Research Article

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Using fuzzy analytical hierarchy process for road transportation services management based on remote sensing and GIS technology

Abstract: The importance of site selection for road transportation management and emergency services has been underscored, particularly in the wake of the global Covid-19 pandemic in addition to road accident injuries, which emphasized the need for swift patient, injured and wounded peoples transfer to hospitals. As a result, comprehensive road transportation management is essential during crises to ensure the safety and convenience of road users. To achieve effective road network management, a robust database is imperative. The aim of this study is to employ multi-criteria decision analysis with the aid of Geographical Information System (GIS) technology and remote sensing for the optimization of site selection for traffic signals, fire stations, and emergency services in Kafr El-Sheikh city, Egypt. The methodology incorporates two different methods which are Fuzzy Analytical Hierarchy Process (F-AHP) and the spline transformation method. The integration of Fuzzy set theory with AHP principles has given rise to a variant of AHP known as F-AHP. F-AHP combines qualitative and quantitative approaches. Fuzzy logic handles situations that are vague or poorly defined by assigning numerical values. Through the F-AHP approach, criteria that decision-makers unanimously deem "absolutely not important" in comparison to others are eliminated, allowing them to focus on the most significant criteria. As a case study, an Egyptian city was selected to apply these techniques. The results revealed multiple sites that were identified and selected through the applied analytical methods. These selected sites were also marked on the city map and verified in reality.

Keywords: traffic management, GIS, Fuzzy-AHP, spline transformation method, MCDA

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1 Introduction

The roadway network is the heart of any country's development. Traffic problems are closely related to human life and are numerous; some of them belong to the road network and the ability to accommodate the daily traffic volume and parking demand [1]. Consequently, the mobility of road users (pedestrians – drivers – passengers) moving from one site to another at an appropriate speed or without exposure to the risks of accidents represents a daily problem in developed countries. In addition, traffic congestion results in consuming the national economy. The optimal use of the available tools and techniques would help manage the efforts and suggest solutions in a crisis.

In Egypt, the central cities suffer from traffic problems such as traffic accidents, congestion, and environmental pollution, especially at peak hours. The crowded cities need emergency transportation and ambulance services, which cannot handle multiple demands simultaneously in those cities. Indeed, it is of paramount importance to ascertain the optimal site selection for road services like fire stations and emergency services, as this decision holds great significance for urban areas. The choice of a suitable location can have a direct impact on reducing response times, optimizing coverage, and minimizing operational costs.

Determining the locations of road services, such as fire stations and emergency services, holds a pivotal role in the planning and administration of urban areas. Optimal site selection can lead to substantial improvements in response times, service coverage, and cost efficiency. To address these challenges, modern technologies like GIS and remote sensing systems are indispensable. They empower planners and administrators to monitor road networks and track the movements of traffic vehicles. GIS, in particular, offers a robust set of capabilities, encompassing data storage, management, analysis, computation, and visualization. It serves as a versatile and powerful tool for efficiently managing and optimizing road services [2–5].

In addition to GIS, the spline transformation method is employed to accurately map source control points to target control points. While it ensures precision for control points, it may not guarantee the same level of accuracy for pixels located at a distance from these control points. F-AHP is another valuable technique used to establish ratio scales through paired comparisons. This method can incorporate both objective measurements like weight and price, as well as subjective evaluations such as preferences and satisfaction. Notably, research by Lagunzad et al. [6] explored the integration of Global Positioning System (GPS), GIS, and traditional database applications to manage highway networks. Their approach involved the creation of a locational reference system (LRS) that consolidates data related to road and bridge inventories. Another study by Yamada and Thill [7] delved into the application of network autocorrelation analysis, focusing on the analysis of spatial relationships within a transportation network using point data. Various software tools are available, providing statistical methods for cluster analysis [7–9].

Road monitoring GIS (RMGIS) plays a crucial role in monitoring road conditions by directly displaying the precise geographical locations of monitored sites, setting it apart from other road monitoring systems. Multiple studies have been conducted to determine the optimal placement of emergency services, emphasizing the significance of geospatial tools and analysis in this process [10–12].

The target of this study is to use GIS technology and remote sensing systems for the identification of optimal locations for the placement of new traffic signals, emergency services, and fire stations. A distinctive aspect of this research lies in the application of F-AHP for site selection, offering a comparative analysis with the conventional spline transformation method. This methodological innovation is implemented in the urban context of Kafr El-Sheikh city and serves as a case study in Egypt, a Middle Eastern country. Specifically, the study seeks to assess the efficacy of F-AHP in contrast to the spline transformation method for enhancing the precision of site selection. The outcomes of this research hold the potential to refine response times and bolster public safety, thereby contributing valuable insights for urban planning and infrastructure development. There are several research works, which used several techniques for site selection for different applications [13–15].

2 Study area

The chosen city for implementing the proposed technique is Kafr El-Sheikh city, the capital of Kafr El-Sheikh Governorate,

Egypt as depicted in Figure 1. Situated on the northern border of Egypt, the city is positioned at approximately 31°6′ 42″ N latitude and 30° 56′ 45″ E longitude. As of the year 2020, it had an estimated population of around 3.6 million, according to data from the Egyptian Central Agency for Public Mobilization and Statistics [15]. Kafr El-Sheikh city boasts a road network comprising both two-lane and multilane roads, with some operating in a single direction and others in dual directions. From visual inspection, the average road width within the city varies between 10 and 20 m. The primary modes of transportation in the city are private cars and public transport. Additionally, the city is equipped with numerous government and private-sector hospitals and dispensaries. However, despite these amenities, Kafr El-Sheikh city grapples with persistent issues of traffic congestion and traffic collisions, particularly during peak hours. As a result, there is a pressing need to identify a lasting solution to address these challenging problems effectively.

3 Research methodology

In this study, two analytical methods for optimal site selection were employed: F-AHP and the spline transformation method. The study utilized multiple-criteria decision analysis (MCDA) approach based on GIS techniques and remote sensing to determine the ideal sites for new traffic signals, emergency services, and new locations for fire stations within the study area. This approach integrates various criteria and spatial data to make informed decisions about site selection, with a focus on enhancing the management of transportation services and emergency response. To select the optimal locations (site selection) for new emergency services, traffic signals, and fire stations throughout managing road transportation services, Figure 2 shows the methodology employed by GIS tools and MCDA. The details of each step are further discussed here.

4 Input and available data

In the current study, several data sources were utilized to gather essential information. These sources include:
1. Satellite images sourced from Landsat 8 with a resolution of 30 m. These images were obtained from internet sites, specifically (Source: https://earthexplorer.usgs.gov).
2. Satellite images specific to the study area obtained from Google Earth, providing a higher resolution of 0.5 m. These images were acquired using the Google Earth program, which is available online.
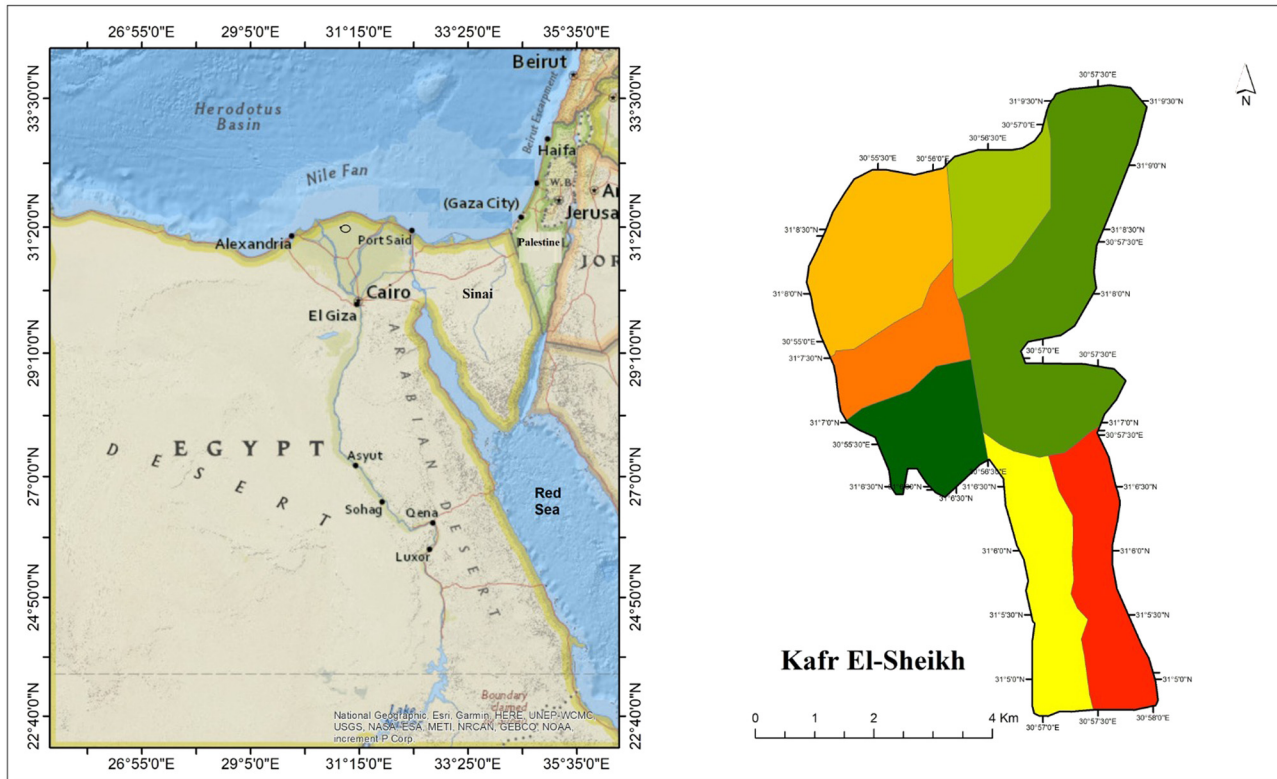
Figure 1: Study area (Kafr El-Sheikh city, Egypt) from Google Earth 2022.

3. The official cadastral map of Kafr El-Sheikh city's urban plan, designed at a scale of 1:5,000. This map included 30 ground control points (GCPs) with known coordinates in the urban area. The GCPs underwent geometric correction by the Kafr El-Sheikh Survey Authority. The RMS of GCPs are few millimeters according to official report.

4. Geometric properties data for various roads in Kafr El-Sheikh city, comprising information such as road widths, the number of lanes, travel times, and road conditions. These data were collected through field observations and obtained from the Roads Directorate in Kafr El-Sheikh. Traffic-related data for the years 2019 and 2020, encompassing statistics on traffic accidents, traffic volume, and speed limits, were sourced from the Roads Directorate in Kafr El-Sheikh.

5 Image processing and analysis

In processing Google Earth images acquired in 2020 with a spatial resolution of 0.5 m, the following steps were undertaken using ArcGIS 10.3 software.

The initial phase involved identifying image coordinates, specifically the row and column values, for distinct points known as GCPs. These GCPs were subsequently paired with their real-world positions in ground coordinates, encompassing latitude and longitude. Formulation of transformation equations: After identifying a satisfactory number of well-distributed GCP pairs, the process employed ArcGIS 10.3 software to establish transformation equations. These equations served to establish the relationship between image coordinates (row and column) and their corresponding new ground coordinates. Mapping coordinates: Subsequently, the transformation equations were applied to the image coordinates, facilitating the mapping of these points to their newly determined ground coordinates. The transformation parameters between image coordinates and GCPs are determined using least square techniques and the accuracy did not exceed few millimeters. This systematic approach ensured the precise georeferencing of the image data. In addition to geographic coordinates, geometric registration can also be performed by aligning one image (or more) to another image. This technique, known as image-to-image registration, was frequently employed prior to various image transformation procedures. The hardcopy
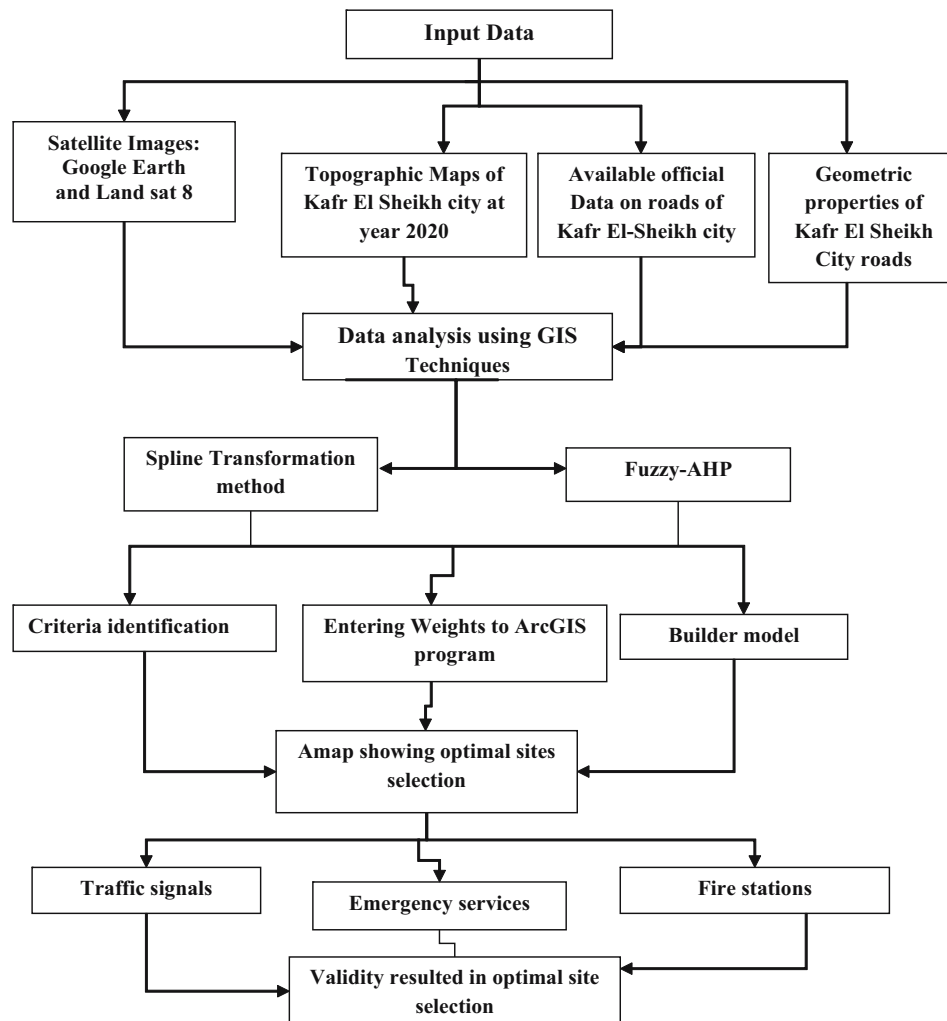
Figure 2: Flowchart of research methodology for the management of road transportation services.

map underwent geo-referencing through the utilization of 20 known coordinate GCPs, with their values established using ArcGIS 10.3 software. The additional points served as checkpoints to assess and validate the precision of the geo-referencing procedure. Subsequently, the study area boundaries were digitized and transformed from ArcGIS shape file format to Google Earth format, ensuring seamless compatibility and integration with the georeferenced data.

6 Applied analytical techniques for the study

Two analytical techniques were used in this research to determine the optimal location for the traffic signals, fire stations, and emergency services as follows.

6.1 Fuzzy analytical hierarchy process (Fuzzy-AHP)

F-AHP is a methodology that extends the traditional AHP by integrating principles from fuzzy logic theory. Although the steps of the F-AHP method resemble those of the traditional AHP, it introduces a distinctive feature by transforming the AHP scale into a fuzzy triangular scale for priority assessment [14,16,17]. This adaptation of AHP has gained considerable attention, especially in the field of risk management and various other domains, owing to its capacity to provide more adaptable scales using fuzzy membership functions [18].

The primary rationale behind adopting this innovative approach is to address the limitations of traditional AHP when dealing with uncertainty. Traditional AHP necessitates decision-makers to select a value from a fixed, predetermined scale, often ranging from 1 to 9. However,

decision-makers frequently require greater flexibility to accommodate uncertainty. F-AHP achieves this by incorporating fuzzy membership functions and linguistic variables like "good" or "poor," instead of relying solely on precise numerical values. This pioneering method has found applications across various sectors, including the construction industry, where its adaptable approach to decision-making in the presence of uncertainty proves to be advantageous and valuable.

Overall, the text effectively argues for the value of F-AHP in overcoming the limitations of traditional AHP when addressing uncertainty in decision-making contexts. While potential limitations exist, F-AHP offers a powerful and adaptable tool for tackling complex problems in various fields.

6.1.1 Pairwise comparison matrix formation

The F-AHP method is widely regarded as a robust mathematical tool for analyzing intricate decision-making problems [19–21]. It operates by establishing the weights of different criteria by means of pairwise comparisons, where decision-makers assess the relative importance of each criterion in relation to others. This process is captured in a pairwise comparison matrix, which forms the foundation for determining the overall priorities and preferences within the decision-making framework.

6.1.2 Calculation of criterion weights

The calculation of criterion weights in the FAHP method is carried out once the pairwise comparison matrix has been established. Here is how the process unfolds:
- Normalization: Initially, the sum of all values in each column of the pairwise comparison matrix is determined. This step helps ensure that the comparisons are balanced and consistent. Each element in the matrix is then divided by the total sum of its respective column. The resulting matrix is referred to as the "normalized pairwise comparison matrix."
- Average row scores: Subsequently, the next step involves computing the average of the elements in each row of the normalized matrix. To do this, the sum of the normalized scores in each row is divided by the total number of criteria. These row averages serve as a preliminary estimation of the relative weights of the criteria being considered [22].

By following these steps, the F-AHP method establishes a quantitative basis for evaluating the importance and significance of each criterion within the decision-making process. These criterion weights are instrumental in making informed and prioritized decisions [23,24].

6.1.3 Estimation of the consistency ratio

The F-AHP method explicitly addresses consistency when conducting pairwise comparisons, involving the following operations [25,26]:
- Calculation of weighted sum vector: Initially, the weighted sum vector is computed by multiplying the matrix of pairwise comparisons on the right by the vector of priorities. This results in a new column vector. Then, each element in this new column vector is divided by its corresponding element in the priorities vector. Finally, these values are summed across all rows.
- Calculation of consistency vector: The consistency vector is derived by dividing the weighted sum vector by the criterion weights. This step ensures that the comparisons remain consistent with the relative importance of the criteria.
- Computation of lambda (λ) and consistency index (CI): Once the consistency vector is obtained, the next step is to calculate two additional terms: lambda (λ) and the CI. Lambda (λ) is determined as the average value of the elements in the consistency vector.
- Calculation of CI: The calculation of the CI is based on the observation that λ for a positive and consistent pairwise comparison matrix is always greater than or equal to the number of criteria under consideration (n). Therefore, the difference between λ and n, denoted as (λ–n), can be regarded as a measure of inconsistency. The CI measure can be normalized using a specific equation [27,28].

$$CI = \frac{\lambda - n}{n - 1}. \tag{1}$$

The term CI is used to quantify the level of deviation from consistency in the AHP. To evaluate the significance of CI, AHP compares it to a reference value called the random index (RI). The result of this comparison is known as the consistency ratio (CR), and it is defined as follows:

$$CR = \frac{CI}{RI}. \tag{2}$$

The RI represents the consistency index of a pairwise comparison matrix that has been randomly generated and typically ranges from order 1 to 10. This value is obtained by approximating random indices for different matrix sizes. To calculate the CI, equation (1) can be used. Equation (2) can be applied to calculate the CR: CR < 0.10, then weights are acceptable.

GIS and MCDA were applied to determine the best sites for emergency services after entering the weights into the ArcGIS 10.3 program. MCDA is used to calculate the relative

Table 1: Degree of importance assigned to the used criteria

Intensity of significance	Description	Classification of suitability
1	Same importance	Lowest suitability
2	Same to moderate importance	Very low suitability
3	Moderate importance	Low suitability
4	Moderate to strong importance	Moderately low suitability
5	Strong importance	Moderate suitability
6	Strong to very strong importance	Moderately high suitability
7	Very strong importance	High suitability
8	Very strong to extremely strong importance	Very high suitability
9	Extreme importance	Highest suitability

weights of individual evaluation criteria [29,30]. The used criteria informing matrix was applied according to Table 1.

6.2 Spline transformation method

The spline transformation method is a precise technique for transforming source control points to target control points. It is particularly valuable when it is essential to achieve precise registration of critical control points. To carry out the spline transformation, a minimum of 10 control points is necessary, as established by previous literature [25–27]. Increasing the number of control points beyond this minimum can enhance the overall accuracy of the spline transformation. The method typically involves three main steps.

6.2.1 Defining and formulating criteria for evaluating the land

Many criteria have been adopted in the planning process through the layers and available databases provided by the GIS system. The system determines the optimum sites for fire stations [31,32], traffic signals, and emergency services [33–35]. Each criterion will be assigned a specific rank according to its importance. The criteria that will be included in the comparison process can be summarized as follows and shown in Figure 3

1. Elevation: It is a layer of the Raster grid type, representing the land heights in the investigated city.
2. The land use layer, a layer of the Raster grid type, represents the description of the study area.
3. Roads layer: includes the road network in the investigated city.
4. Layer with traffic jams in Kafr El-Sheikh.
5. Layer of hospital and fire station locations in the city, study area, and existing government institutions, as well as banks, schools, and service areas.
6. Layer for the areas with the most accidents.

6.2.2 Dealing with criteria by using analysis of spatial functions

The methodology used in planning the optimum sites depends on statistical analysis to process the data types (Vector and Raster), which include:

Tools management data: It was used to find emergency services that were established before the new planning and to take a certain distance from them.

The buffer zone: This tool has been used to exclude areas near other aid centers.

Rasterization: The modeling processes make it easy to work with data in grid mode, so all vector maps are converted to a Raster grid.

Reclassification: Use this step to rearrange and distribute cells. This makes it easier to deal with, so the criteria are classified, with the most suitable cells receiving a rank of 10 and the least suitable receiving a rank of 1 on the common scale.

Overlay weighted criteria tool: GIS tools have been provided with the flexibility to give the influencing criteria greater weight than the rest. From this standpoint, the study resorted to using the weighted values by giving the influencing elements greater than the other elements.

7 Site analysis and applied criteria for the case study

Site analysis work was completed to manage the geographically established resources available to the study site, analyze the information available for the site, and show the potential obstacles to the development of the site under investigation. As a result, when analyzing any site, computer techniques can be used to prepare data and studies in digital form, which contributes to the development of a
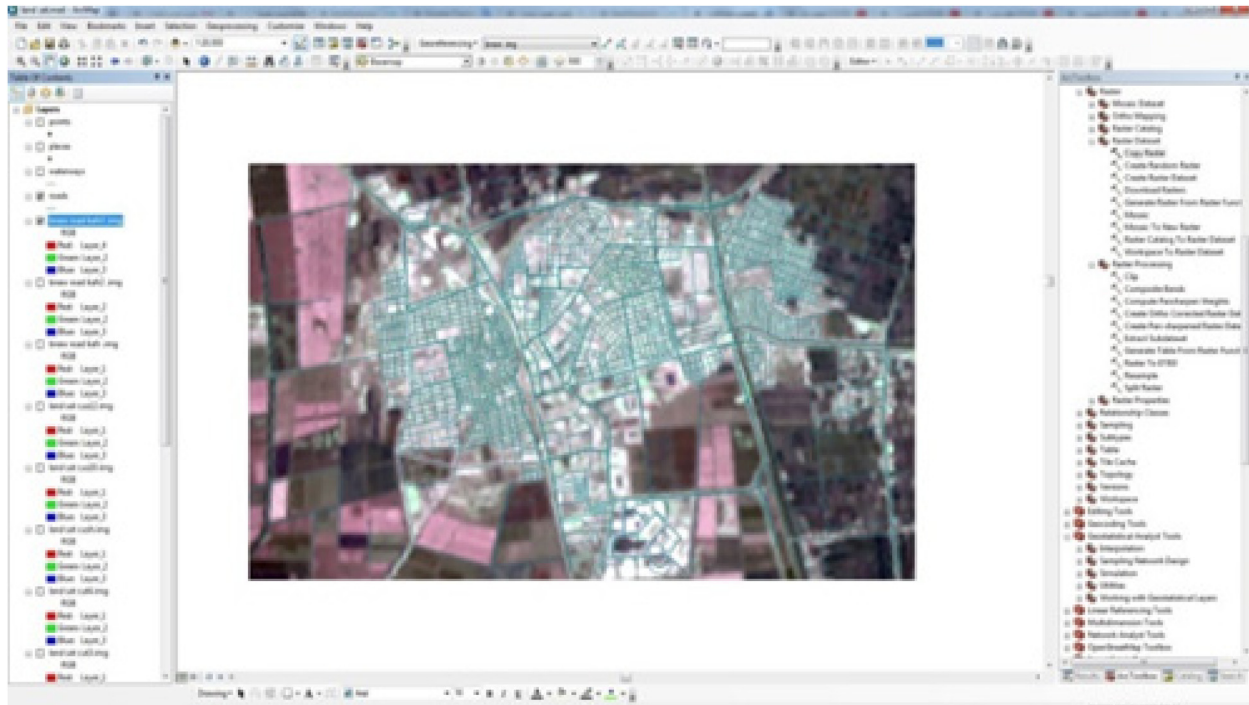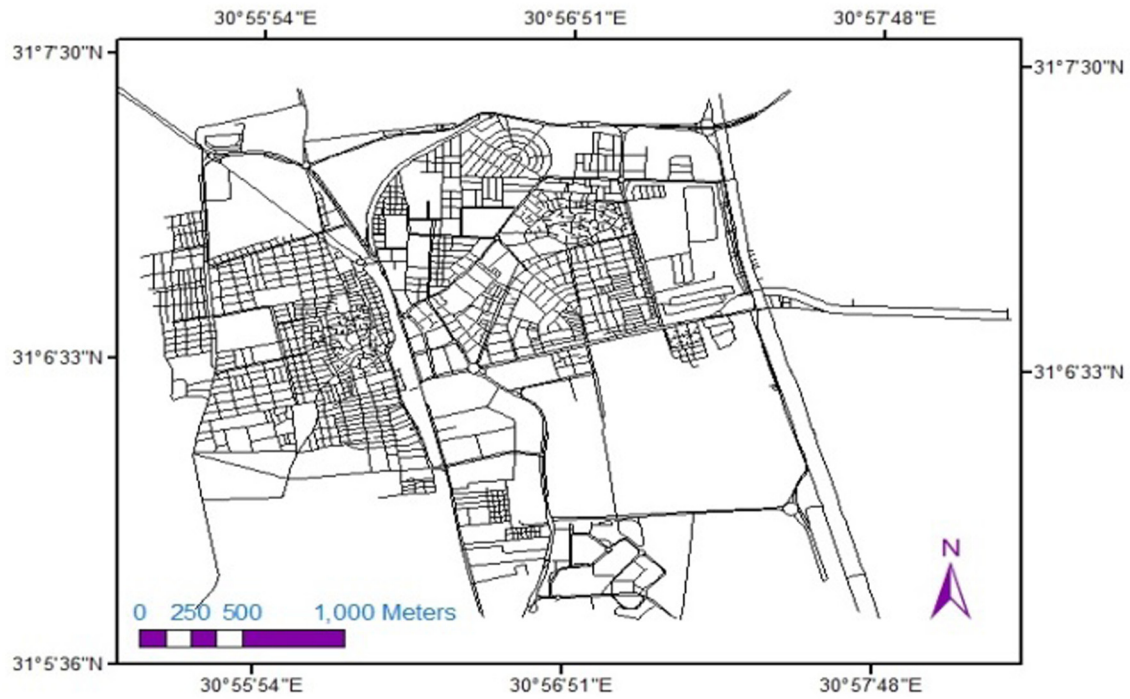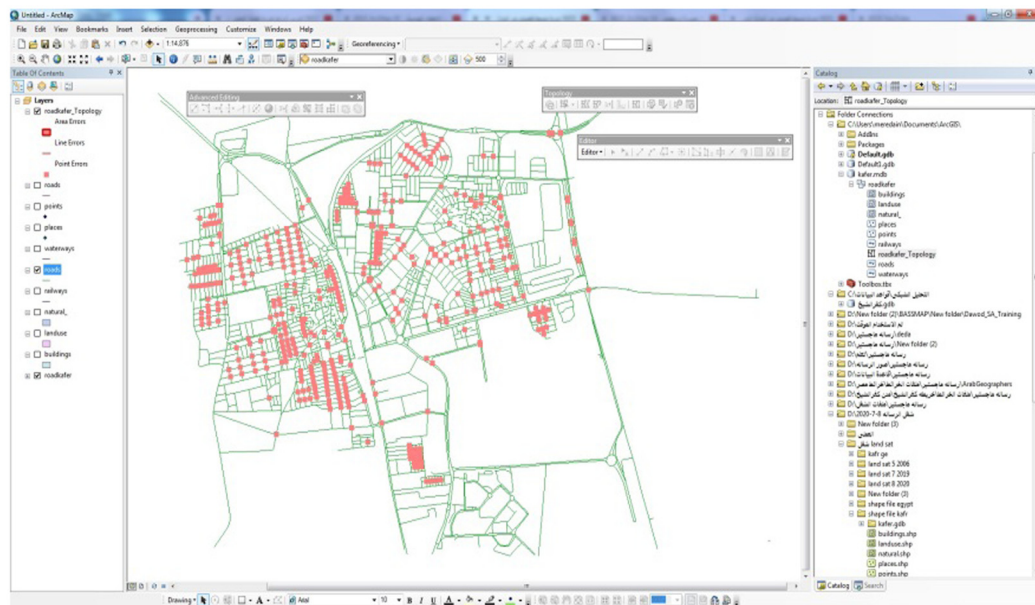
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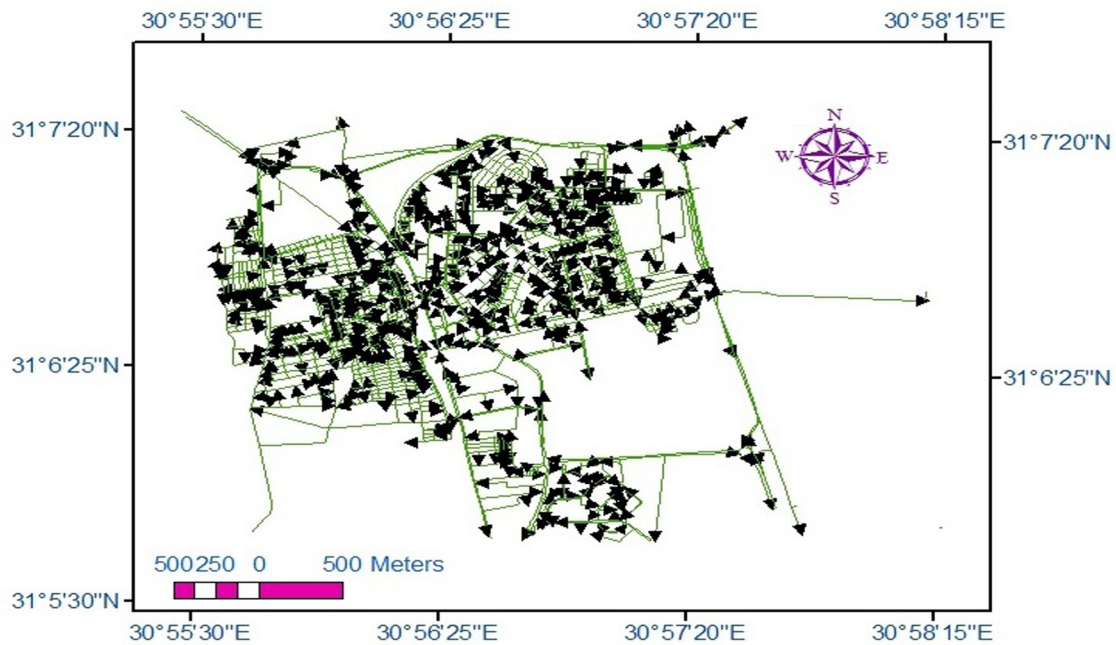
b)

Figure 3: Land use maps for the study area. (a) Feature class for roads. (b) Directions for roads. (c) Road networks in Kafr El-Sheikh City. (d) Area errors for roads. (e) Roads in Kafr El-Sheikh city.
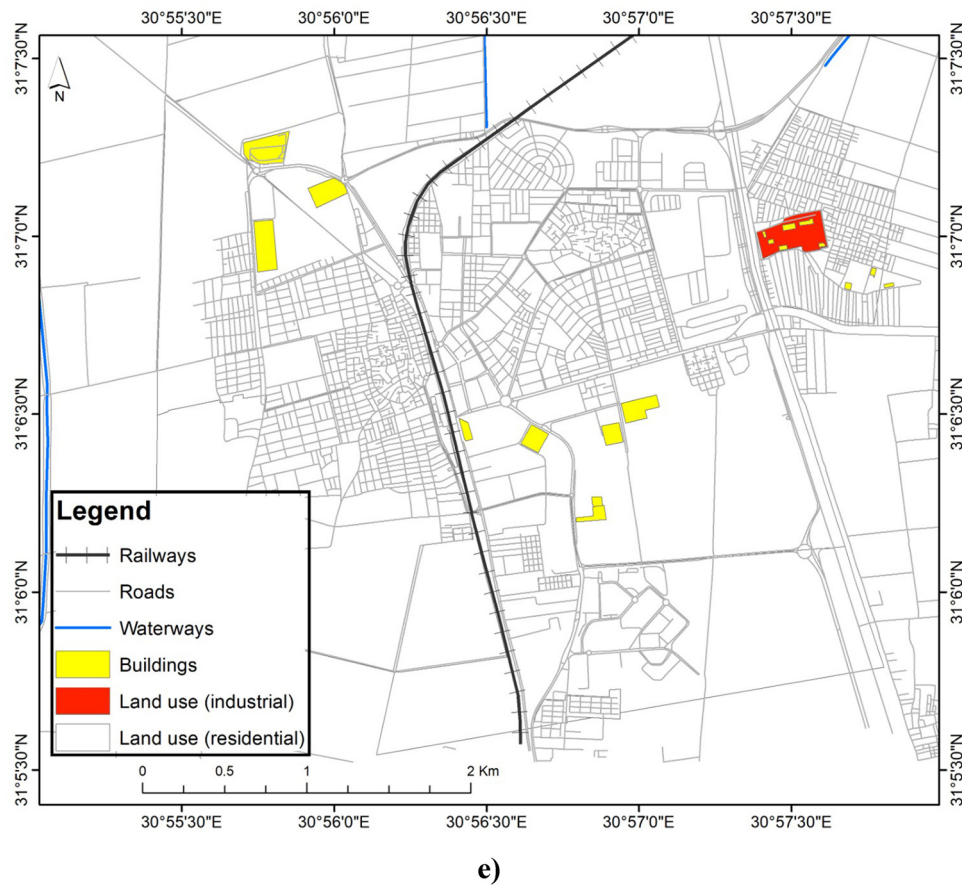
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Figure 3: (*Continued*)

e)

Figure 3: (*Continued*)

Table 2: Applied criteria for emergency services, fire stations, and traffic signals

Criteria	Description
Buildings	Existing buildings
Land uses	City landmarks such as schools and petrol stations
Road	Roads, whether main or secondary roads within the city
Railways	City railways
Waterways	The city's waterways, canals, and drains
Heavy traffic	City heavy transport vehicles
Hospitals	Hospitals, medical centers, dispensaries, and health units in the city
Ambulances	Ambulance centers currently exist and are located in the city
Fire fighter	Fire stations in the city
Highway roads	City highways roads
Crossroads	City intersections

digital information system for site studies and analysis, resulting in increased efficiency of the site analysis process and the generation of accurate, correct, and spatially referenced results. Consequently, each criterion was analyzed separately. An appropriate map was produced for it by giving each cell or group of cells in the stratum an appropriate degree according to its importance or sensitivity to determine the optimum sites. Where two methods were used, where the appropriate areas for establishing the optimum sites were given number 6 and the inappropriate areas number 1, this was applied to road layers, residential communities, traffic congestion, and the rest of the other layers. However, the second method was given in the stratum and arranged according to its importance. The appropriate areas took the number 6 and the least appropriate 5, then 4, and so on until it reached number 1, which is the least appropriate for the establishment of service sites

Table 3: Pairwise comparison matrix for the determination of new sites

Criteria	Buildings	Land uses	Road	Railway	Waterways	Heavy traffic	Ambulances	Hospitals
Emergency services								
Buildings	1	0.3	0.11	0.3	0.3	0.2	0.3	0.5
Land uses	3	1	0.11	0.2	0.3	0.1	0.3	0.5
Road	9	9	1	0.3	0.5	0.3	0.5	0.3
Railway	3	5	3	1	0.3	0.5	0.2	0.5
Waterways	3	3	2	3	1	0.3	0.5	0.5
Heavy traffic	5	7	3	2	3	1	0.2	0.3
Ambulances	3	3	2	5	2	5	1	0.5
Hospitals	2	2	3	2	2	3	2	1

Criteria	Road	High way	Landmark	Cross section	Heavy traffic
Traffic signal					
Road	1	0.2	0.2	0.2	0.2
High way	5	1	0.3	0.2	0.14
Landmark	5	3	1	0.3	0.14
Cross section	5	5	3	1	0.16
Heavy traffic	5	7	7	6	1

Criteria	Fire fighter	Landmark	Buildings	Land use	Road	Railway	Waterways	Heavy traffic
Fire stations								
Fire fighter	1	0.2	0.3	0.3	0.2	0.2	0.5	0.2
Landmarks	5	1	0.3	0.5	0.2	0.3	0.5	0.2
Buildings	3	3	1	0.5	0.3	0.2	0.3	0.2
Land uses	3	2	2	1	0.3	0.5	0.3	0.11
Road	5	5	3	3	1	0.2	0.2	0.3
Railway	5	3	5	2	5	1	0.5	0.3
Waterways	2	2	3	3	5	2	1	0.5
Heavy traffic	5	5	5	9	3	3	2	1

The criteria used to determine the optimal site selection for emergency services, fire stations, and traffic signals were established based on a combination of available previous studies and the guidelines set forth by the Egyptian Ministry of Housing. These criteria play a crucial role in the decision-making process, helping identify the best locations for these essential services. While the specific criteria are not listed in your message, Table 2 is likely to provide a detailed breakdown of these criteria and their associated attributes. These criteria may encompass factors such as population density, response time, and proximity to critical infrastructure, traffic patterns, and more, with each criterion contributing to the overall assessment of optimal site selection.

8 Results and analysis

The cartographic model was constructed within the ArcGIS software using the Builder Model tool. This approach is rooted in the concept of simplifying intricate problems, dealing with overlapping data, and considering their spatial and descriptive connections. Prior to creating the model, the following steps were undertaken: establishing

Table 4: Final resulting weights of applied criteria using F-AHP for emergency services, traffic signals, and fire stations

Criteria	Emergency services	Traffic signals	Fire stations
Buildings	0.04		0.06
Land uses	0.05		0.07
Road	0.14	0.04	0.12
Railway	0.10		0.17
Waterways	0.11		0.18
Heavy traffic	0.16	0.53	0.31
Ambulances	0.21		
Hospitals	0.20		
Highway		0.09	
Landmark		0.13	0.06
Cross section		0.2	
Fire fighter			0.03

criteria, defining their categories, determining the degree of their importance, and assigning weights to these criteria. Subsequently, the model was developed to break down the primary problem into smaller, more manageable sub-problems. This strategy relies on spatial analysis techniques and leverages the capabilities of the software to formulate a step-by-step approach for problem-solving, ensuring that it fully addresses the spatial and analytical aspects of the task at hand.

8.1 F-AHP method

Tables 3 and 4 play a significant role in the decision-making process by providing a structured approach to evaluate and prioritize criteria for optimal site selection. Table 3 presents a pairwise comparison matrix for emergency services, traffic signals, and fire stations. The matrix includes hypothetical numbers that represent the relative importance of each criterion. These numbers are assigned
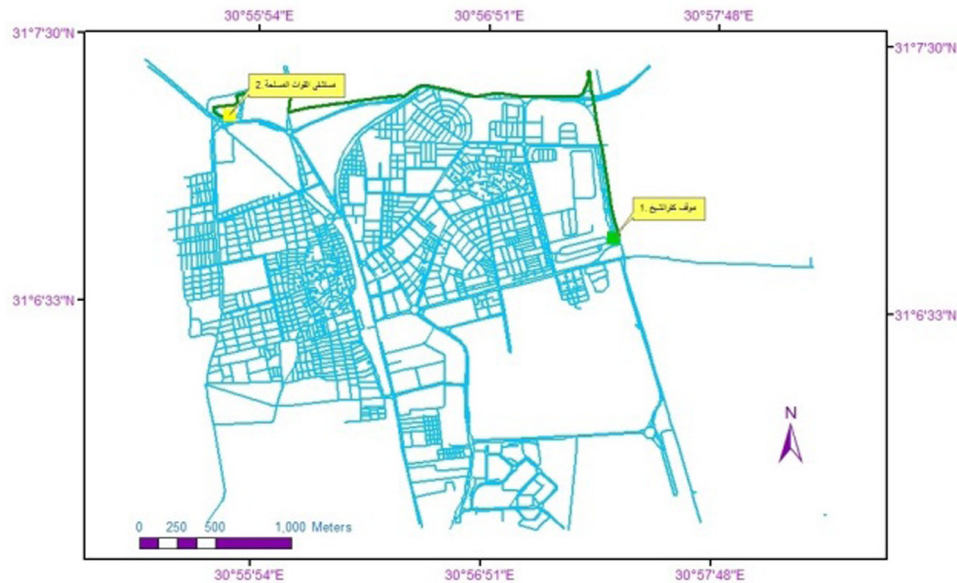
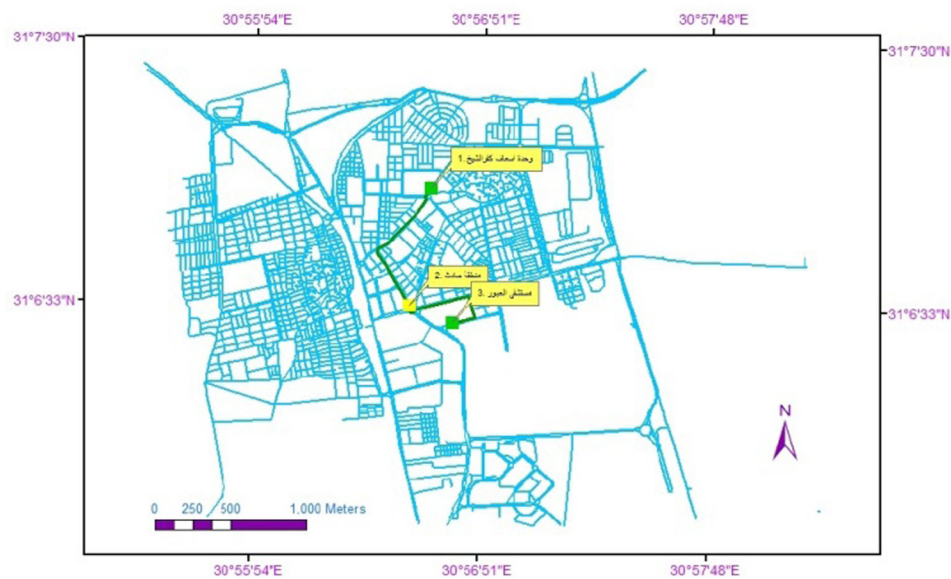**Figure 4:** The short and quick path from main barking to armed forces hospital.

Figure 5: The closest ambulance to a specific accident site and the best way to get to it and move to the hospital.
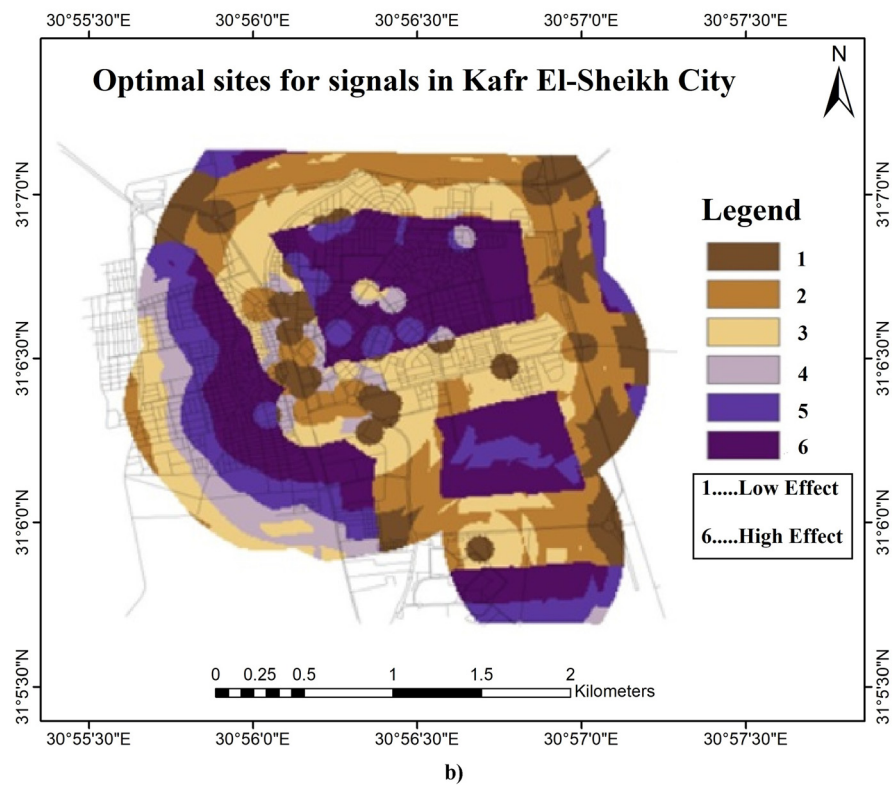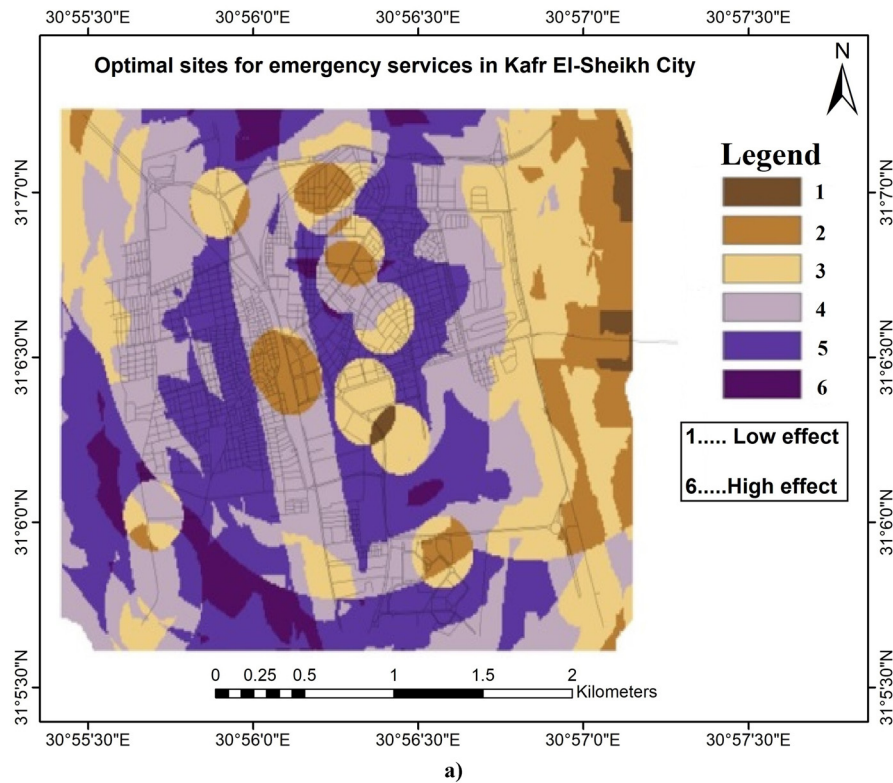
a)

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Figure 6: Optimal sites selection for emergency services, traffic signals, and fire stations based on the F-AHP method. (a) Emergency services. (b) Traffic signals. (c) Fire stations.
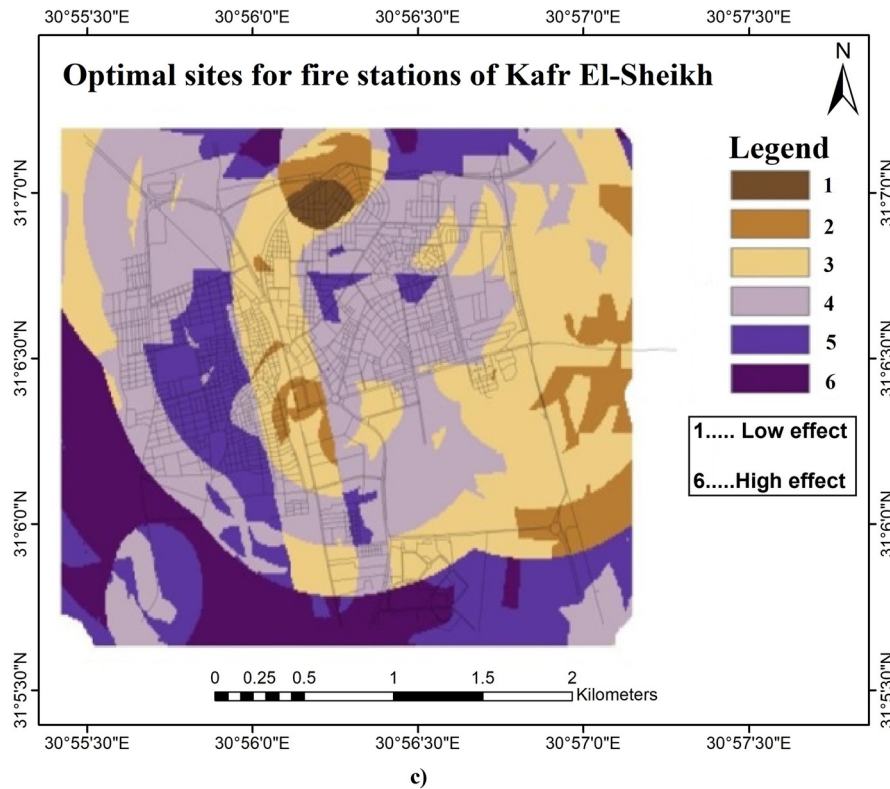
Figure 6: (*Continued*)

on a numerical scale where "extremely important" is denoted by number 6 and the least important criterion is assigned number 5, with the scale descending in decreasing order of importance.

Table 4 displays the final weights of the criteria applied using F-AHP method. These weights represent a quantitative measure of the relative importance of each criterion specifically for the studied city. The resulting weights allow decision-makers to prioritize and make informed decisions based on the significance of each criterion within the context of the site selection process. In essence, these tables provide a structured framework for assessing and ranking the criteria based on their importance, helping guide the selection of optimal sites for emergency services, traffic signals, and fire stations in the studied city.

Weights were entered using the F-AHP method on the model builder on the ArcGIS program. The maps in Figure 6 show the optimal sites for emergency service, traffic signals, and fire stations, where the purple number 6 indicates the optimal sites for establishing new services, the number 5, with the mauve color, indicates the least suitable sites for establishing new emergency services.

The system determines the nearest emergency center to eliminate a problem when reporting on the accident site by determining the shortest and fastest path to reach it, and finally it is drawn on the map to facilitate tracking and arrival in a timely manner and providing the service quickly. If there is an accident, the shortest path is calculated in terms of time to reach the nearest hospital or ambulance to that center, and it is drawn on the map, and so on in any other type of accident.

The first model of the analysis shows how to calculate the shortest path between the Kafr El-Sheikh parking lot and the Armed Forces Hospital and the shortest time it takes to get from the parking lot to the hospital. This example is considered the general case for finding the shortest path, where the starting and ending point is determined, and the system calculates the shortest path, using the specified speed for each part of the road according to the type of road, whether it is a highway, secondary, or other road, and the length of the road to calculate the time taken to cross the road. Then, the most appropriate path, i.e., the lowest, is chosen to cut the distance between the parking lot and the hospital, as shown in Figure 4.

The second model assumed that an accident occurred in a certain area in the city of Kafr El-Sheikh, as shown in Figure 5. Using the system, the location of the accident is determined and displayed on the map, and then the nearest
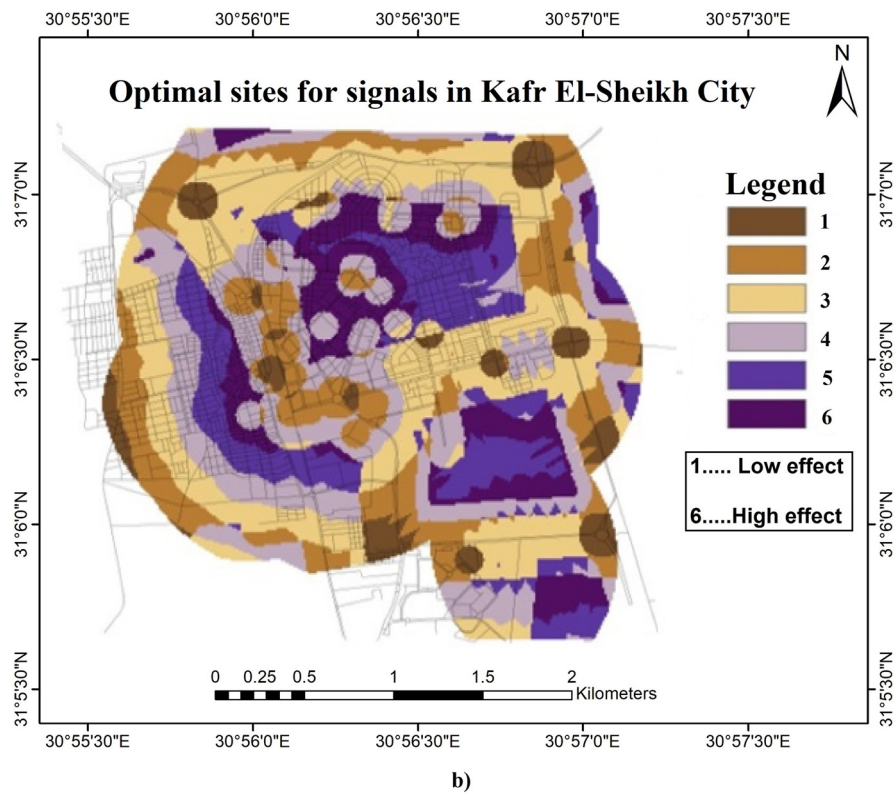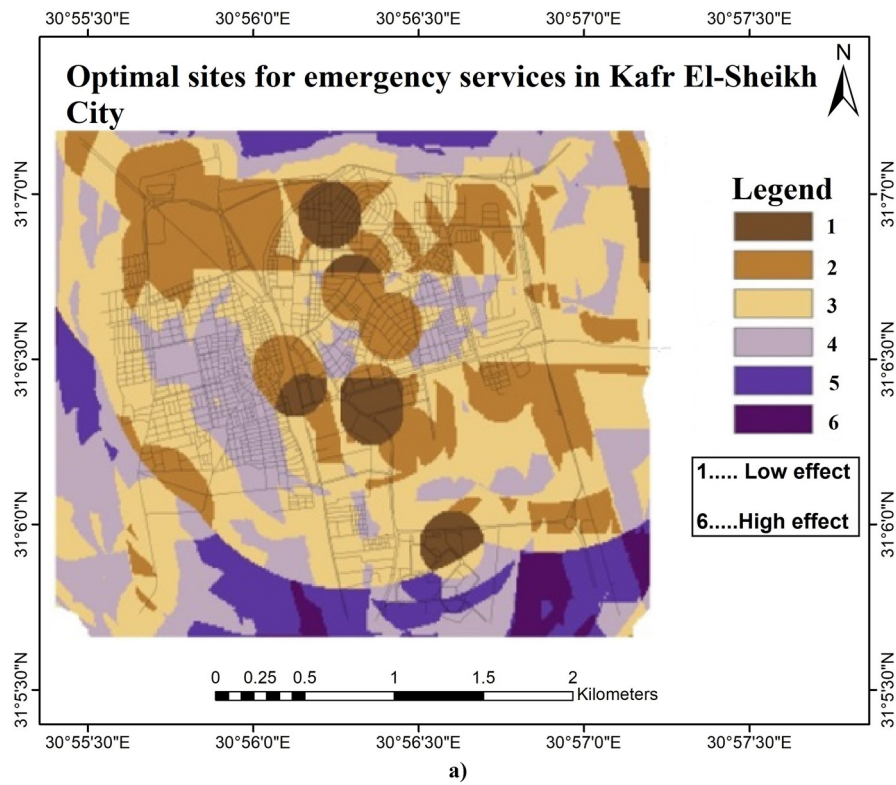
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Figure 7: Optimal sites selection for emergency services, traffic signals, and fire stations based on the spline transformation method. (a) Emergency services. (b) Traffic signals. (c) Fire stations.
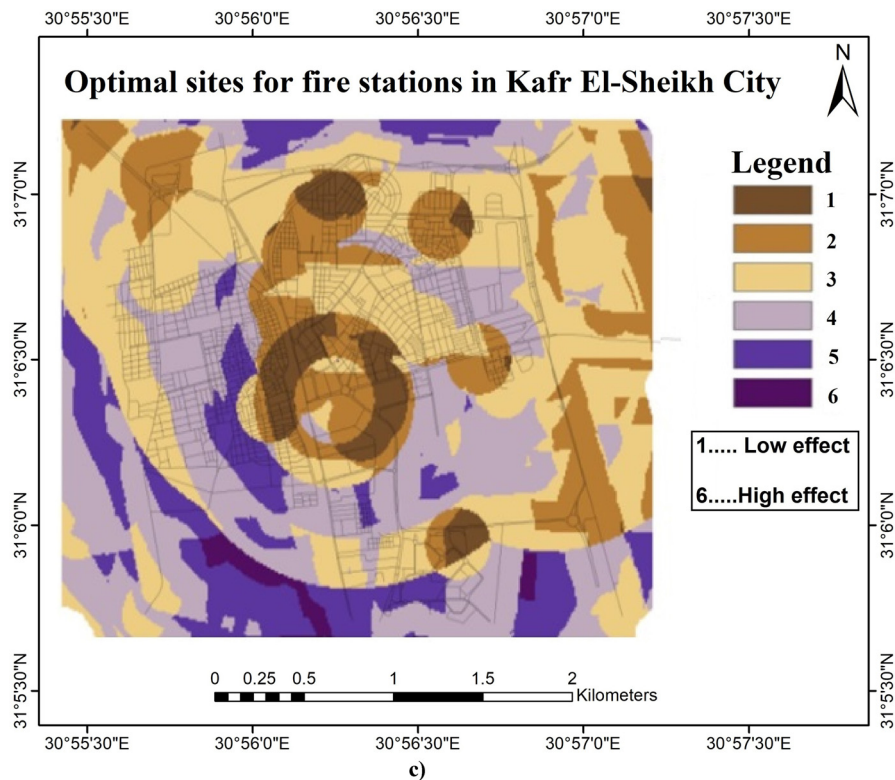
Figure 7: (*Continued*)

ambulance is determined. And the most appropriate path for the ambulance to take is determined to reach the site of the accident in the shortest time, by studying the speed tables for the roads used, as well as avoiding areas with traffic congestion and reducing risk (Figure 6).

The common scale is based on values from 6 to 1, with 6 being the highest degree deemed suitable for ideal sites and 1 being the lowest degree deemed suitable for site selection.

8.2 Spline transformation method

Based on previous research and following the standards of the Egyptian Ministry of Housing, the weights assigned to the applied criteria have been determined as follows:
- Traffic congestion: 20%
- Emergency services located in the city: 20%
- Hospitals: 10%
- Roads: 15%
- Residential compounds: 15%
- Railways: 5%
- Schools and service areas: 15%

After inputting these weights into the model using the spline transformation method within the Model Builder of the ArcGIS program, a resulting digital map is generated. This map displays the new optimal sites, where number 6 represents the most optimal sites, and number 5 represents the least important sites, as depicted in Figure 7. It is important to note that the areas represented by different colors or classifications in Figure 7 can be analyzed and interpreted using the functionalities of the ArcGIS program. This map provides valuable insights for decision-makers regarding the optimal locations for emergency services in the studied city based on the weighted criteria and the spline transformation method.

8.3 Comparison between the two analytic methods for emergency services

Table 5 and Figure 5 provide a breakdown of the areas resulted from the spline method and F-AHP method for three different services: Emergency service, traffic signals, and fire stations. It can be observed that the distribution of areas for individual sites differs between the spline and F-AHP methods. For emergency service, site 2 has a

Table 5: Comparison between the estimated areas from F-AHP and spline method analysis

| Area number	Area resulted from F-AHP method (m²)	Percentage	Area resulted from spline method (m²)	Percentage
Emergency service				
1	129,165	1	69,701	1
2	1,358,338	10	506,646	4
3	3,061,977	24	2,786,867	22
4	4,097,574	32	5,083,484	39
5	3,704,264	29	3,055,805	23
6	516,949	4	1,365,764	11
Sum	**12,868,267**	**100**	**12,868,267**	**100**
Traffic signals				
1	130,605	3	111,064	2
2	783,580	10	357,519	5
3	1,510,546	20	1,355,740	18
4	1,603,897	21	1,984,253	26
5	553,916	7	1,769,253	23
6	2,965,280	39	1,972,916	26
Sum	**7,547,824**	**100**	**7,550,745**	**100**
Fire stations				
1	99,121	1	9,546	1
2	593,561	7	625,221	5
3	2,988,553	28	2,142,076	17
4	4,737,209	36	4,498,637	34
5	2,008,500	16	3,817,662	29
6	914,147	12	1,777,869	14
Sum	**11,341,091**	**100**	**12,871,011**	**100**

substantial increase in area when using the F-AHP method. However, for fire station, sites 3 and 4 have notable increases in area when using the F-AHP method, suggesting different site preferences compared to the spline method. The difference between the areas resulting from the two analytic methods is approximately 2–7%. In the F-AHP model, the correlation between applied criteria was considered in optimal site selection. Therefore, this method is better than the spline transformation method. In general, the F-AHP method seems to allocate larger areas to certain sites compared to the spline method in all three services. Differences in percentage distribution between the two methods indicate variations in site prioritization or selection criteria. It is important to consider the specific factors and criteria that led to these results (Figure 8).
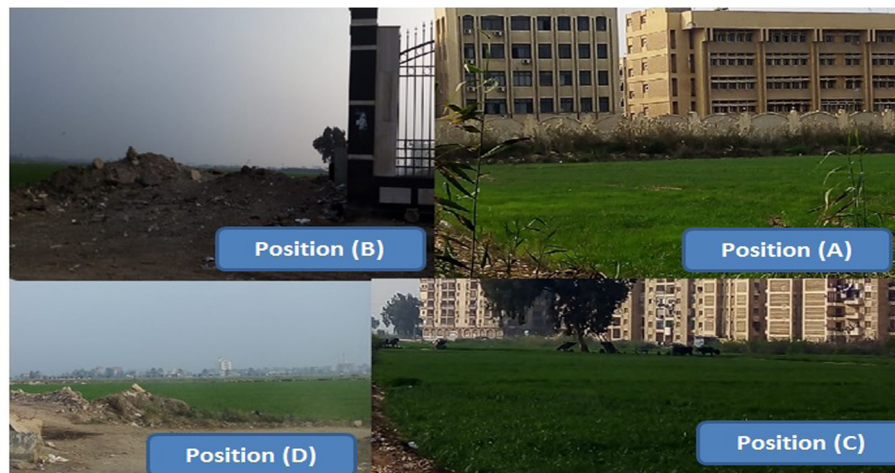
9 Validation of optimal sites

The validation of the results for the selection of the four optimal sites for each service involves a comprehensive

a)

b)

c)
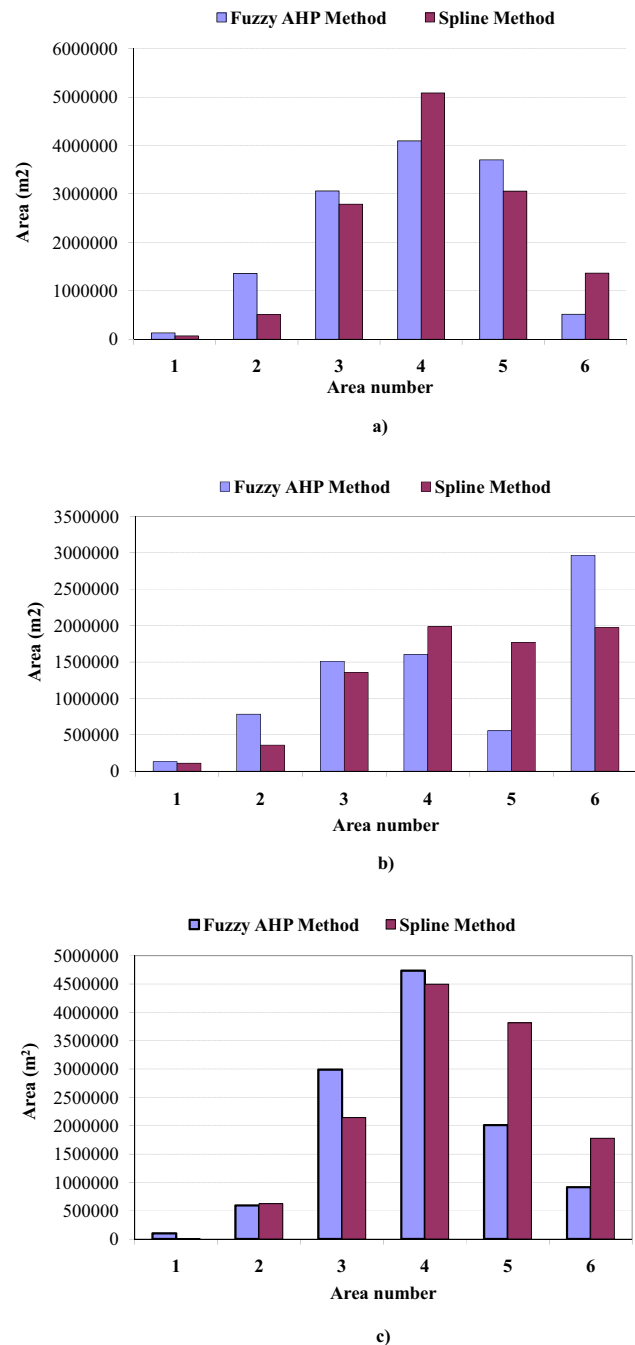
Figure 8: Comparison of the estimated areas for emergency services, traffic signals, and fire station sites using F-AHP and spline techniques. (a) Emergency services. (b) Traffic signals. (c) Fire stations.

process. The identification of these new sites is visualized on the Google Earth city map, as depicted in Figure 9. A meticulous visual examination is undertaken to confirm the selected sites in a real-world context and to ensure the absence of existing buildings. Subsequently, a field visit to the specified sites, as extracted from the preceding results, validates their excellent location suitability for
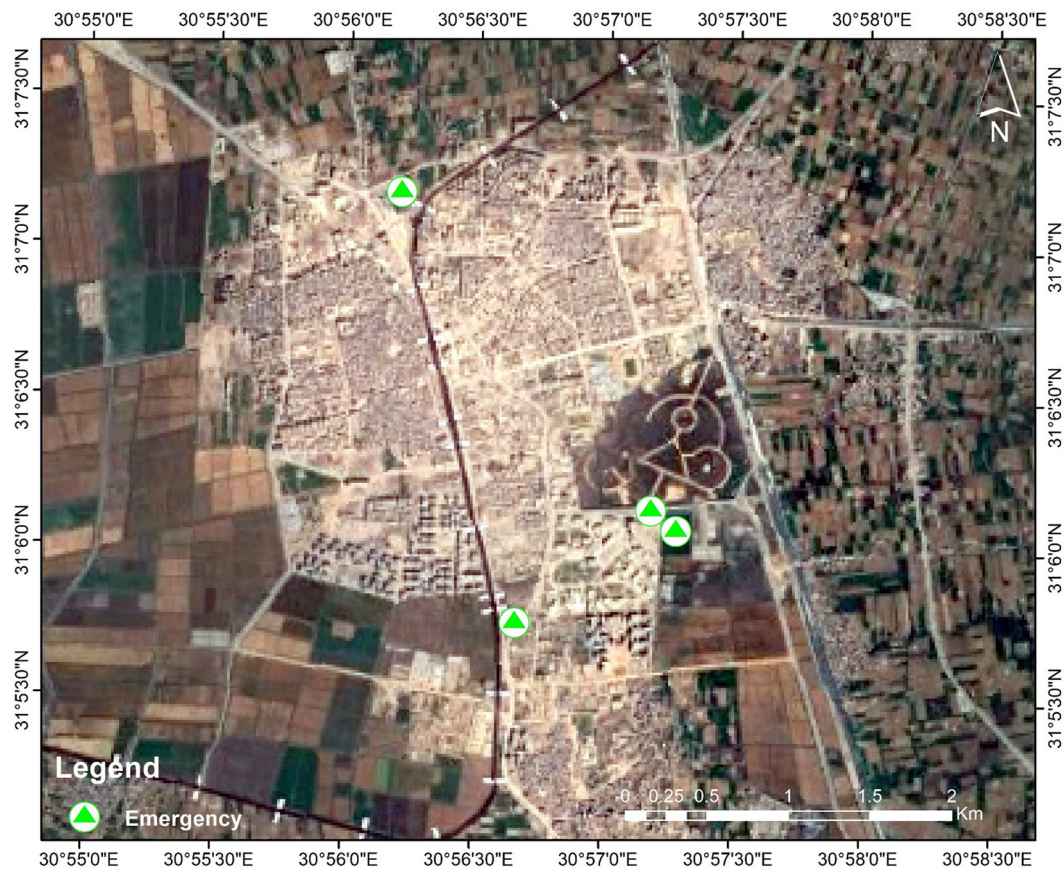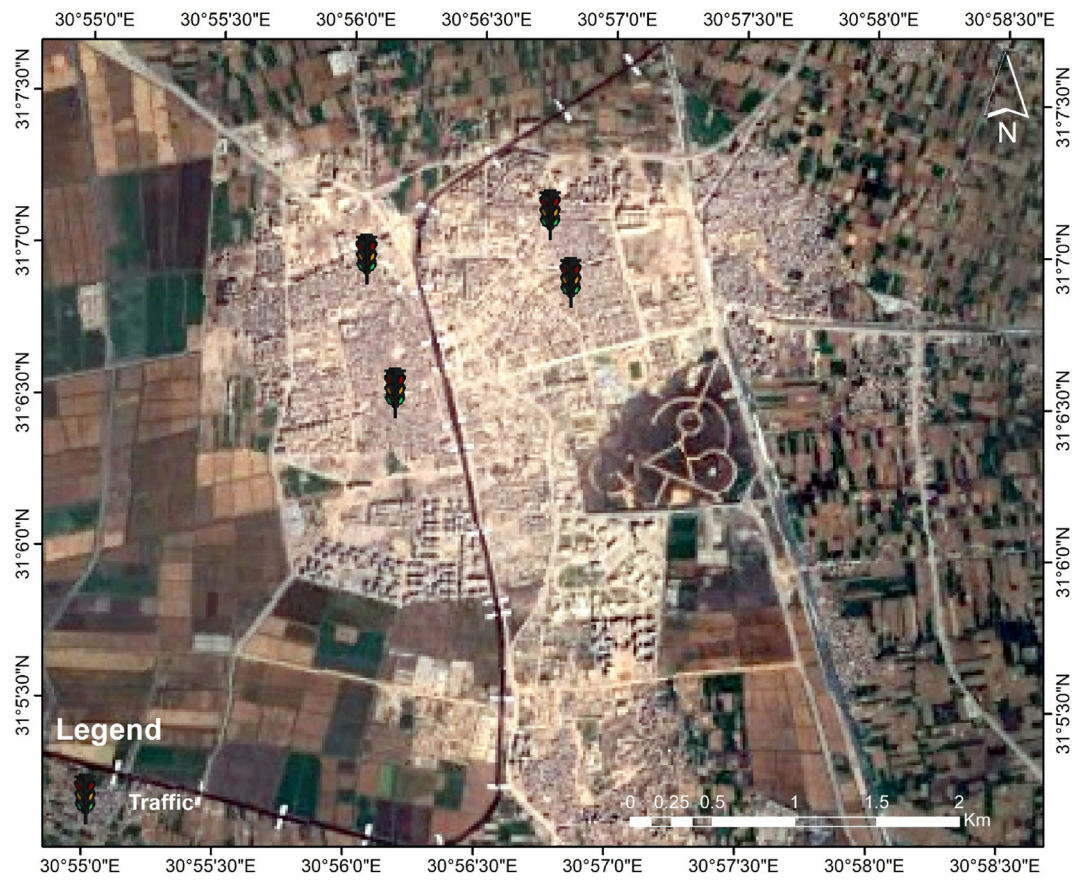
Optimal site selection for Emergency Services on Kafr El Sheikh city on Google Earth map

Validation of resulted site selection for Emergency Service through visual examination

a)

Figure 9: Validation of results from optimal site selection for new emergency services, traffic signals, and fire stations on Kafr El-Sheikh City on Google Earth map and visual examination. (a) Emergency services: Optimal site selection for emergency services on Kafr El-Sheikh city on Google Earth map. Validation of resulted site selection for emergency service through visual examination. (b) Traffic signals: Optimal site selection for traffic signals on Kafr El-Sheikh city on Google Earth map. Validation of resulted site selection for traffic signals through visual examination. (c) Fire stations: Optimal site selection of fire stations on Kafr El-Sheikh city on Google Earth map. Validation of resulted site selection for fire stations through visual examination.
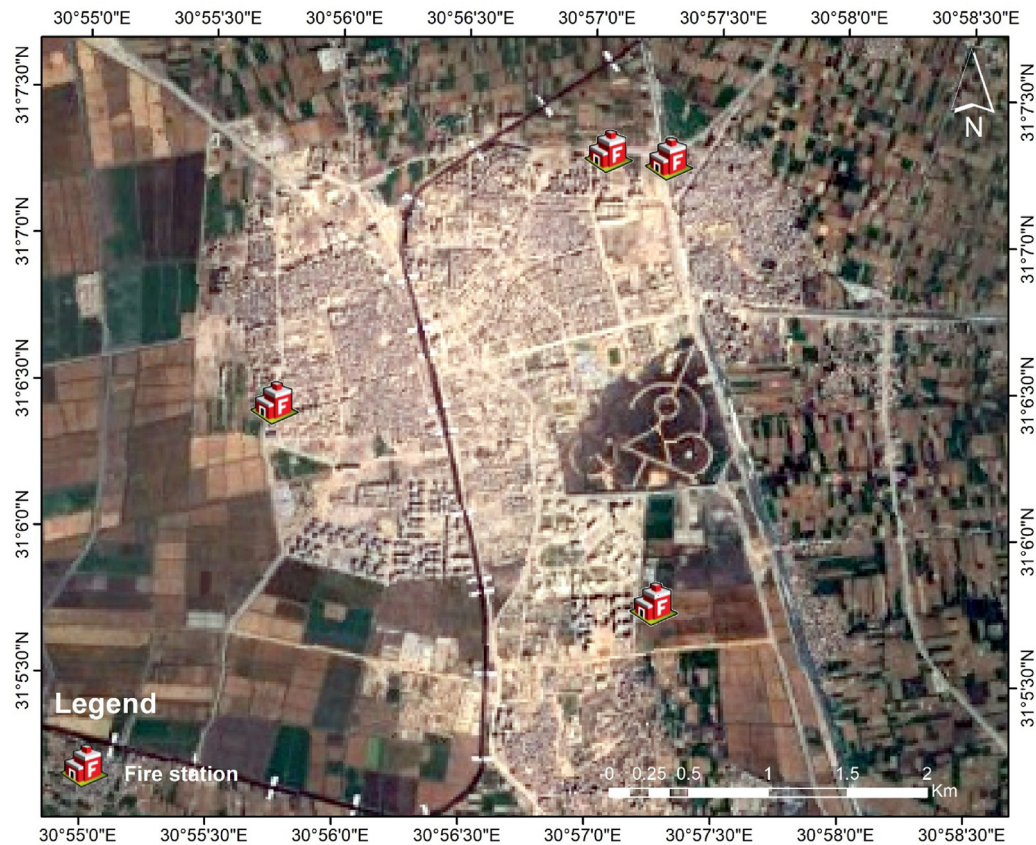
Optimal site selection for Traffic Signals on Kafr El Sheikh city on Google Earth map

Validation of resulted site selection for Traffic Signals through visual examination

b)

Figure 9: (*Continued*)

Optimal site selection of Fire Stations on Kafr El Sheikh city on Google Earth map

Validation of resulted site selection for Fire Stations through visual examination

c)

Figure 9: (*Continued*)

the intended purposes. The findings affirm that the predetermined goals are successfully achieved through this site selection process.

10 Conclusion

In summary, the effective management of road transportation is paramount in addressing the complex challenges arising from population growth, transportation congestion, and the impact of external factors such as the development of the corona virus. This study leverages GIS Network Analyst, incorporating remote sensing data, to analyze and propose solutions for road-related issues in Kafr El-Sheikh city, Egypt. Based on the obtained results, the following key conclusions can be drawn:

1. The combination of GIS techniques and MCDA employing F-AHP proves to be highly effective in identifying optimal new sites for constructing traffic signals, emergency services, and fire stations within residential cities.
2. Kafr El-Sheikh city stands to benefit from the establishment of four new traffic signal sites at specified locations outlined in the study. This strategic placement aims to mitigate accidents, alleviate traffic congestion – particularly during peak hours – and minimize delays in travel time.
3. The study recommends the establishment of four new emergency service sites at resulted identified locations to expedite the transportation of patients to hospitals efficiently. Additionally, four new fire station sites are deemed essential, strategically positioned as indicated in this research. The comparison between the F-AHP and spline transformation methods reveals a close alignment in the location and area of resulting new sites for traffic signals, fire stations, and emergency services. The differences in site areas range from 2 to 12% across all studied cases.
4. Satellite imaging emerges as a crucial and useful tool for detecting changes in both urban and rural areas, underscoring its importance in the context of this study.
5. The outcomes of this research empower decision-makers in the study area with comprehensive data to expedite problem-solving efforts. The identified and verified sites, validated through ground-trothing, serve as a robust foundation for optimizing site selection for emergency services. Ultimately, this approach facilitates timely and efficient decision-making, addressing current and future challenges related to the establishment of fire stations and traffic signals in the study area.

The study provides valuable insights for urban planners, enabling them to optimize the placement of critical infrastructure such as traffic signals, fire stations, and emergency services. This can contribute to more efficient city planning and improved public safety.

1. Decision-makers can use the identified optimal sites to allocate resources more effectively, ensuring that emergency services are strategically positioned to minimize response times and enhance overall service delivery.
2. The establishment of new traffic signal sites at recommended locations holds the potential to significantly reduce accidents and alleviate traffic congestion, positively impacting overall transportation efficiency.

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Data availability statement: The submitted work contains all data, models, and code generated or used during the study.

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