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Accessibility assessment of urban public services using GIS-based network analysis: a case study in Eskişehir, Türkiye

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Abstract The rapid growth of urbanization and the growing need for fair and equitable distribution of urban services is one of the important issues and challenges for urban planners and managers. Eskişehir city has been experiencing rapid urbanization in recent decades. This can lead to imbalances in the distribution of public services. The purpose of this study is to determine the coverage radius and spatial distribution of some public services as well as the location-allocation of new facilities in Eskişehir city. For this purpose, data related to some services such as fire stations, emergency centers, and urban parks were collected, preprocessed, and analyzed using network analysis in the Geographic Information Systems (GIS) environment. Service area and location-allocation analyses were applied. The findings of this study showed that the majority of the city population has access to emergency health centers within a 10-min drive time. However, Eskişehir city center does not have a sufficient distribution of fire stations and urban parks in terms of service coverage. Significant parts of the city are out of the range of fire stations at optimum response time (3–4 min). The study showed that the amount of green space per person is about 8.2 m^2. Green spaces in some neighborhoods were found to have been inadequately distributed in relation to population. For this purpose, using GIS-based location-allocation network analysis, some suggestions have been presented to fill the service area gaps and solve the distribution problem by using the appropriate algorithm. The research provides valuable insights for urban managers and planners, emphasizing the need for accurate and effective management of urban areas using GIS technology.

Keywords Emergency center · Fire station · Location-allocation · Network analysis · Service area spatial analysis · Equitable distribution of urban public services

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Introduction

Today, one of the major concerns of cities is easy and fast access to different parts of the city as well as reducing transportation costs. To solve this problem in cities, urban planners seek to find the shortest and best transportation route and also to determine the most appropriate service area for users to improve services in cities. In geographic information systems (GIS), network analysis plays a significant role; network analysis is an important area of research with a strong theoretical background, a solid scientific foundation, and a wide variety of methodological approaches (Curtin, 2018). GIS is a powerful tool for collecting and analyzing information obtained from various sources such as remote sensing and ground-based mapping. Information has a significant role in planning, and it is crucial in achieving the objectives of planning (Scholten & Stillwell, 2013). According to Scholten and Stillwell (2013), planning is an information-processing activity, which means that all of the data utilized in the planning process must be structured, controlled, and presented properly. GIS provides the framework for network analysis of large data and can compare this information and heterogeneous data in a coordinated and simultaneous manner. GIS is of great importance in planning and mapping such as classification of land use and land cover information, exploration of mines, maintenance of facilities, etc. While networks in geography can be very diverse (utility networks, road networks, river networks, etc.), it is the similarity in structure that truly provides the value of research and practice rather than diversity in application (Curtin, 2018). The network analysis method is used to analyze the current state of the spatial distribution of services to examine their functional radius, accessibility, and identify areas outside their coverage radius (Mohammadi et al., 2017).

Balanced spatial distribution of urban services is one of the most important signs of social justice in a city. Social justice in the city means continuing to protect the interests of different social groups based on the optimal expansion of urban resources, revenues, and expenditures (Gray, 2002). An important issue in the equitable distribution of facilities as a social justice strategy is how services and capabilities are distributed among urban areas (Harvey, 2010; Mitchell, 2003). The land-use system has become one of the areas of intensification of social inequalities in cities (Mohammadi et al., 2017; Wheeler & Beatley, 2014). Land-use planning refers to the use, distribution, and protection of lands, spatial and spatial organization of urban activities and functions based on the needs of urban society. Since changes in urban population lead to land-use change, effective land-use planning and monitoring based on urban growth is required (Wheeler & Beatley, 2014). Therefore, suitability assessment, service area and location-allocation analysis lead to effective land-use planning, which is crucial for sustainable urban development (Nguyen et al., 2015; Scholten & Stillwell, 2013).

One of the topics of sustainable urban land-use planning is the spatial distribution of urban services. The practical importance of distributing services in urban areas is based on the need for these services for the viability of urban life and contributing to the comfort and welfare of citizens (Abd El Karim & Awawdeh, 2020; Mohammadi et al., 2017; Serag El Din et al., 2013). The distribution of facilities and services and their quality are inextricably linked to social welfare (Boyne et al., 2001; Mohammadi et al., 2017; Serag El Din et al., 2013). Future generations' initial welfare will be determined by the decisions we make today (Bentivegna et al., 2002). The goal of spatial justice is the equitable distribution of basic needs, facilities, and urban services among urban neighborhoods so that no neighborhood is superior to another neighborhood in terms of spatial superiority. The issue of access to urban green space is one of the most controversial issues in sustainable urban planning, especially in issues such as environmental justice and health imbalances (La Rosa, 2014). Green spaces are vital elements of urban ecosystems, providing relaxation and entertainment places to residents (Oh & Jeong, 2007; Wang et al., 2021). Estimating the spatial accessibility to urban parks is one of the initial steps in urban planning and development to enhance social and environmental justice in the city (Wang et al., 2021). The World Health Organization (WHO, 2012) recommends the availability of a minimum of 9 m^2 of green space per capita with an ideal UGS (Urban Green Space) value of 50 m^2 per individual (Russo & Cirella, 2018). Another critical issue in service area coverage is the immediate response to fire and emergency health incidents. Immediate response to such incidents is crucial for emergency management because delays in arrival at the scene can result in serious injuries, property damage, and even death. Based on standards, the optimum response time for fire incidents is 3 to 4 min (Davoodi & Mesgari, 2018; Mohammadi et al., 2017; Oppong et al., 2017). The above-mentioned service area analysis can be performed using network analysis.

The rapid growth of urbanization and the growing need for the provision and equitable distribution of urban services is one of the important issues and challenges for urban managers and planners. Eskişehir city has been experiencing rapid urbanization in recent decades. This can lead to imbalances in the distribution of public services. In this study, response time and service coverage of emergency centers, fire stations, and access to parks (green spaces) are analyzed using service area analysis, and the best locations for new facilities are determined using location-allocation analysis in the GIS environment. This study reveals the gaps in some urban services in the city and discusses the importance of selecting candidate locations in the location-allocation analysis. The paper is organized as follows: Sect. "Introduction" presents introduction and literature review. In Sect. "Materials and methods", the approaches for modeling, the study area, and the utilized geo datasets are discussed. The results and discussion are presented in Sect. "Results and Discussion", and Sect. "Conclusions" provides a summary of the findings. It is important to note that this study contributes to the understanding of the imbalances in the distribution of public services in rapidly urbanizing areas and highlights the significance of selecting appropriate locations in location-allocation analysis for improving service coverage and response times.

Literature review

Network analysis has been one of the most significant scientific topics in the field of GIS (Curtin, 2018). The use of GIS-based accessibility analysis, including network analysis and location-allocation tools, has been utilized by researchers to assess and improve the distribution and coverage of public services, such as ambulance services, fire stations, neighborhood parks, and healthcare facilities. Comber et al. (2008) used GIS-based network analysis to determine urban greenspace accessibility for different ethnic and religious groups in Leicester, UK. The authors compared access for different religious and ethnic groups based on the UK government standards on greenspace provision (2 ha of accessible natural greenspace per 1000 population). As a result, Indian Hindu and Sikh groups were found to have limited access to green space in the city. Their research demonstrates how a GIS-based network analysis combined with statistical analysis of socio-economic data may be utilized to analyze and assess the equity of access to social goods and services. Kuta et al. (2014) carried out a similar study specifically, related to deprivation in Leicester, UK. Comber et al. (2009) also utilized GIS-based network analysis to evaluate service provision of post offices in the UK. Neutens et al. (2012) proposed a GIS-based method to identify spatiotemporal gaps in public service delivery. The authors suggested the use of time-specific measurements of service accessibility and demand. They used the variables in a GIS-based multi-criteria analysis to detect spatial and temporal changes in service deprivation. Forkuo et al. (2013) studied a GIS-based fire emergency response system using Network Analysis in Ghana. They analyzed the adequacy of fire hydrants, and their results showed an insufficient number of fire hydrants in areas considered to be fire-intense. La Rosa et al. (2014) studied accessibility to greenspaces using GIS-based indicators for sustainable planning in a dense urban context. The authors emphasized the effectiveness of GIS techniques in network analysis. Tansley et al. (2015) used GIS-based network analysis to investigate geographic access to emergency services in low- and middle-income countries. Their findings revealed a large discrepancy in possible access to emergency services.

Similarly, Unal et al. (2016) conducted a GIS-based accessibility analysis for Cukurova's neighborhood parks. Their research goal was to look at the accessibility, spatial distribution, size of neighborhood park spaces, and usage intensity of neighborhood park services in the Cukurova region. Their results revealed uneven distribution of neighborhood parks and insufficiency for the population. Mohammadi et al. (2017) used the service area model of the GIS-based network analysis to determine the scope and coverage of the public services within a city. The researchers analyzed the distribution of the public urban services and concluded that most public services were distributed unfairly and inadequately. Baloyi et al. (2017) evaluated the service level of the public ambulance by applying a GIS-based accessibility analysis. The authors found GIS-based network analysis very useful in accessibility analysis and decision-making. Efiong (2019) investigated the use of the GIS-based location-allocation tool in identifying public facilities which can be closed while saving cost and without making a negative impact on the beneficiaries. El Karim et al. (2020) integrated GIS access models and location-allocation with multi-criteria decision analysis to assess the quality of life in a city. Shahparvari et al. (2020) studied the accessibility of fire stations to improve operational response in Melbourne. The authors found network analyst a powerful tool in location-allocation of fire stations, especially in restructuring existing fire station locations. They increased the coverage of existing fire stations in the city from 81 to 95% by relocating fire stations using network analysis. Parvin et al., (2021) used network analysis to find a suitable place for healthcare services. They used a GIS-based hybrid decision approach. They found network analysis effective for site selection. Wang et al. (2021) compared spatial accessibility indicators using three GIS-based methods (transport modes, distance thresholds, and network complexity) to analyze access to urban parks. The authors concluded that the choice of distance thresholds and modes of transportation matters more to accessibility measurements than the destination selections across all three methodologies.

In summary, the application of GIS-based accessibility analysis, including network analysis and location-allocation tools, has been demonstrated as a useful approach for evaluating and improving the distribution and coverage of public services across various domains, including urban planning, healthcare, and emergency response. This study provides valuable insights into the challenges of providing and distributing urban services in rapidly urbanizing areas, using Eskişehir city as a case study. The use of GIS-based service area and location-allocation analyses highlights the importance of effective planning and decision-making in improving the accessibility and distribution of public services, and can serve as a valuable resource for urban managers and planners facing similar challenges.

Materials and methods

The purpose of this study is to determine the scope, radius, and distribution of public services (emergency centers, fire stations, and parks) coverage in Eskişehir city and to analyze their sufficiency for the city as well as location-allocation of new facilities. According to the purpose, this study includes applied research that uses a network analysis model in the distribution of urban services. The research method is descriptive and analytical, and it is based on literature (e.g., Efiong, 2019; Mohammadi et al., 2017; Unal et al., 2016; Oh & Jeong, 2007) and using network analysis in the GIS environment. Figure 1 shows the overall flowchart of the research methodology.

Study area

The study area is within the Tepebaşı and Odunpazarı districts of Eskişehir city center—the most populated areas of the city. Eskişehir is a city located in the Central Anatolia region of Türkiye, situated at an elevation of around 782 m above sea level and located on the banks of the Porsuk River. The province is

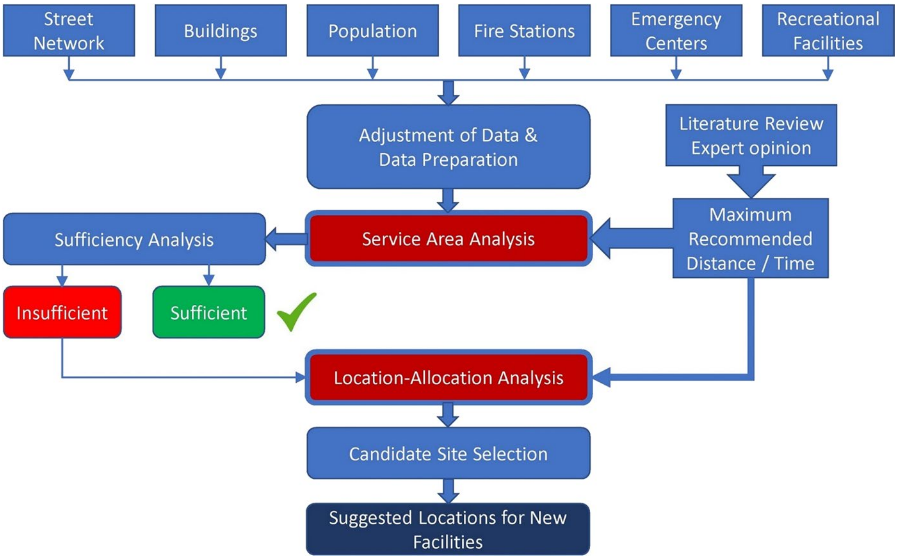

Fig. 1 Overall flowchart of the research methodology

divided into 14 districts and 536 neighborhoods and has a total size of 2678 km^2. According to 2017 figures, the city's urban population is 784,036, with a metropolitan population of 860,620 and an annual growth rate of 1.85% (Deliry & Uyguçgil, 2020). Eskişehir is one of the developed cities in Türkiye, with a modern, regular, and high urbanization rate. It is one of Türkiye's most important cities in terms of socio-economic growth. Eskişehir is an important economic and industrial center in Türkiye. The city is home to several large companies, including Eti Soda, a major soda ash producer, and TUSAŞ Engine Industries, a leading aerospace engine manufacturer. The city is famous for its traditional handicrafts, such as pottery and meerschaum carving, which attract many tourists. In terms of population, Eskişehir is the 20th largest city in Türkiye. The city has a high literacy rate, with many universities and research institutions, making it a hub for education and innovation.

The climate of Eskişehir is humid continental, with warm summers and cold and snowy winters. The average lowest and highest temperatures reach − 3.5 degrees Celsius and 29.1 degrees Celsius, respectively. The average yearly precipitation is around 400 mm. The majority of the urban settlement and commercial areas are flat. Figure 2 shows the study area. The population density map of neighborhoods inside the study area is shown in Fig. 3. The study area is 143.5 km^2, of which approximately 10% of the area consists of residential areas, and 2.2% are parks and green spaces.

Data

Among urban services, emergency centers, fire stations, and urban parks were considered in this study. Street network dataset, spatial data of buildings in vector format as well as infographic data were used as a basis for analysis. Layers related to buildings and population were obtained from various sources, especially Eskişehir Metropolitan Municipality (digitized buildings and related data of 2015), and other data were obtained from OpenStreetMap (OSM). Some preprocessing such as clipping, project transformation, and conversions were performed in the GIS environment. Figure 4 shows the data used in this study. There are 7 emergency centers (public hospitals) and 4 fire stations within the study area. Based on OSM data, there are 291 parks and green spaces inside the study area, 25 of which are large parks and considered urban parks. Urban parks are usually established on a surface area of 2 hectares and above (Aysun, 2015).

Method

Network Analyst allows performing analyses on network datasets. In ArcGIS Pro software, network analyses can be performed using Network Analyst Geoprocessing Tool. Finding the service coverage, shortest pathways, drive-time polygons, locating the nearest facilities, selecting the best site, and determining the optimum routes for a fleet of vehicles are all part of these analyses (ESRI, 2021). To perform network analyses, the layer must be connected to a network dataset in a geodatabase or a shared network location. This layer must be created and added to the dataset before the analysis can be performed. The network analysis layers can be created by the user using a local network dataset (from OSM or digitizing routes) or with logistic services hosted in ArcGIS Online or ArcGIS Online Portal Network Dataset.

The mathematical sub-disciplines of graph theory and topology are used in GIS network analysis (Curtin, 2018; ESRI, 2021). A network is made up of a collection of linked vertices and edges. Graph theory is a branch of mathematics that studies, measures, and compares graphs and networks (Curtin, 2018; ESRI, 2021). Connectivity, adjacency, and incidence are the topological features of networks. These characteristics serve as a foundation for analysis. To be able to perform network analysis, first, all routes are digitized based on the actual directions of traffic in the city. After creating the topology in the ArcGIS environment, information such as route length, driving time in minutes, and the route hierarchy is given, and a spatial relationship is created between the network lines. Other additional information of the network, such as being one-way or two-way, the width of the existing passages and intersections are added to the network and is prepared for analysis. Preparation of network datasets is not only a time-taking process but also needs consistent maintenance and assessments to make them ready for analysis. Fortunately, nowadays, ready-to-use ArcGIS Online Portal Network Data Source is available globally. It is worth noting that a Network Analyst license is required to perform the

Fig. 2 Study area, population, and buildings

network analysis, and credits are consumed with each analysis if the online network dataset is used. In this study, ArcGIS Online Portal Network Dataset was used for service area and location-allocation analysis.

To achieve the study aim, Service Area (SA) analysis and Location-Allocation (LA) analysis were performed. GIS-based network analysis was performed as follows. First, the network analysis type was defined, and the network dataset was set. Then the dataset was prepared accordingly and added to GIS software. After that, the network analysis layer (e.g., service area) was created and network analysis features were assigned. Subsequently, the analysis parameters such as drive time, walking time, or distance were defined based on standards in the literature. Finally, service area analysis was applied to each facility and sufficiency analysis was performed. After sufficiency analysis, based on demand, the location

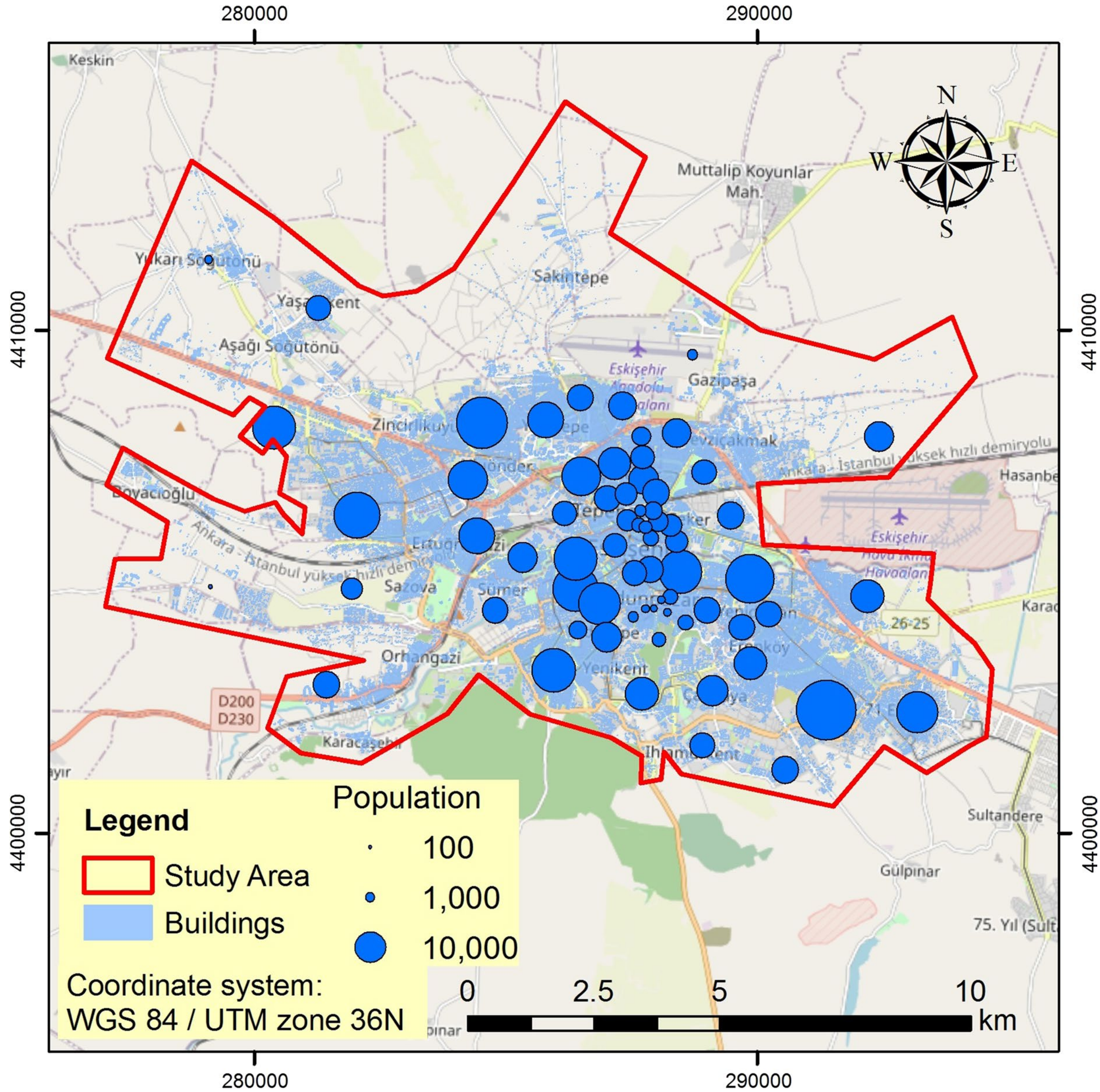

Fig. 2 (continued)

and number of new facilities were chosen by performing Location-allocation analysis.

Service area analysis

Service area analysis determines the network service regions around facilities. A network service area is a geographic area that includes all streets that may be reached within a given travel time or distance from one or more facilities (ESRI, 2021). Such analysis cannot be performed using simple buffer analysis. Accessibility is commonly visualized and measured using service areas. For example, a facility's 5-min service area covers all streets that can be accessed within 5 min from that facility. Service Area Analysis consists of three simple steps: create a layer, add locations, and solve. In this study, the operational radii or service areas of facilities including emergency

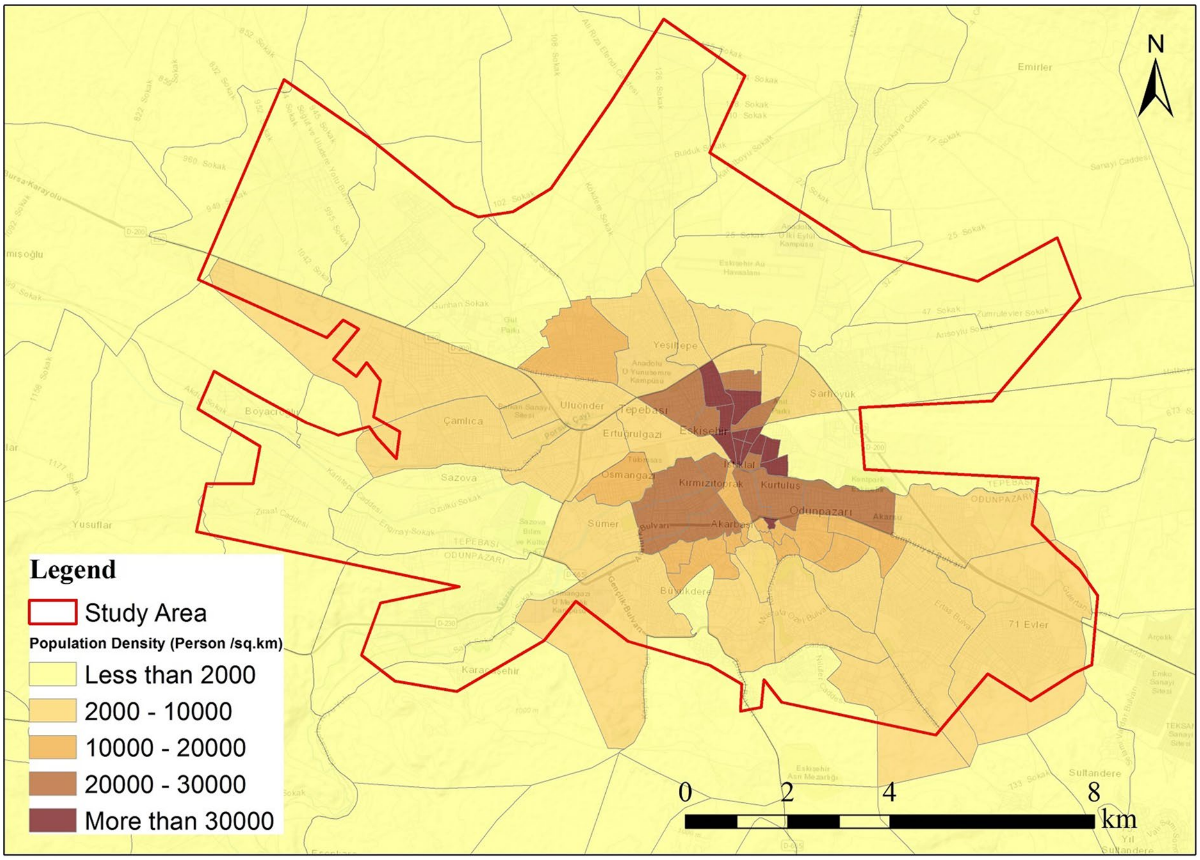

Fig. 3 Population density (person/km^2)

centers, fire stations, and urban parks were investigated according to planning standards and literature (Aktaş et al., 2013; Algharib, 2011; Bürger et al., 2018; Do et al., 2013; Kaczynski et al., 2008; Mell et al., 2017; Mohammadi et al., 2017; Oh et al., 2019; Unal et al., 2016) as follows:

- Emergency centers (5, 10- and 15-min driving time);
- Fire Stations (3-, 4-, and 5-min driving time); and
- Recreational Facilities (500 m, 1000 m and 5-, 10-, and 15-min walking distance)

Location-allocation analysis

Location-allocation helps in determining the optimum locations for facilities based on optimization goals to serve a set of demand locations (ESRI, 2021). There are many options in this analysis, it is possible to choose locations to cover the most amount of demand, maximize market share, or minimize costs to reach the demand.

The location-allocation analysis is comprised of four steps:

- Create a layer
- Import required, candidate, and competitor facilities
- Add demand points
- Select the problem type, enter parameters, and solve the problem

As the type of problem, two types were used in this study, Maximize Coverage and Target Market Share. Maximize Coverage solves the fire station location problem. It chooses facilities such that all

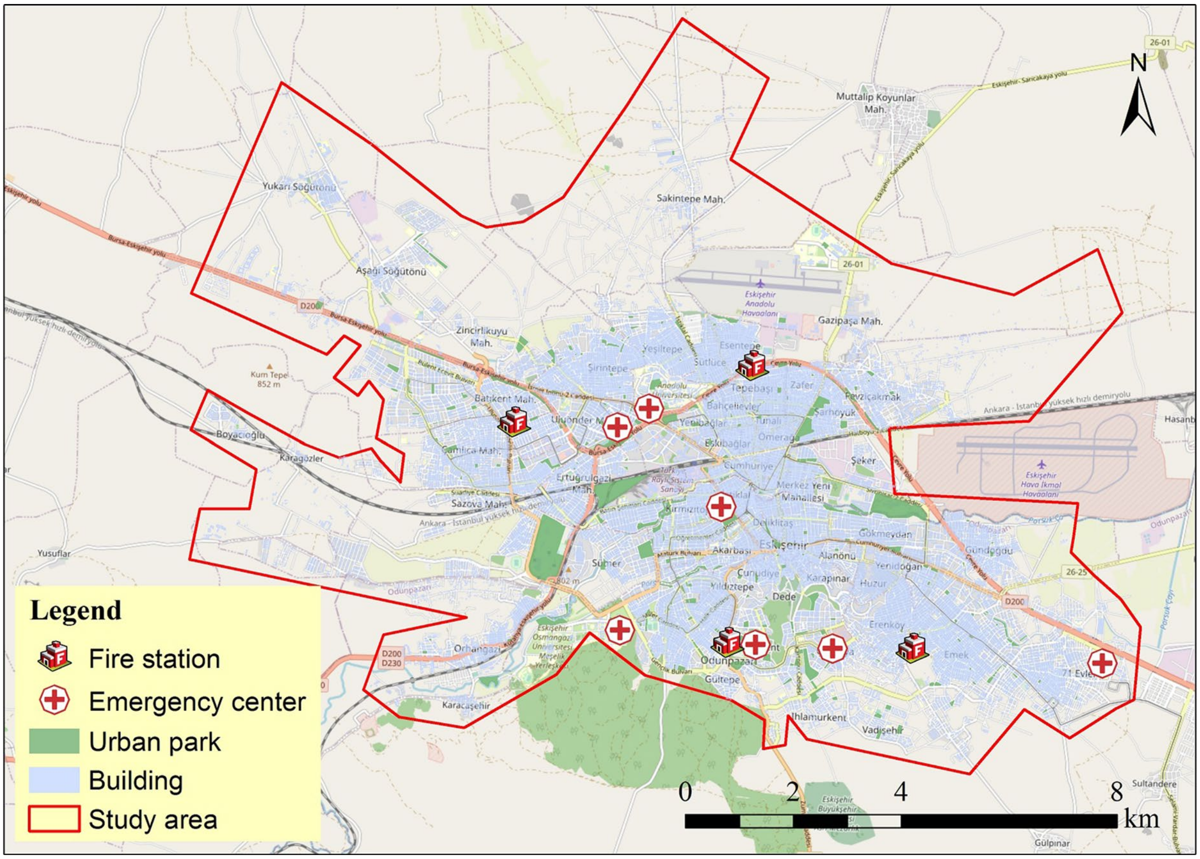

Fig. 4 Data used in this study

or the greatest amount of demand is within a specified impedance cutoff. Target Market Share solves the competitive facility location problem. It chooses facilities to reach a specified target market share (percentage) in the presence of competitive facilities. Gravity model concepts are used to determine the proportion of demand allocated to each facility. The minimum number of facilities needed to reach the specified target market share is chosen.

Results and discussion

GIS software and network analysis are commonly utilized in urban geographical studies, particularly in urban and rural planning, to examine the service area or functional radius of specific facilities. In this study, we conducted an accessibility assessment of urban public services in the city center of Eskişehir, Türkiye, focusing on fire stations, emergency centers, and urban parks. The application of network analysis, location-allocation analysis, and service area analysis allowed us to gain insights into the current situation of these services and propose potential locations for new stations. While our study did not introduce a new method per se, its originality lies in the application of these established GIS analyses to the specific context of urban public service accessibility. The results and discussion are given in the following sections.

Emergency centers

To analyze the coverage of emergency centers using 5, 10, and 15 min driving time, service area analysis was performed. Figure 5 shows locations of existing emergency centers and their service area polygons with response times of 5, 10, and 15 min. After creating a service area layer and performing

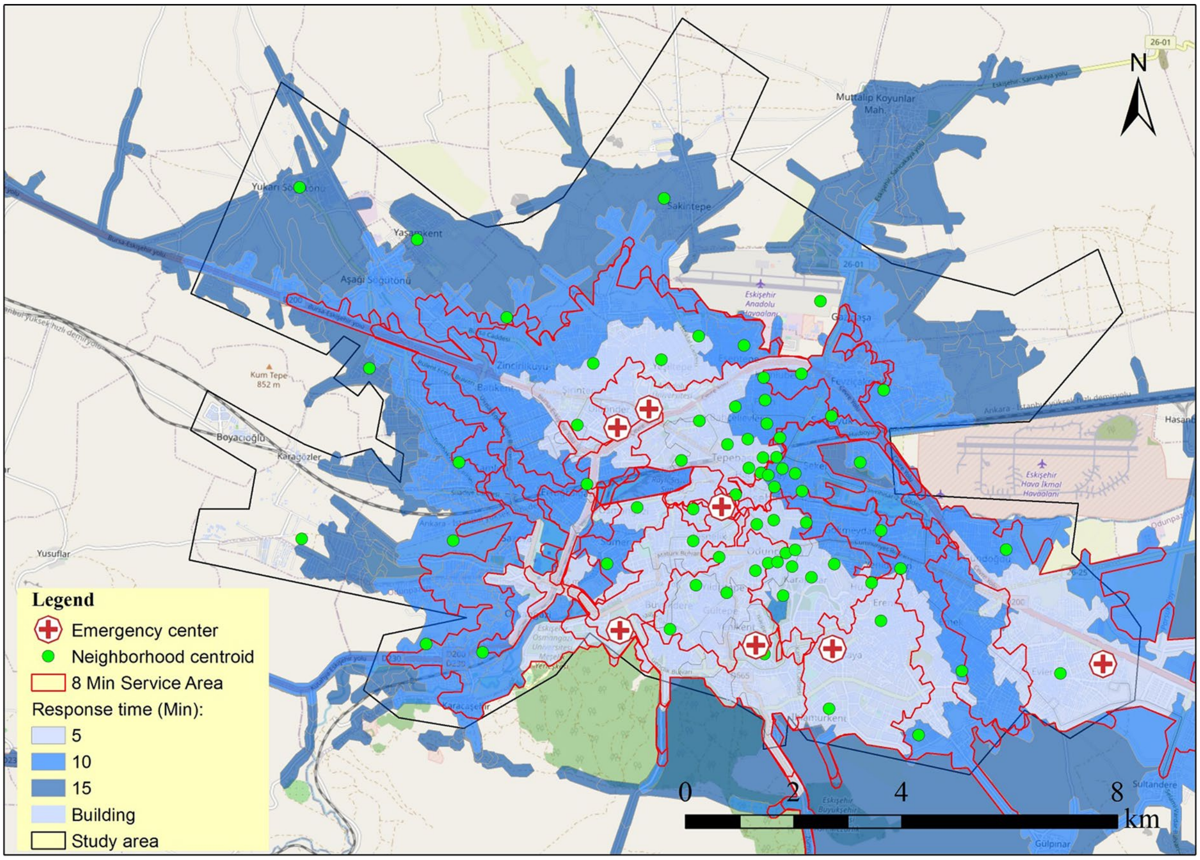

Fig. 5 Existing emergency centers service area with response times of 5, 10, and 15 min

service coverage analysis, each polygon (5, 10, and 15 min coverage) was analyzed to see the covered buildings and their population. After selecting the polygons, buildings were selected using the *Select by Location* geospatial tool. Since in the geodatabase, the building feature class was related to the population table using a one-to-many relationship, the population under each polygon was simply calculated using spatial analysis.

The results showed that 54% of the population is within 5 min coverage, and 99% within 10 min. Since in 10 min, the emergency centers cover 99% of the city population, we conclude that the facilities are almost sufficient because the accepted response time as per standards is 8 min or less and the average is 10 min in developed countries (Bürger et al., 2018; Do et al., 2013; Mell et al., 2017; Peleg & Pliskin, 2004). This means that in 8 min, 95% coverage can be achieved.

Fire stations

According to standards, firefighting facilities in emergencies should be able to be present at the incident scene in 3 to 4 min (Algharib, 2011; Davoodi & Mesgari, 2018; Mohammadi et al., 2017; Oh et al., 2019; Oppong et al., 2017). Some studies also used 5 min response time as impedance cutoff distance in service area analysis of fire stations (Aktaş et al., 2013; Bolouri et al., 2018; Şen et al., 2011; Shahparvari et al., 2020; Uddin & Warnitchai, 2020). To perform sufficiency analysis, service

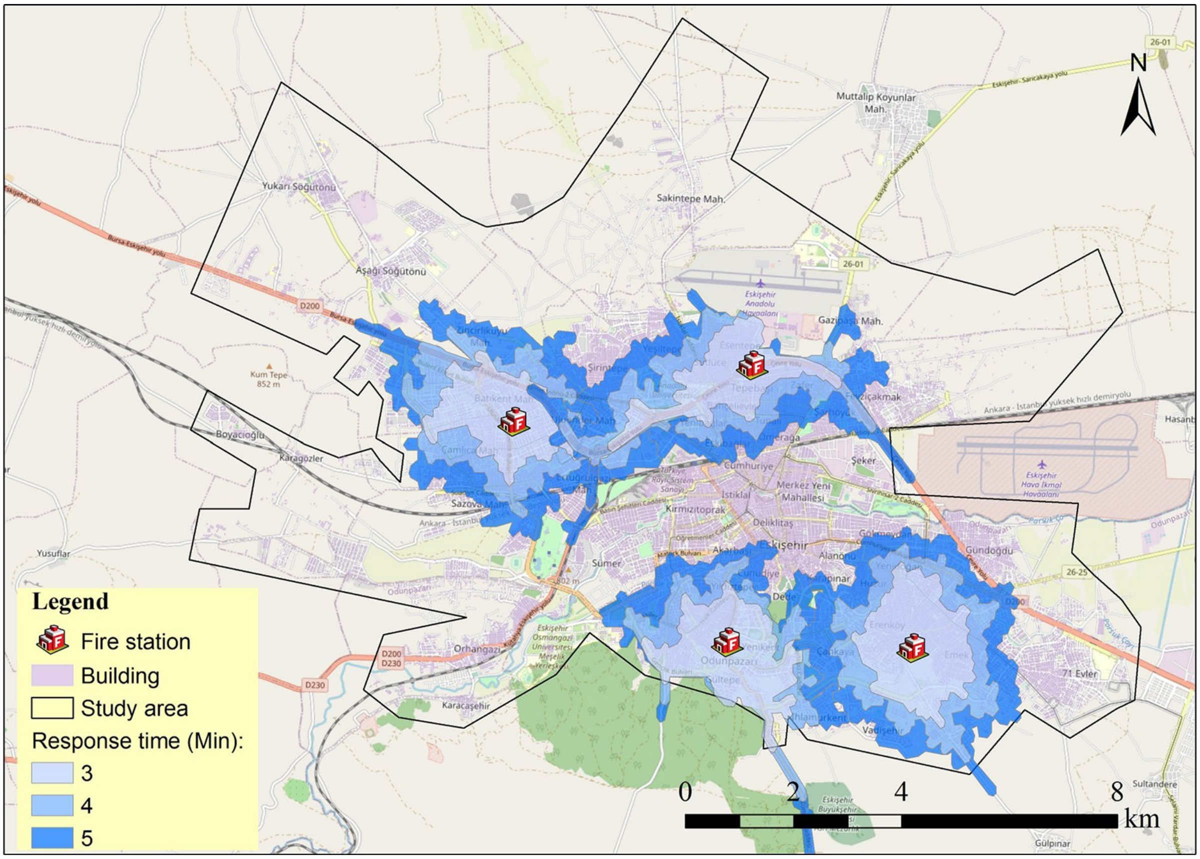

Fig. 6 Service areas of existing fire stations with response times of 3, 4 and 5 min

area analyses for the location of fire stations were performed.

Service area analysis

Service area analyses for the four existing fire stations were performed based on critical response time standards (3, 4, and 5 min). Figure 6 shows service areas of existing fire stations with response times of 3, 4, and 5 min. As the figure illustrates, most of the buildings are not covered even with 5 min response time and there are many gaps in densely populated areas within the study area. As a result of the analysis, the standard 3-min response time covers 25,903 buildings, accounting for 25% of all buildings in the study area. 4-min response time covers 43,577 buildings, which is about 42% of the buildings. 5-min response time coverage is 60% of buildings. Therefore, it is obvious that new fire stations need to be allocated to fill the coverage gaps. To solve the problem, new fire stations should be opened in the dense areas of the city which the existing ones cannot cover. We performed the Location-Allocation Network Analysis to effectively optimize the number and location of new fire stations in the city.

Service area analyses with higher response time values were performed to find the actual response time and coverage of the existing fire stations. Figure 7 shows the service area of existing fire stations with response times of 6, 8, and 10 min. Red points demonstrate the centroid of neighborhoods. Experiments were performed by changing the response time cutoff parameter. The result of location-allocation analysis using the 8-min response time revealed that the existing fire stations can reach about 93% of

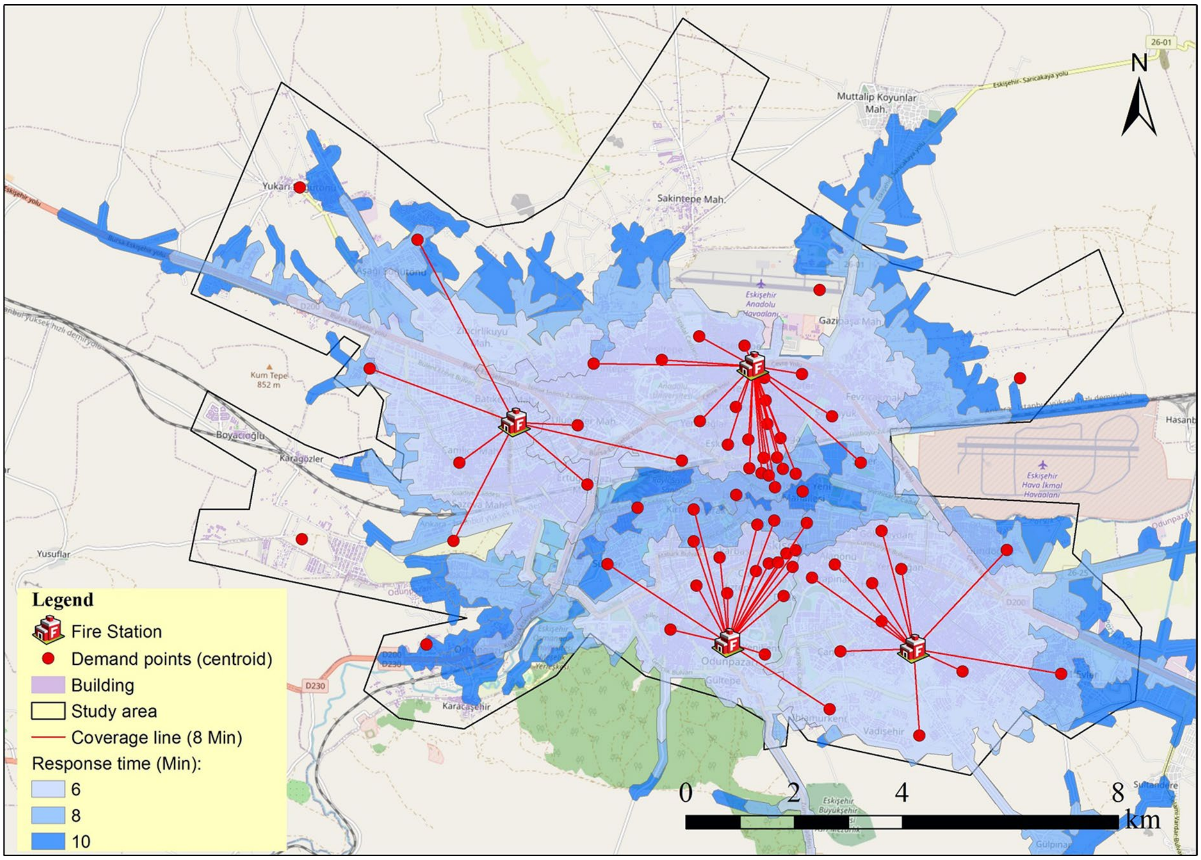

Fig. 7 Service area of existing fire stations with response times of 6, 8 and 10 min

the buildings within 8 min and 97% of the buildings in 10 min.

Location-allocation analysis

To determine the optimal locations for new fire stations to serve the city, location-allocation analyses were performed. Under location-allocation in the network analyst tool, two types of problem solvers were used: Maximize Coverage, and Target Market Share. For finding the most suitable locations and the number of new fire stations, different experiments and assessments were performed as follows.

First experiment how many new fire stations do we need to open to cover the study area with a response time of 3 min and 100% coverage? We have 4 existing (required) fire stations; 65 locations were selected as candidate locations and point features were created at those locations. Neighborhood centroids with population fields were also created. To test the decision-making capabilities of the location-allocation solver, some candidate points were intentionally created inside the service area of existing fire stations. Since there are 4 existing fire stations, and we do not know the number of new fire stations with the selected parameters, Target Market Share is the best problem solver choice for this perspective. Using this algorithm, we can specify the share percentage, and the result will give us the number and location of chosen points. Target Market Share was used as the problem type, existing fire station points were added as required, selected new points were defined as candidate locations, and neighborhood centroids with population weight were defined as demand points. Location-allocation solver was executed, and as a result, 24 points out of 65 were chosen by software to cover the entire area. Since 24 new stations are not affordable based on the city

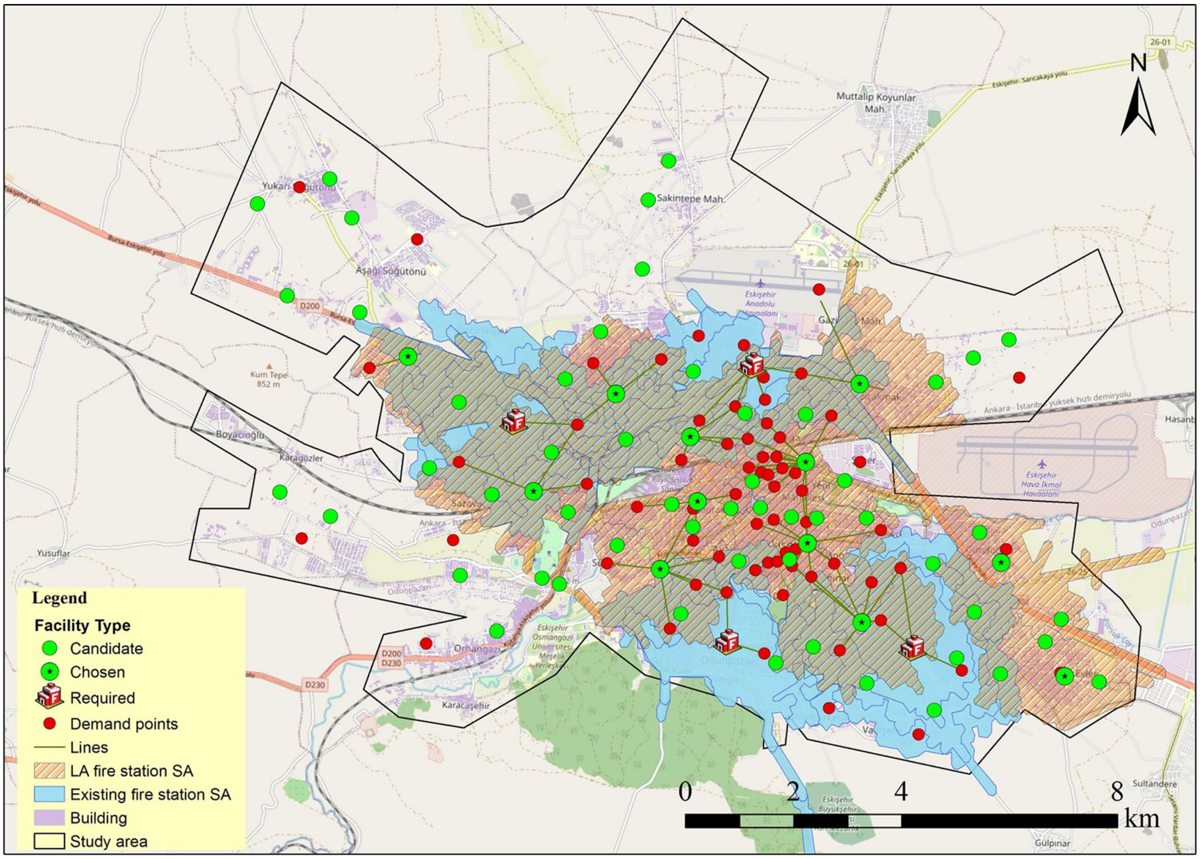

Fig. 8 Randomly selected candidate locations, 4-min response time, and 90% coverage

budget, response time and coverage parameters were reduced to 4 min and 90% coverage (which is still a good coverage). With such parameters and the same inputs, after executing the solver, 11 locations were chosen by software as the new fire station locations (see Fig. 8).

After we analyzed the chosen points, we realized that the chosen locations do not seem logical, so we performed a service area analysis to reveal the problem with the algorithm. Figure 8 shows that the service area polygons of the newly chosen points overlap with the existing (required) fire station service area polygons. After analysis, we found that the algorithm chooses the points based on the weight of demand points (in this case population) and creates the points on densely populated areas without considering the overlapping issue with the existing facilities. The findings revealed that careless and random selection of candidate points can lead to unacceptable results. The planner must choose the candidate locations as carefully as possible, then, from those candidate areas, the location-allocation tool can help to find the best locations and number of new facilities. To do so, we conducted the second experiment as follows.

Second experiment Eleven candidate locations were carefully selected to be outside of the coverage of existing fire stations. Then with the same parameters (4-min response time and 90% coverage, neighborhood centroids with populations weights as demand), the algorithm was executed. As a result, 8 new locations were chosen by software (see Fig. 9). Figure 9 shows that the resulted 4-min response time service area polygons do not overlap with the existing coverage polygons. The result of second experiment showed that by keeping the existing fire stations, the city needs to open 8 new fire stations to cover 90% of the demand areas with a 4-min response time.

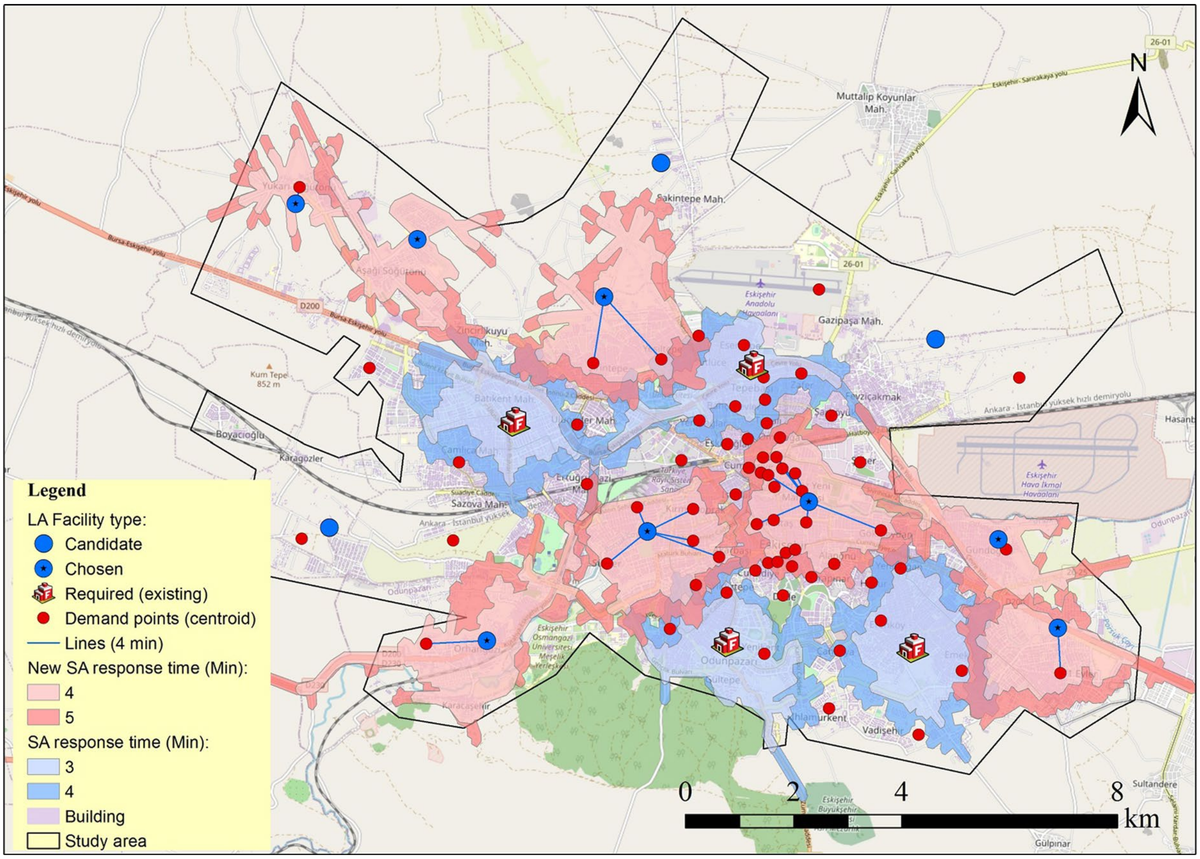

Fig. 9 Location-allocation Target Market Share, 11 carefully selected candidate locations, 4-min response time, and 90% coverage

Third experiment what if the city cannot afford to open 8 new fire stations? Supposing that in terms of budget, the city can only open 4 new stations. By keeping the response time to 4-min and maximum coverage, where should we open the new fire stations to ensure maximum coverage with a 4-min response time? In other words, how to choose the best locations from 11 candidate points? This problem can be solved with Maximize Coverage algorithm, which solves the fire station location problem. The same inputs and parameters were used with only one difference that instead of specifying the coverage percentage, we have the option to select the number of new facilities to be chosen. By adding the required, candidate, and demand points, selecting the number of facilities as 4, the response time as 4-min driving time, the location-allocation algorithm was executed to solve the problem. Figure 10 shows the result of location-allocation network analysis. After location-allocation analysis, a service area analysis was also performed using the chosen points to see the coverage of new facilities. By comparing with the population density map, it can be realized that the new locations were selected reasonably because the building density is also high in those locations.

The number and location of fire stations determine an urban system's fire resistance. Urgent response to fire incidents is essential for emergency management since delay in reaching a fire scene can have dire consequences and result in injuries, property damage, and even death. Based on standards, the optimum response time for fire incidents is 3 to 4 min; however, some studies performed in Türkiye, show the use of a 5-min response time in Istanbul (Aktaş et al., 2013; Şen et al., 2011). In most studies, especially in developing countries, fire stations are insufficient to meet the needs of their inhabitants. The work of Shahparvari et al. (2020) shows that in some countries, the

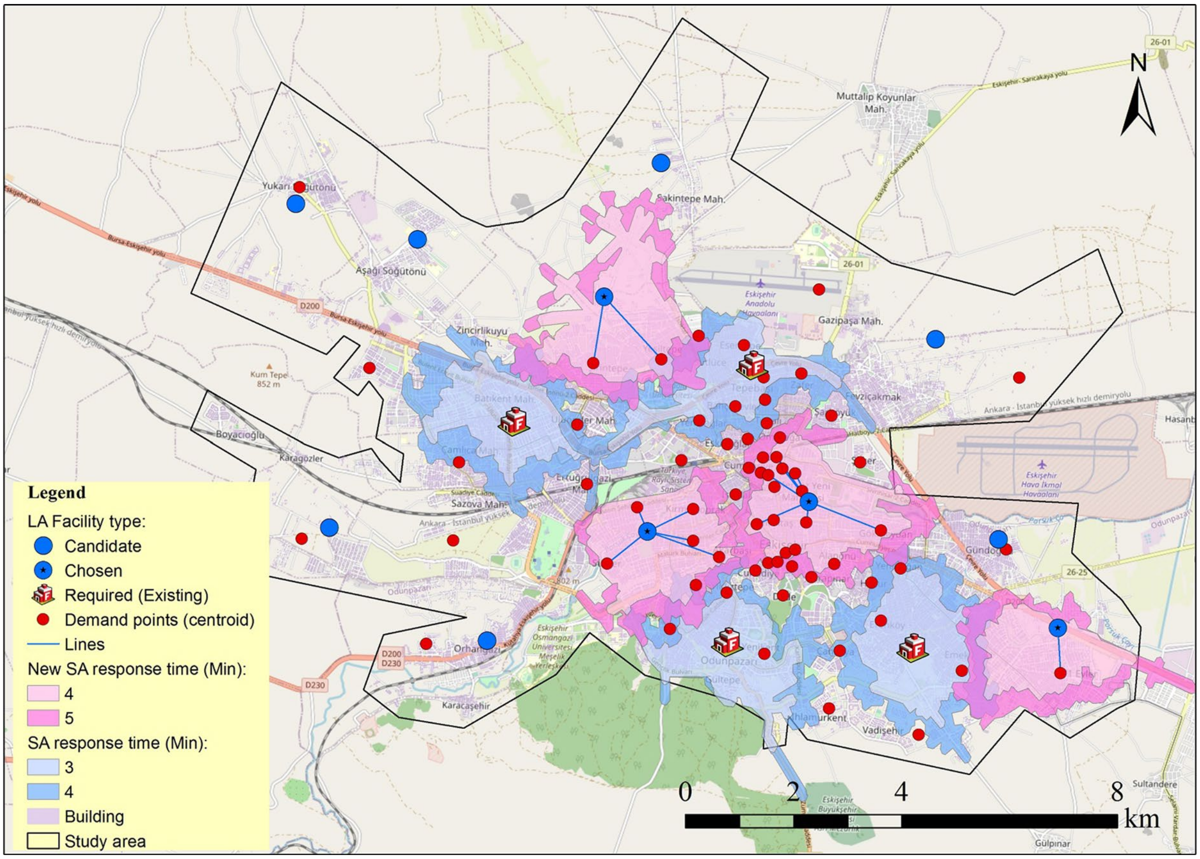

Fig. 10 Location-allocation Maximize Coverage, 11 carefully selected candidate locations, 4-min response time, and 4 facilities

fire station response time is 10 min. Increasing the number of facilities is the simplest solution; however, this is not always possible due to limitations in the budget of cities. Using location-allocation analysis and choosing the right algorithm, the location of existing facilities can be evaluated and optimized.

Urban parks and neighborhood green spaces

Since in most studies, the planning standard for accessing green spaces is 500 m (Kaczynski et al., 2008; Unal et al., 2016), to analyze the size and coverage sufficiency of parks for the population, 500 m and 1000 m walking distances were used, and service area analyses were performed accordingly. Figure 11 shows service areas of existing parks with walking distances of 500 m and 1000 m from residential buildings.

The results showed that 500 m and 1000 m service areas of parks inside the study area cover 82% and 92% of buildings, respectively. Similarly, the population living within 500 m and 1000 m walking distance from parks are 91% and 98%, respectively. Based on service area polygons, another analysis was also performed to find the adequacy of the allocated size of parks for the population inside the service area. The findings indicate that although the percentage of the population with access to green spaces within the standard walking distance of 500 m is high, the size of the parks is not sufficient for densely populated areas compared to the standard 2 hectares per 1000 population (Comber et al., 2008; Kuta et al., 2014). For the majority of parks, the population is several times higher than the standard of 2 hectares per 1000 population. Although the number and size of the parks are not sufficient for most of the neighborhoods, there are also deprived neighborhoods such

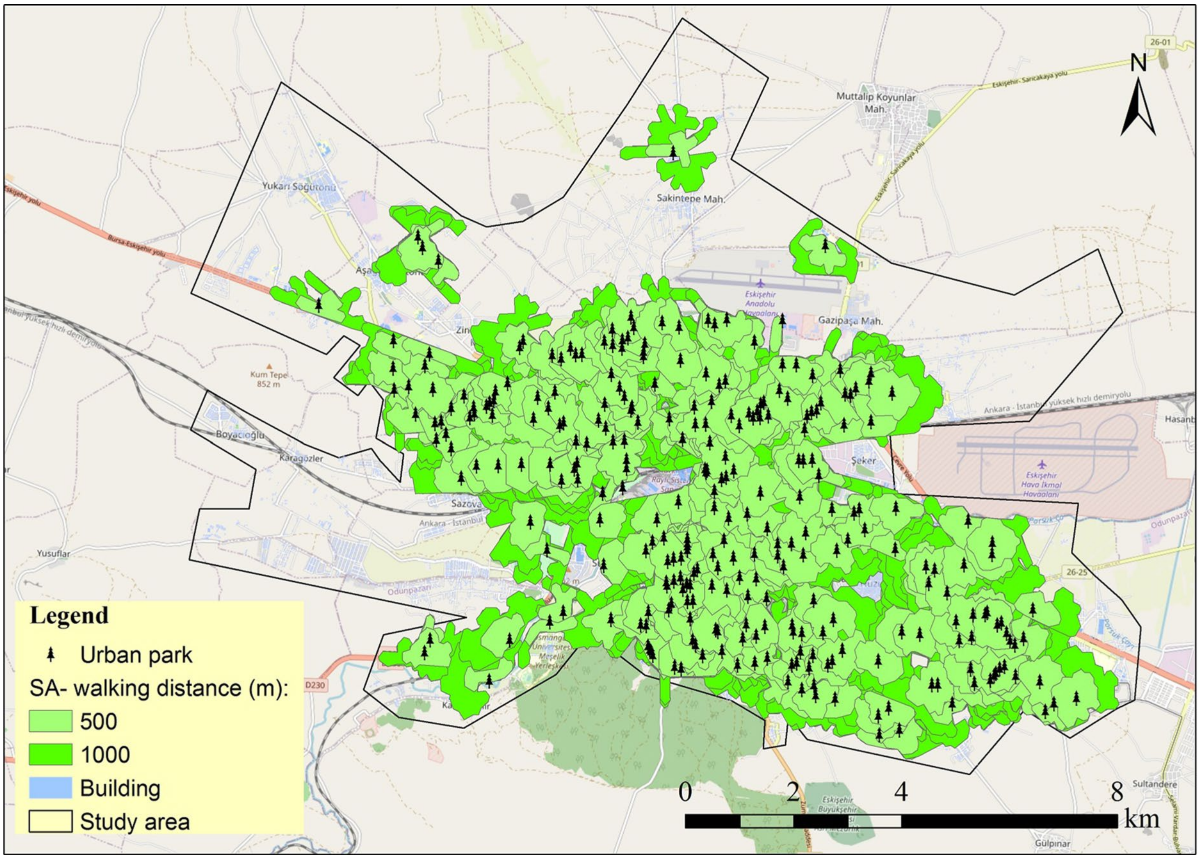

Fig. 11 Service area of existing parks with walking distances of 500 m and 1000 m from buildings

as Huzur Mahallesi. Since the locations of deprived neighborhoods are clear on the map, location-allocation analysis has not been performed for green spaces.

The total area of urban parks and green spaces inside the study area is 3.2 km^2, which is approximately 2% of the study area. The average size of parks is about 1 hectare. According to OSM data, there are 291 parks and green spaces inside the study area, 25 of which are large parks (urban parks). Parks with a surface area of 2 hectares (0.02 km^2) and above are considered Urban Parks (Aysun, 2015). According to World Health Organization (WHO, 2012), the recommended availability of minimum green space per capita is 9 m^2. Based on the existing vector data for the study area obtained from OSM, the amount of green space (including neighborhood parks) per person is about 8.2 m^2, and the amount of urban park space per person is approximately 5 m^2. Of course, green areas outside the study area are not included in these calculations; otherwise, the space per capita is generally more than 9 m^2. Moreover, since OSM data is open-source data, it is worth noting that the completeness and accuracy of the data have not been evaluated in this study.

In terms of quantitative aspects, the size of parks is the most challenging factor. In planning, the appropriate park size can considerably increase the effectiveness of the service area. However, field size is not the only factor contributing to the quality of urban life. Therefore, both the size and the spatial population distribution for neighborhood parks should be determined in accordance with the development plan's population density (Unal et al., 2016). Unfair distribution of green spaces is a common issue in the literature (Comber et al., 2008; Oh & Jeong, 2007; Unal et al., 2016; Wang et al., 2021).

Since parks are used for recreational activities, another analysis was also carried out using 5, 10, and

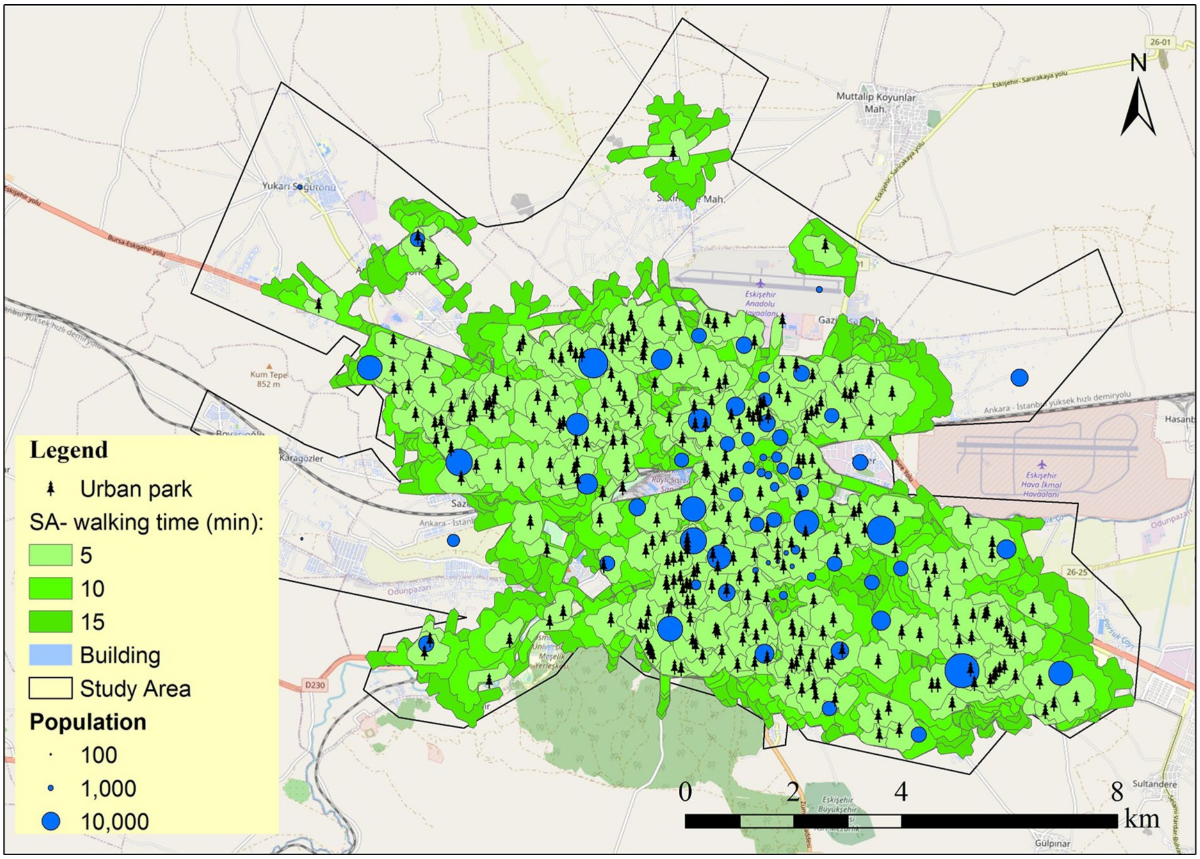

Fig. 12 Service area of existing parks with walking time of 5, 10, and 15 min

15 min walking time to observe coverage areas. Figure 12 shows the coverage of parks inside the study area with walking times of 5, 10, and 15 min. The figure shows that the 15-min service area polygons of the parks cover 95% of residential buildings and approximately 99% of residents have access to green spaces. A 10-min walk, which is about 800 m, is a reasonable distance to reach a park (Kaczynski et al., 2008). The majority of the population has access to green spaces within a 15-min walking distance; however, the size of the parks is not sufficient for the residents in the service area.

Advantages and limitations of the applied methods

The application of network analysis in this study provided a thorough understanding of the existing infrastructure and service accessibility. Using service area analysis, we were able to quantify the coverage and sufficiency of the existing facilities by considering factors such as road networks, travel distances, and transportation modes. Moreover, by considering population distribution and target response times, location-allocation analysis enabled us to identify optimal locations for new fire stations. These methods have been widely employed in various urban planning and public service studies, demonstrating their reliability and effectiveness.

However, it is important to acknowledge the limitations of the method applied in this study. First, the accuracy of the results heavily relies on the quality and accuracy of the input data, particularly the road network data and population distribution information. Although we utilized institutional data and publicly available data from reliable sources such as OpenStreetMap, potential inaccuracies or incomplete data should be taken into account. Future studies should consider validating the results through field surveys and data collection to enhance the reliability of the analyses.

Applicability of the methods and findings

The methods employed in this study can be a useful resource for researchers, policymakers, and urban planners working on related studies in various contexts. When evaluating the accessibility of different public services, such as healthcare facilities, educational facilities, fire stations or other facilities in metropolitan areas, the approach of using GIS-based network analysis can be applied. Decision-makers can make well-informed decisions regarding where to locate facilities, how to allocate resources, and how to improve services by examining the current infrastructure and locating any gaps or deficiencies.

Additionally, the findings of our study can be utilized as a guide for future urban development plans. The identification of underserved areas, such as the densely populated Huzur Mahallesi, highlights the need for targeted interventions to improve accessibility to urban parks and green spaces in the city. The insufficiency of park sizes in densely populated areas emphasizes the importance of considering population density and demand when planning park layouts and sizes. Urban planners can utilize the results to inform land-use planning, prioritize park expansions or new park developments, and ensure equitable access to green spaces for all residents.

Usability of the results

The findings of our study offer insightful information regarding the existing state of accessibility to fire stations, emergency facilities, and urban parks in the Eskişehir city center. The results can help with evidence-based urban planning methods and decision-making processes. For instance, to improve emergency response capabilities and speed up response times, local authorities and emergency service providers might use the optimal location suggestions for new fire stations. These findings can help with resource allocation and budget planning for the establishment and maintenance of public services.

Moreover, the findings regarding urban park accessibility and size inadequacies can inform strategies aimed at promoting public health, recreational activities, and community well-being. By identifying areas with limited access to green spaces and undersized parks, urban planners can prioritize the development of new parks or the expansion of existing ones in these areas. This approach will contribute to creating more equitable and inclusive urban environments, where residents have convenient access to recreational opportunities and nature.

Furthermore, the accessibility assessment conducted in this study can also support initiatives aimed at sustainable urban development. By promoting the availability and accessibility of urban public services, such as fire stations and emergency centers, the safety and resilience of the city can be improved. Efficient emergency response systems play a vital role in minimizing potential damages during critical situations, such as natural disasters or emergencies.

Implications for future research

While this study provides valuable insights into the accessibility of urban public services in the city center of Eskişehir, there are several avenues for further research. Firstly, future studies can consider incorporating additional factors into the analysis, such as socio-economic characteristics, land-use patterns, or demographic trends. By integrating these variables, a more comprehensive understanding of service accessibility and its relationship with urban development can be achieved.

Moreover, it is crucial to evaluate the long-term effectiveness of the proposed optimal locations for new fire stations and emergency centers. Conducting simulations and scenario analyses to assess response times, resource allocation, and the impact on overall emergency management systems can provide valuable insights for decision-makers. Additionally, considering the evolving nature of cities and urban environments, regular updates and monitoring of accessibility measures are necessary. As urban areas undergo changes in population distribution, infrastructure development, or transportation networks, reassessing service accessibility becomes vital to ensure the continued provision of quality public services.

In conclusion, while the methods employed have inherent strengths and limitations, they offer valuable insights into the current state of service accessibility and contribute to evidence-based decision-making. The findings can be utilized by urban planners, policymakers, and service providers to guide resource allocation, facility location decisions, and future urban development plans. Further research in this field can enhance the methodologies, incorporate additional variables, and ensure the ongoing evaluation of service accessibility to promote sustainable and inclusive urban environments.

Conclusions

Resilience and sustainability are the most focused topics in academic research. Resilient essential infrastructures are foundations for sustainable development since they are critical for regular city operation. In this study, the role of GIS and network analysis methods in the distribution and access to urban services were investigated using Service Area and Location-Allocation Analysis. Geographic information systems with accurate and integrated management of spatial and non-spatial data are of great importance in service area accessibility and location-allocation analysis. Today, due to the growth of the urban population and the concentration of services and facilities in cities, the time factor is very important in access to services. Therefore, GIS-based network analysis is essential for solving network problems such as finding the service area, the optimal route, closest facilities, etc. In this study, the operational radius and service area of emergency services, fire stations, and urban parks were investigated using the network analyst tool in the GIS environment. The results showed that the existing emergency health centers are accessible to 99% of the city population within 10 min of driving time; however, Eskişehir city does not have sufficient distribution of fire stations and urban parks in terms of coverage of public services. Significant parts of the city are out of range of fire stations at optimum response times. To cover all densely populated areas of the city in 4 min with 90% coverage, location-allocation analysis was performed, and the results indicate that 8 new fire stations are needed to be established to fill the gaps in the city. The findings of further analysis showed that with a limited budget, by using the appropriate algorithm, establishing 4 new fire stations can fill the critical gaps and provide maximum coverage for the city center. The result of analysis on neighborhood parks revealed that although most residents have access to green spaces within a 10-min walk, the size of the parks is not sufficient for the designated population. For most neighborhood parks, the population is several times higher than the standard of 2 hectares per 1000 population. The results show that network analysis plays an important role in planning and spatial distribution studies; however, a fair distribution of services can be achieved by choosing the right method. Increasing the number of infrastructures may be the easiest solution. However, it consumes resources and cities may not be able to afford extra costs associated with the increased number of infrastructures. In this case, location-allocation is the best solution to optimize the location of existing facilities. Therefore, in order to accurately and effectively manage urban areas, the use of GIS technology and network analyst method is highly recommended for urban managers and planners. By utilizing the power of GIS-based spatial analysis, we can make informed decisions that enhance the quality of life for urban residents, promote safety and resilience, and contribute to the creation of vibrant and inclusive cities.

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Data availability All data and models generated or used during the study are available from the corresponding author upon reasonable request.

Declarations

Conflict of interest The authors declare that they have no conflict of interest associated with this publication.

Ethical approval We have no conflicts of interest associated with this publication, and there has been no financial support for this work to disclose. As the corresponding author, I confirm that the manuscript has been read and approved by all the named authors for submission to the journal.

Consent to participate Not applicable.

Consent to publish Not applicable.

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