidents

A total of 24,013 waste fires were responded by the Izmir Fire Department in 1,112 neighborhoods in Izmir between 2018 and 2021. Statistical analyses of fire incidents were carried out temporally and spatially, and the total number of waste fires in each neighborhood in a 4-year period was calculated. It is possible to visualize fire incidents spatially with the help of GIS. For this purpose, the total number of waste fires in each neighborhood was added to the neighborhood locations data in ArcMap. At this stage, fire incidents that have uncertain neighborhood or district information were ignored. Then, a total of 23,774 fire cases in 1.,086 neighborhoods were added to the geodatabase. Inverse Distance Weighted (IDW) is a deterministic interpolation method that produces cell values from known sample points. IDW is faster to apply than geostatistical imterpolation methods such as Kriging due to its deterministic approach. When interpolating a surface of fire incident for a fire station analysis IDW is a suitable interpolation method since the surface is a locationally dependent variable. IDW method splits the study area into cells and performs calculations for each cell. The weight of the sample point is inversely proportional to its distance from the cell in the process (Yalcinkaya & Kirtiloglu, 2021). Fire densities were estimated using IDW as illustrated in Equation 1. The variable Z_j estimates the value at j; Zi represents the value of a sampled location; i indexes sampled locations; d indicates distance. The n is the weight parameter applied as an exponent to the distance. Therefore, a large n results like a Thiessen interpolation in which nearby points yielding a much greater influence on the unsampled location than a point further away. On the other hand, a very small value of n will result in equal weight for all points within the search radius (Gimond, 2022). In the study, fire density maps with 10-meter cell sizes were created from fire incidents points, by surface IDW interpolation.

$$Z_j = \frac{\sum_i \frac{Z_i}{d_{ij}^n}}{\sum_i \frac{1}{d_{ij}^n}} \qquad \text{Equation 1}$$

2.4. Measuring Spatial Accessibility

The investigation of the spatial accessibility of the fire stations in the study area was carried out with the location-allocation application in ArcGIS. Location-allocation (LA) has two main components: Facilities and demand points. LA aims to determine the most suitable facility or facilities to serve the demand points (Höke & Yalcinkaya, 2021; Yalcinkaya et al., 2021, Yalcinkaya & Ruhbas, 2022). There are various problem types (minimize impedance, maximize coverage, target market share, etc.) in LA that find solutions to different questions. In the maximize coverage problem type, it is aimed that the facilities will serve the maximum demand point within the determined impedance cutoff. Maximize coverage problem type is frequently preferred in studies on emergency services (ESRI, 2022). 60 fire stations (excluding the sea search and rescue station) and 1294 neighborhoods were introduced as facilities and demand points in the LA model, respectively. Since the time from the station to the neighborhoods will be the focus, the time (minute) was determined as the impedance. Each neighborhood was allocated to the closest station by performing the maximize coverage problem type at different impedance cutoff values (5, 10, 15, 20, 25, 30, and 62 minutes).

3. RESULTS AND DISCUSSION:

3.1. Waste Fire Incidents

In the 4 years between 2018 and 2021, a total of 42,602 fire incidents were seen in Izmir. 24,572 of these incidents were waste fires. The distribution of fire incidents by year is seen in Figure 4. The number of fire incidents was similar in 2019, 2020, and 2021. Waste fires and all fires occurred less frequently in 2018. The ratio of waste fire incidents to all fire incidents between 2018 and 2021 is as follows, respectively (%): 59.8, 59.9, 58.8, 53.2.

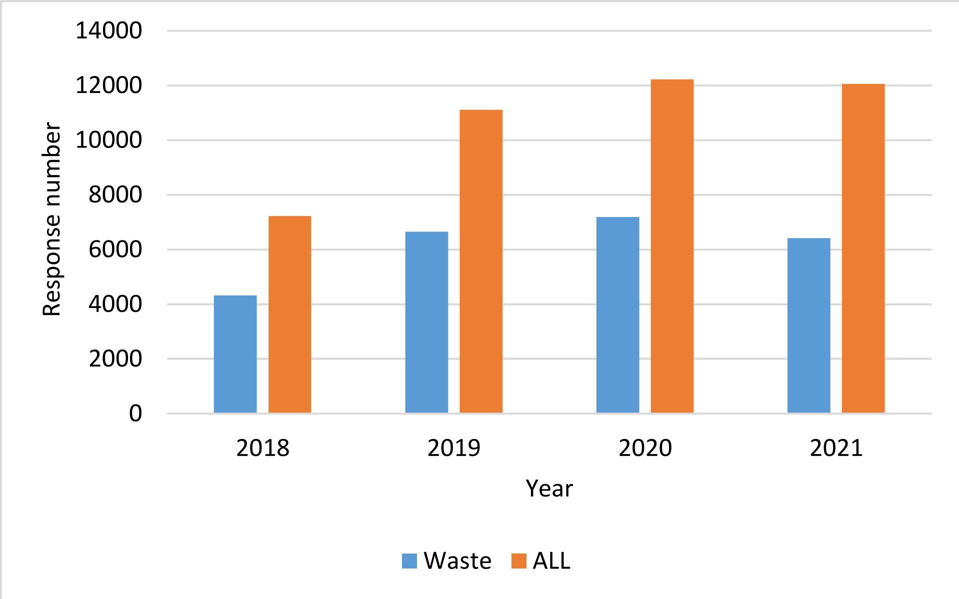

Figure 4. Number of fires by year.

When the waste fire incidents are analyzed temporally, the lowest number of fire incidents was observed in January 2018, and the highest number of fire cases was observed in July 2021 (Figure 5). As in all fires, while waste fires are mostly seen in the summer months, a decrease is observed in the number of waste fire incidents in the winter months. Considering the geographical location of the study area, the high average temperature in the summer months and increased human activity can be seen as the reason for the increase in waste fire incidents.

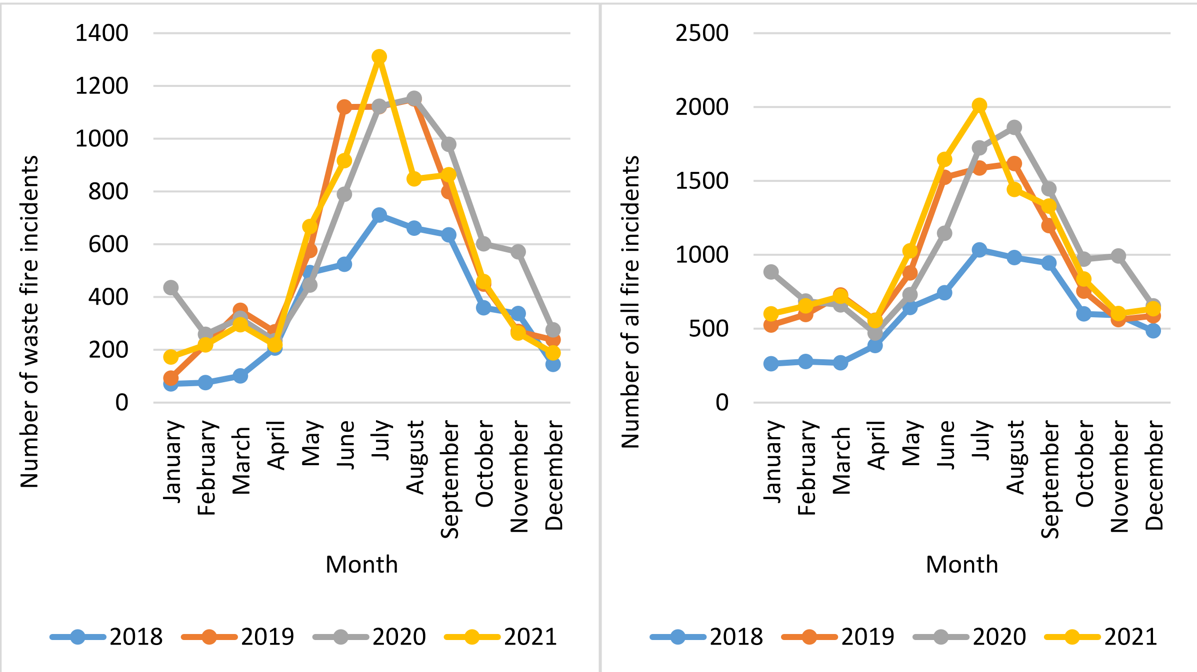

Figure 5. Number of waste fire and all fire incidents by month between 2018 and 2021.

The total number of fire incidents that occurred in 30 districts of Izmir between 2018 and 2021 is presented in Figure 6. Considering all fire incidents, the districts with the highest number of incidents were Bornova, Buca, and Menemen, respectively. The districts with the lowest number of incidents were Beydağ, Karaburun, and Güzelbahçe. While the districts with the highest number of waste fire incidents were Bornova, Menemen, and Buca, respectively, the districts with the lowest number of incidents were Beydağ, Karaburun, and Güzelbahçe. In addition, the neighborhood with the highest number of both all fire and waste fire incidents is the Seyhan neighborhood in the Buca district.

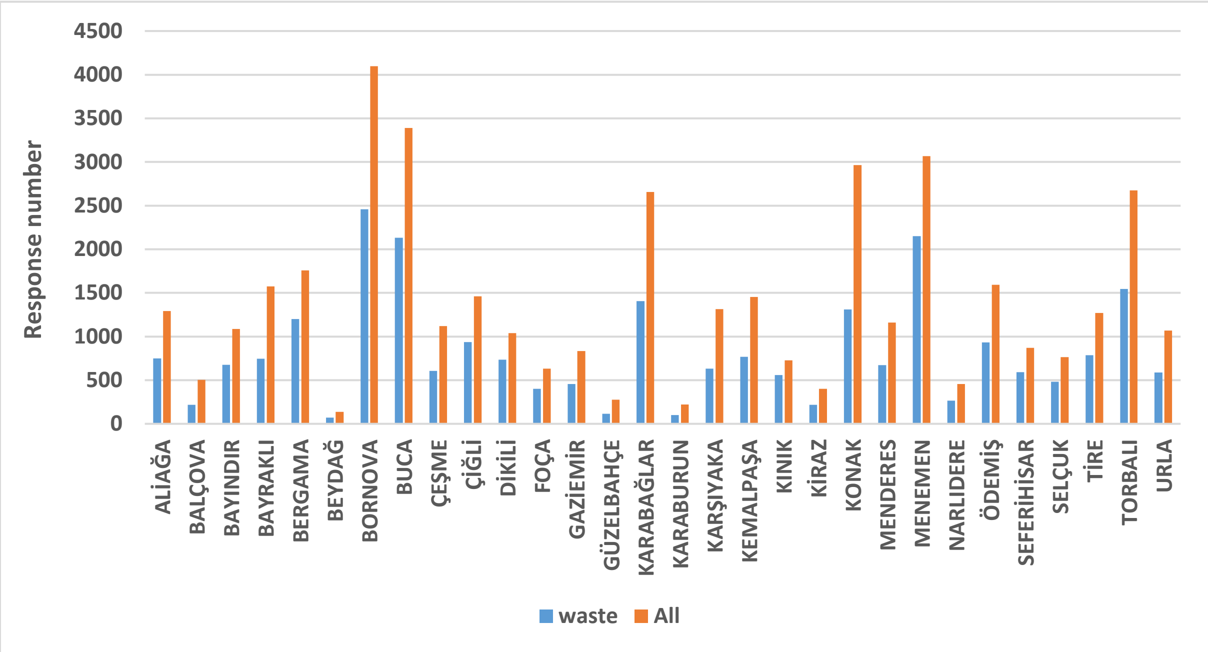

Figure 6. Number of fire incidents by district.

Figure 7 shows the spatial incident density for all fires and waste fires in 2021. Areas with higher fire incident density are represented by red, and areas with low fire incident density are represented by green. The areas where waste fire incidents are intense and the areas where all fire incidents are intense show similarities. As seen on the maps, fires are generally observed in Izmir Bay Area (city center) where the human population is dense.

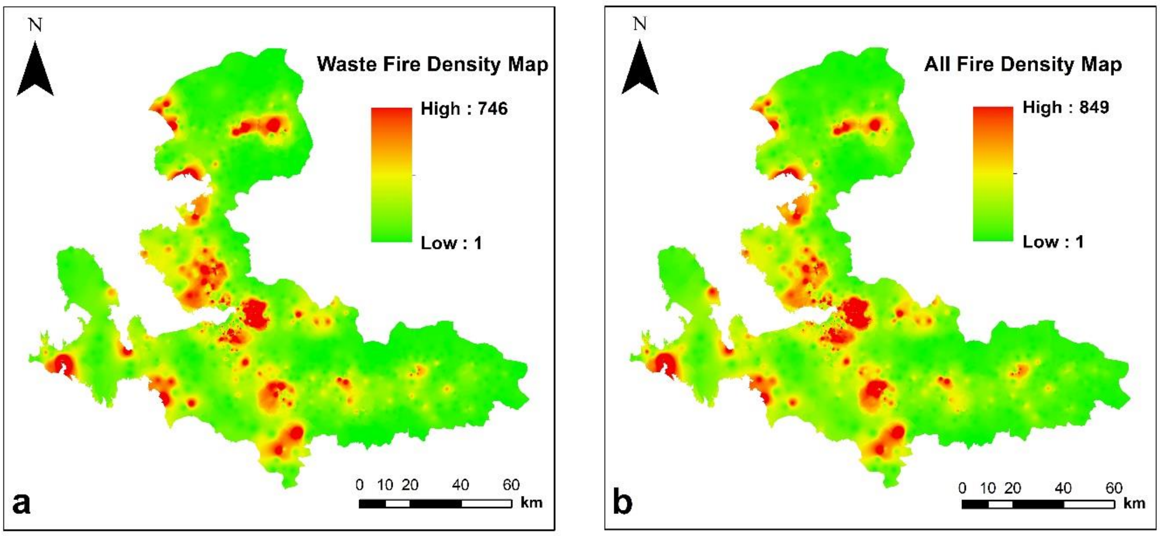

Figure 7. Waste fire density (a) and all fire density (b) maps.

3.2. Spatial Accessibility of Fire Stations

The spatial accessibility map of fire stations is given in Figure 8. When the accessibility is classified in seven different time intervals, it is seen that the majority of the areas fall into more than 30 minutes time intervals. These areas are generally far from fire stations, in rural or mountainous areas of the city where the road network is limited.

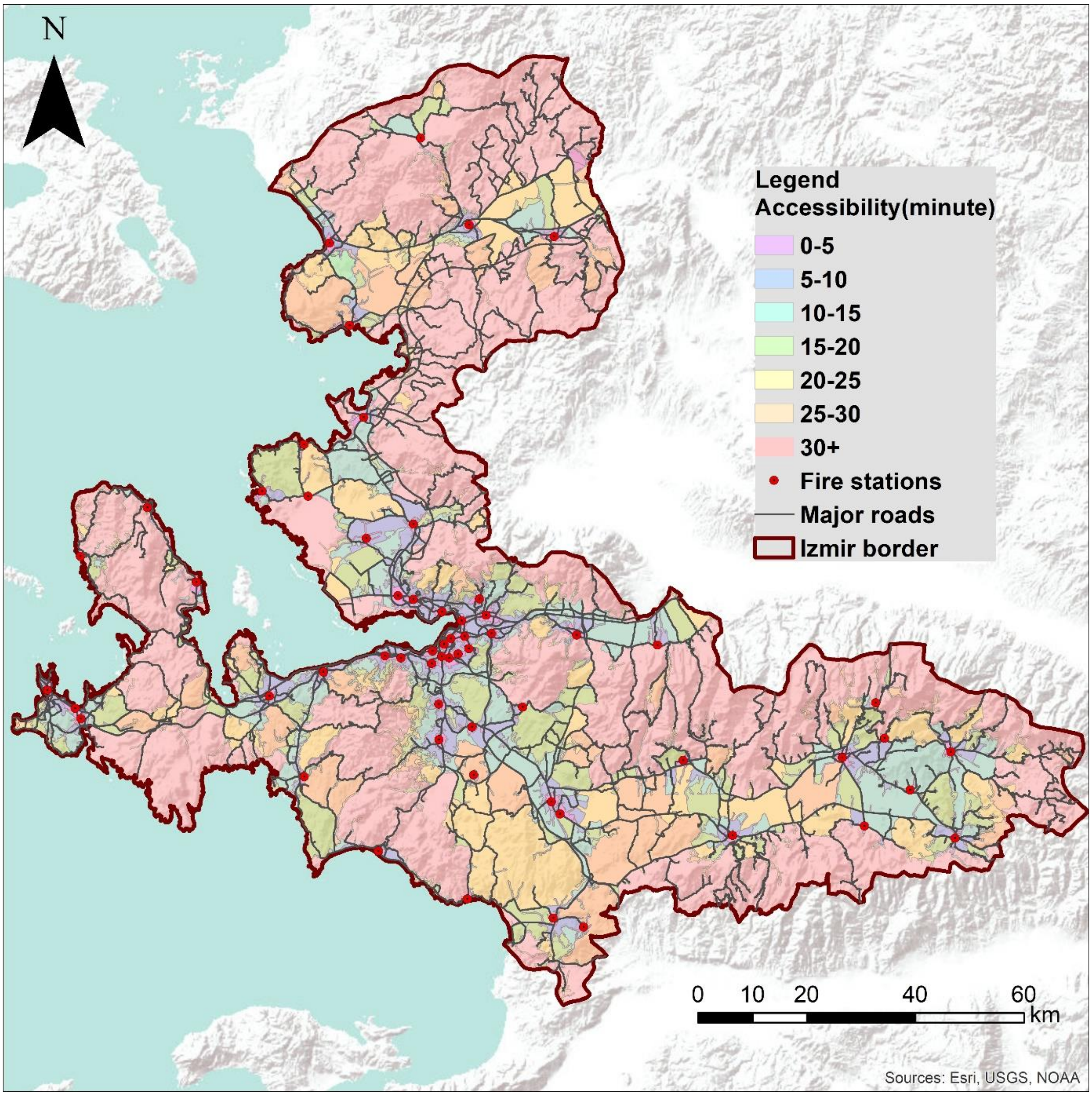

Figure 8. Spatial accessibility map of fire stations.

The spatial accessibility of fire stations to the neighborhood centers was determined by location-allocation analysis for access times of 5, 10, 15, 20, 25, 30, and 62 minutes (Table 1). While more than 90% of the population can be reached within 15 minutes, only 68% of the neighborhoods can be reached at the same time. This shows that the high-population areas in the city are mostly within the 15-minute access time. More than 90 percent of the neighborhoods can be accessed within 30 minutes. It was determined that the time required to access the entire study area is 62 minutes.

Table 1. Accessibility of population and neighborhoods according to service time.

Time minutes	Served population	%	Served neighborhood	%
5	1,294,622	30.25	270	20.87
10	3,481,419	81.35	650	50.23
15	4,061,014	94.89	880	68.01
20	4,155,632	97.10	1,026	79.29
25	4,220,131	98.61	1,129	87.25
30	4,253,445	99.39	1,197	92.50
62	4,279,647	100.00	1,294	100.00

3.3. Fire Station Performance

Allocation of neighborhoods to the nearest fire station was achieved with LA analysis, besides establishing service areas. The allocation of neighborhoods to the fire stations in 62 minutes, which is the minimum time that all neighborhoods in Izmir can receive service, is presented in Figure 9 as an example.

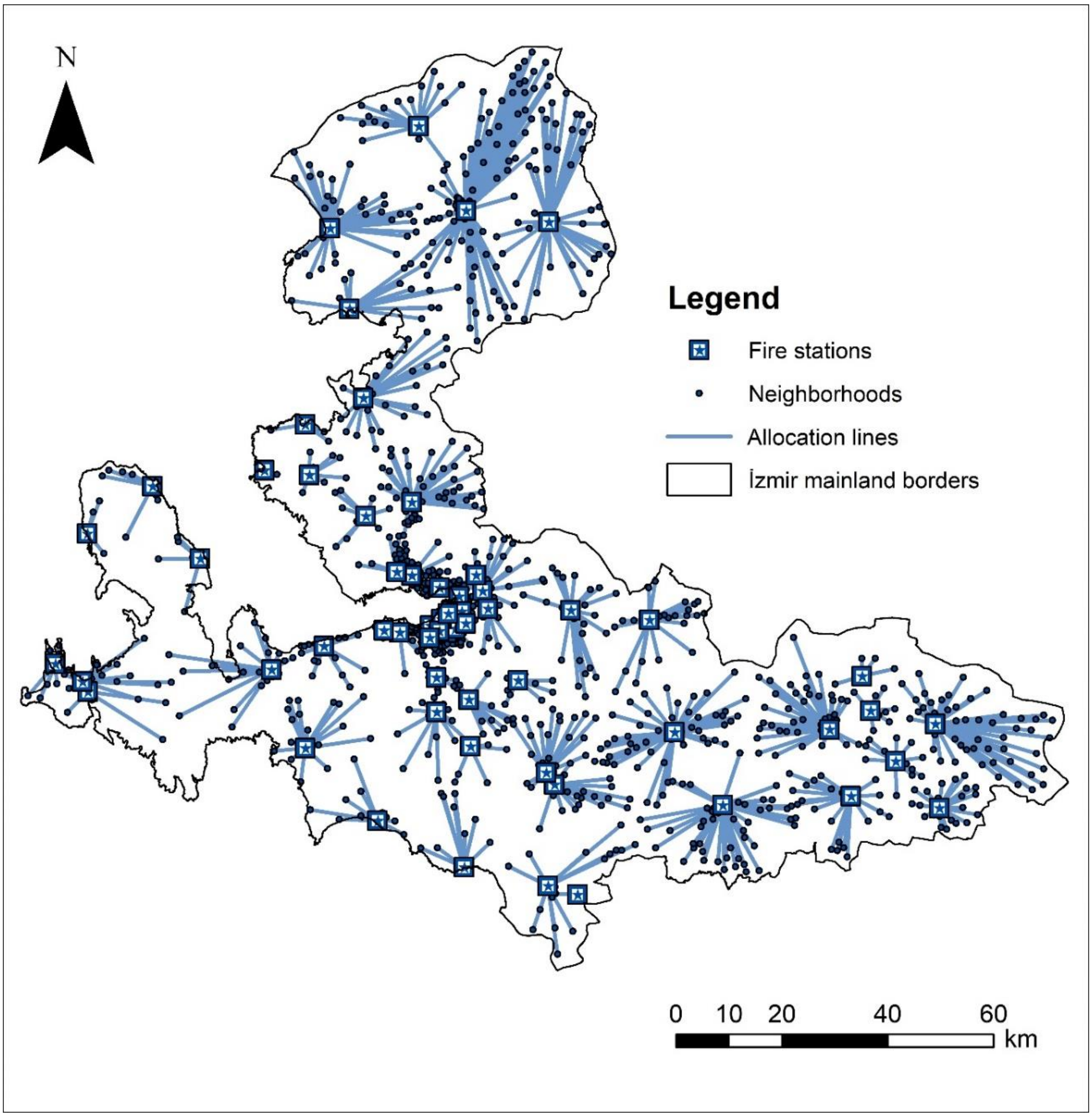

Figure 9. Allocation of neighborhoods to the fire station.

The population-based performance of each of the 60 fire stations in Izmir, which can serve in seven different access times, is shown in Figure 10. For example, the station with ID number 20 can serve 89,181 inhabitants in 5 minutes, 167,797 inhabitants in 10 minutes, and 200,833 inhabitants in 15 minutes. Since the station has reached the maximum population coverage in 15 minutes, the population performance that can serve in 5, 10 and 15 minutes is expressed as cumulative in the graph. Stations 11, 12, and 27 served the highest population, while stations 42, 24, and 3 served the lowest population. It is seen that some stations can serve the hundreds of thousands in population. These stations are of high importance in terms of emergency management, since they are located in areas with a high population density. Stations 1, 24, 38, and 42 are waiting points. It is seen that the amount of population that these stations can serve is less than many other stations. The fact that the waiting points are located to support the forest fires is the reason for their lower performance.

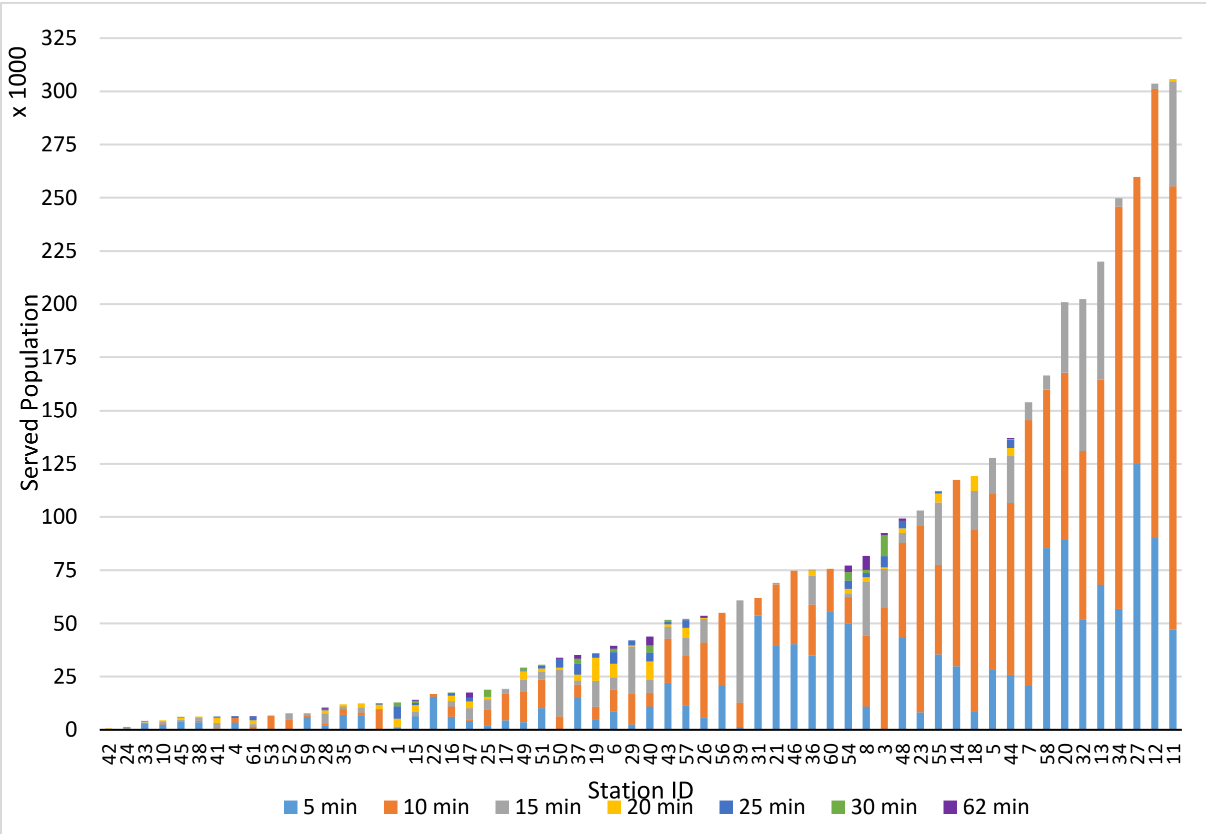

Figure 10. Population-based performance of fire stations.

Considering the fire density maps, service area map, and population-based fire station performance graph together aids in determining areas in need of new fire stations. 4 regions distinguishes with high fire density and less fire stations: Bergama – Kınık, Selçuk, Seferihisar, and South Çeşme. Station ID 8 and 37 are located in Bergama – Kınık region. Station ID 8 and 37 serve the 62% and 72% of population in this service area within 10 minutes, respectively. Station ID 51 and 53 are located in Selçuk region. Station ID 51 and 53 serve the 83% and 100% of population, respectively, in their service area within 10 minutes, which indicates an almost perfect siting of fire stations and no need for additional fire station in this region. Station ID 50 is located in Seferihisar region. Station ID 50 serves only the 19% of population in its service area within 10 minutes. Station ID 2 is located in Seferihisar region. Station ID 2 serves the 83% of population in its service area within 10 minutes. It can be concluded that new fire stations can be planned for Seferihisar, Bergama – Kınık, and South Çeşme regions based on the results.

3. CONCLUSION:

Waste fires are one of the biggest causes of fire incidents in Izmir. Generally, waste fires occur in dumpsites, waste containers, and industrial sites. These fires may have adverse effects on climate change, the economy, and public security. For this reason, comprehensive and systematic policies should be developed for the management of waste fires. Raising social awareness and strict control on waste management play key roles in preventing waste fires, which are generally human-induced by intention.

In this study, the population-based performances of fire stations at specific service times were evaluated in Izmir by performing GIS-based network analysis. Since information such as technical infrastructure, the number of vehicles and firefighters about fire stations are not available, it is not known whether these stations can meet the service needs of the population the model results address. By adding detailed information about the stations to the analysis, comments can be made about the need for fire stations or the detection of unnecessary fire stations.

Response time is an important criterion in emergency situations such as fire. While it is possible in terms of environmental and economic sustainability to not provide services to the entire population or to provide less frequent services in solid waste collection service, it is necessary to provide service to the entire population in cases such as fire. Therefore, attention should be paid to how much of the population can be served at optimum service time in planning new stations or evaluating the performance of existing stations. In emergency cases, the first 10 minutes are critical (Erkal & Değerliyurt, 2013). As a result of the analysis, 19% of the population and 50.23% of the neighborhoods cannot receive fire service within 10 minutes. The results indicate that there is still need for more fire stations in Izmir. It is necessary to provide fire stations to the neighborhoods that cannot benefit from the fire service within 10 minute access time. In future studies, this criterion should be considered in the site suitability analysis for fire stations. Since this study can model fire accessibility with high accuracy using GIS techniques, it will set an example for future studies in the development of fire management policies.

Etik Standart ile Uyumluluk

Çıkar Çatışması: *Yazarlar herhangi bir çıkar çatışmasının olmadığını beyan eder.*

Etik Kurul İzni: *Bu çalışma için etik kurul iznine gerek yoktur.*

Finansal Destek: *Bu çalışma için finansal destek sağlanmamıştır.*

Teşekkür: *Teşekkürümüz yoktur.*

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