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Site Selection of Fire Station Based on GIS Approach for Baquba District Eastern Iraq

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Abstract: ***This study aims to nominate a suitable location for a new fire station in Baquba District Eastern Iraq. The suitability model was selected using GIS-based on five criteria layers including the roads, hospital, existing fire stations, population, and police stations. All the dataset was processed using ArcGIS 10. The criteria layers were standardized using fuzzy liner membership (FLM) and then combined to produce the final fire station suitability map using the fuzzy overlay method. The study area divided into three classes namely: unsuitable, low suitability, and high suitability according to the five criteria applied. The study shows the efficiency of the fuzzy overlay method for multi-criteria spatial modeling based on the fuzzy logic principle. The Fuzzy overlay defines the membership using the liner function on each of the input rasters.***

Keywords: Fire Station, Fuzzy Overlay, GIS, Safety, Site Selection.

1. INTRODUCTION

Recent years have seen an enormous shift in the geographic dynamics of urban fires, which has raised the risk of fire in urban areas. There are several factors that contribute to this shift, including urbanization, climate change, and changes in building materials and construction practices (Zhang et al., 2018). Urbanization has led to the expansion of cities and the development of high-density housing, which increases the risk of fire. Climate change has also led to more extreme weather conditions, including droughts and heatwaves, which increase the risk of fire. Changes in building materials and construction practices have also contributed to the shift in fire dynamics, as some modern building materials are more flammable and can contribute to the rapid spread of fire. It is essential to take these factors into account and implement measures to prevent and respond to urban fires effectively. This may include implementing building codes and regulations, providing fire education and training to residents

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and first responders, and developing effective response plans and strategies (Ardianto and Chhetri, 2019).
It is necessary to manage the increased rate of fire more effectively because it is outpacing the measures intended to reduce it (Thapar, 2000). Due to the urgent necessity to meet fire safety criteria, city fire stations are a vital emergency service that must be taken into account by every urban designer and planner who will construct and develop any city. The population of Iraqis has grown rapidly, and as a result, Diyala City's development and building activities—particularly in the Baquba District—have grown significantly. Due to a number of factors that existed in Iraq and its cities during the recent decade, the provision of essential services needed in the city was not matched by the increase in population growth. This has increased pressure on service activities in Diyala city and exacerbated the infrastructure services of the fire and rescue services. Therefore, fulfilling the provision of fire stations and their distribution requirements has become a necessity that designers must address and solve.

A Geographic Information System (GIS) assisted the planners in the development of cities by making the site selection task less complicated. GIS is a useful planning tool that also makes it possible for users to comprehend the circumstances behind the creation, alteration, display, and analysis of locations from actual to digital maps (Cheng et al., 2007).

When an emergency is reported, time is of the utmost importance. The rate at which a fire grows can be many times its volume each minute. For the rescue of residents and the use of extinguishing agents to reduce loss, time is a crucial aspect. Fire loss is directly correlated with the interval between the commencement of a fire and the beginning of fire suppression. Emergency medical quality service is also time-sensitive. Rapid action by skilled emergency medical staff is necessary to increase survival chances in several types of medical situations. The chances of survival and property preservation are often higher the faster trained emergency medical or fire rescue workers arrive (Esri, 2007; Mohamed, 2017). Based on the above concepts, fire stations must be strategically placed; in an emergency, the fire department ought to be able to get there in under five minutes. In other words, the quantity and location of fire stations have a big impact on how quickly emergency personnel can respond to fire accidents. The coverage matrix is crucial for identifying the possibility of alternate places as a result. With the aid of mathematical model based GIS technique, the overall objectives of reducing the response time and associated cost besides the maximisation of coverage area can be fulfilled. More specifically, the understanding of the urban fire is a very important issue because it affects social, political, and economic life. It has become a key scientific problem to utilize the urban fire and efficiently select the proper cite of fire services. In order to solve the problem of urban fire, a number of scholars have carried out worldwide a lot of research using a GIS-based site selection suitability model for allocation of facilities in the modern planning process and conducted fruitful results (Nisanci et al., 2012). For example, Liu et al. (2006) provided a comprehend study to significantly situating new fire stations in Singapore. A novel Ant Algorithm and GIS environment were used to find the proper locations of fire stations to reduce the response time to an accident happening in traffic jam roads besides maximising the covered area. The performance of ANT algorithm has outperformed the conventional genetic algorithms and enhanced the spatial analytical capacities. Also, Esri (2007) introduced GIS and

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its capabilities to support the planning process and preparedness for emergencies and its importance in the spatial distribution of fire stations. He showed the level of information provided in the form of plans and based on pre-determined criteria related to the nature of roads, street networks, speed of vehicles and the possibility of giving alternatives for emergency situations concerning the bottlenecks that occur on the roads and the real travel distances. The study focused on the adoption of a specific standard of response time as the first determinant of signing fire stations, besides the need to specify a response time that is practical based on the volume of demand and the type of risk resulting from the outbreak of fires in different occupations. In this regard, the study included international standards related to this time and its classifications.

Şen et al. (2011) studied the optimum location of fire station in Istanbul _ Turkey using a GIS-based network analysis using seven criteria layers. One of the difficulties in applying the model was the travel times in the networks due to the traffic jam in Istanbul. Reik and Hyde (2012) were assessed the fire risk using a GIS model. The critical locations of infrastructure were determined using a real-time fire probability model.

To the best knowledge of the author, the concept of urban fire in Iraq, and especially in Baquba, the city centre of Diyala governorate, has not been precisely studied. Due to the increased population, building capacity and traffic jam in Baquba, this study intends to select a suitable location for new fire stations based on five criteria layers using ArcGIS 10, multi-criteria method based on Fuzzy to investigate the suitability map. More specifically, this study dealt with the establishment or installation of new fire stations that are applicable to the planning approach and evaluating the alternatives resulting from the application of GIS for the purposes of future urban management and planning. Fires and the definition of firefighting equipment standards, response time and the number of firefighting personnel in Baquba will be assessed. To explore more suitable alternatives, the study will identify alternatives to a site that used some service coverage models and evaluated the work of each component. In the end, the study will compare the consistency of several districts, which of them are more in conformity with the planning standards that pertain to emergency services.
Based on safety and emergency response, this study would aid the decision makers and disaster management engineers to appropriately select the optimum location of a fire station in Baquba considering the analysis of associated strong and weak positions.

Study area
Baquba is one of the important districts of Diyala governorate, which is located in the Southern part of the governorate (Fig. 1), and in the North-eastern part of Iraq. It is located about 50 km (31 mi) to the northeast of the capital, Baghdad. The geographical location of Baquba is situated between the longitude 44°- 46°E and the latitude 33°- 35°N. The district has an area of about 1,630 km^2 (GDS, 2009). Its average height is about 55 meters above sea level. Administratively, the Baquba is composed of five districts (Baquba, Kanaan, Buhraz, Al-A'abarh, and Bani Saad) (Nsaif et al., 2020). Recently, the urban expansion in the district has increased significantly as a result of the economic and historical factors of the Baquba district. However, this expansion occurred randomly and without proper planning, which negatively

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affected the master plan of the district. Specifically, many residential neighborhoods showed a severe lack of many services (Hassoon, 2017).

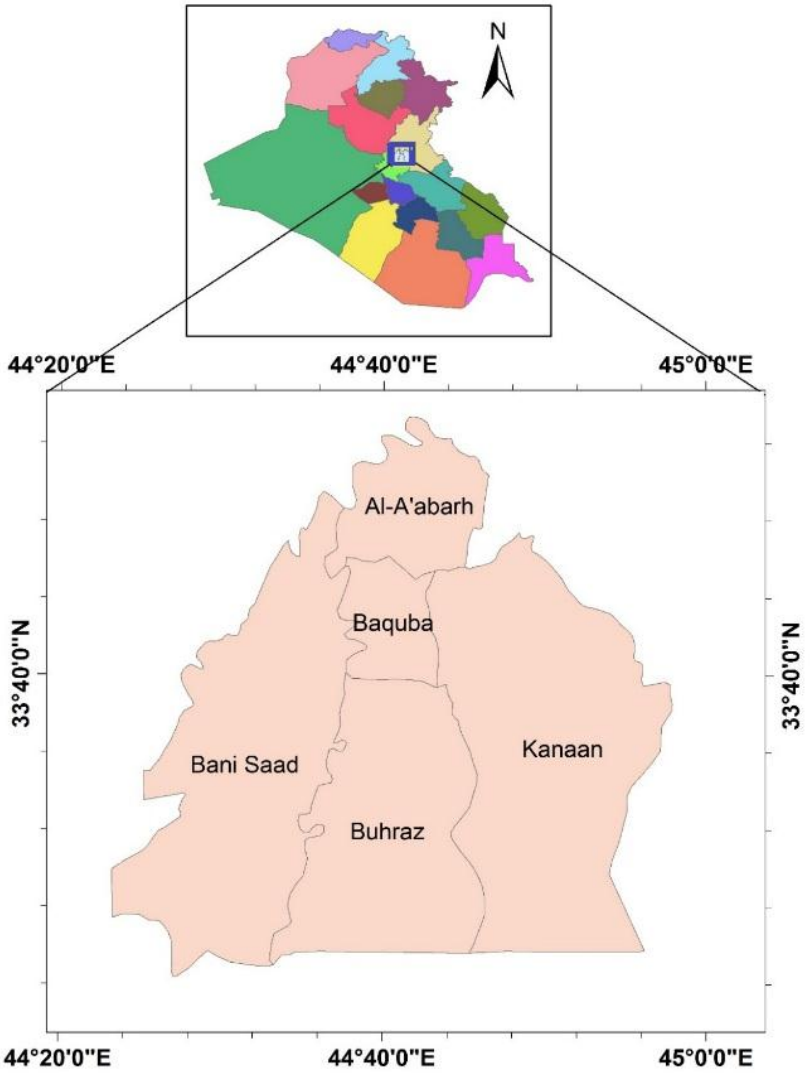

Fig. 1. The study area location

2. MATERIAL AND METHODS

In this study, various dataset was prepared in the GIS environment, some data must be reformatted, and reclassified. Defining criteria is the most important part of framing results by limiting factors and constraints to achieve the study objective. The used criteria are based on previous worldwide experience as illustrated in Table 1. The Fuzzy method is one of the commonly used analyses to solve multi-criteria problems (e.g. suitability model). Fuzzy membership was also used to reclassify the input raster values to the fit preference scale from 0 to 1. Finally, these criteria will be combined to select built the suitability model using the Fuzzy overlay method. The fuzzy overlay method is based on set theory, where a set generally

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corresponds to a class. Fuzzy overlay analysis reclassifies or transforms the data values to a common scale, but the transformed values represent the probability of belonging to a specified.

Table 1. The used criteria in this study to analyze fire station site suitability

Criteria	Constrain	Reference
Roads	1. To be within one Km from the highway 2. To be within 500 meters from the arterial road	(Authority and Orange, 2002)
Hospital	To be near from	(Şen et al., 2011)
Police Stations	Within 3 kilometers	(Yagoub and Jalil, 2014)
Existing Fire Stations	To be away from existing fire station from 1-9 Km	(Liu et al., 2006)
Population	High density is favored	(Algharib, 2011)

a. Dataset

The dataset used in this stud was projected in World Mercator with the geographic coordinate system WGS 1984 as demonstrated in Fig. 2. The arterial and major roads data were clipped based on district border to limit the amount of data (Fig. 2, A and B). The existing fire stations, hospitals, and police stations were collected using GPS, and then convert the Excel sheet to a map as shown in Fig. 2, (C, D, and E). Finally, the population estimates data for Baquba district until 2018 was shown in Fig. 2 (F).

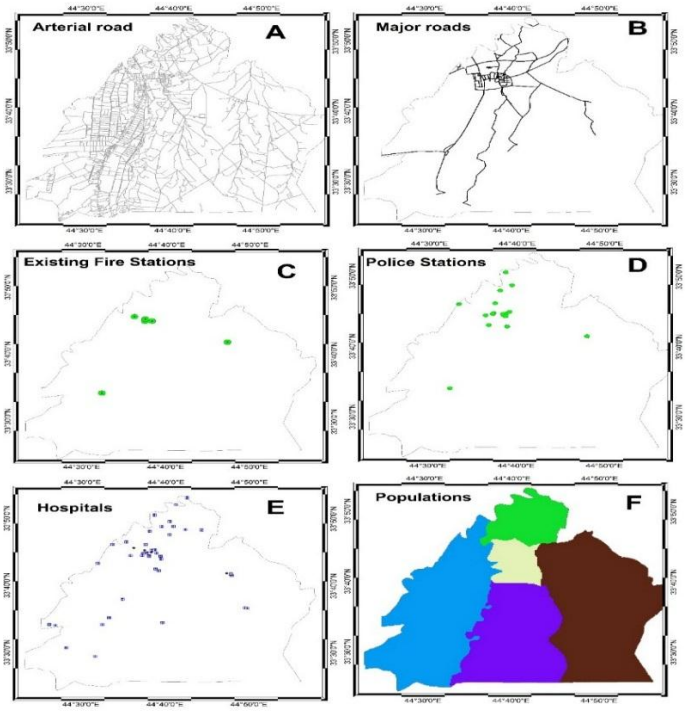

Fig. 2. The criteria layers used in this study

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3. RESULTS AND DISCUSSION

The goal of this study is to establish or implement a GIS technique for new fire stations that are appropriate to the planning approach, and to assess the alternatives that resulted from the implementation of GIS for the sake of future urban management and planning. The study then will discover substitutes for a site and assess the performance of each component in order to investigate more suitable alternatives. In this regard, the research will evaluate a number of districts in Baquba to determine which ones are more in line with the emergency services planning guidelines.

The selected alternative location of a new fire station in Baquba should consider several parameters such as the population, number of current fire stations, registered fire accidents, crowded areas, response time and traffic jam. Thus, the new location of the fire station should guarantee the maximum covered area of Baquba with realizing the most associated constraints. The combination of GIS and fuzzy liner membership has led to find the suitable location of the fire station. The first step to creating the suitability model is to uniform the values to a uniform scale. This step is done using the Fuzzy membership that transforms the input raster into 0 to 1 scale, indicating the strength of membership in a set, based on a specified fuzzification algorithm. All the values are converted to a uniform scale from 0 to 1, where 0 represents unsuitable while 1 is suitable as shown in Fig. 3 (the red color refers to value 1 whereas the green color refers to 1).

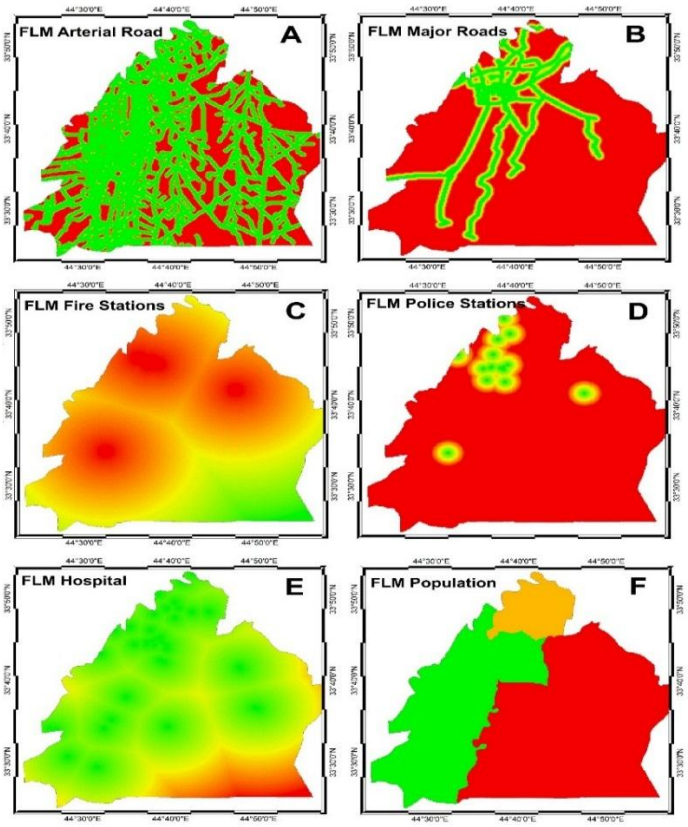

Fig. 3. FLM for the criteria layers

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The final step is to combine the criteria layer to produce the suitability map. This step is conducted using the Fuzzy overlay method. Fig. 4 shows the suitability map that divided the study area into three classes namely: unsuitable (red color), low suitability (yellow color), and high suitability (green color) according to the five criteria. Clearly Fig. 4 depicts the northern and southern parts of Baquba can be considered as the most preferable locations for the new fire station. These are specifically Al-A'abarh area and Buhraz are of Baquba. These two selected alternatives areas are characterised by several merits including the closeness to the main roads, hospital, buildings and amenities besides the increased population rate and the intensity of agricultural density and farms. In addition to the presence of the Diyala River branches in these two areas.

The associated results of this study corroborate the collected data using the ARC GIS under the supervision of the Directorate of Civil Defense in Diyala Governorate. Table 2 presents the population number, number of current civil defenses in five districts of Baquba with the number of unserved population, and finally the deficit in the number of centers for each district. Determining the scope of service for each of the civil defense centers in Diyala governorate contributes to understanding and knowing the serviced and unserved areas, determining their percentage, and extracting the percentage of the deficit through (ARC GIS) programs. This criterion is determined on the basis of the distance traveled 1200 meters. Considering the standards of 12000 persons that can be served per each civil defense center, it can be noted that all civil defense centers are located in the center of Baquba with an area of 91 km^2. This is specifically counted as a served area of 13.5 km^2 of the overall district area of Baquba that roughly has a rate of 14.84%. Thus, the unserved area is 77.5 km^2, with a deficit rate of 85.16%. Most importantly, it can be stated that both Al-A'abarh area and Buhraz districts have the high necessity of constructing a new fire station due to no civil defense centers.

Table 2. Data of the Directorate of Civil Defense in Diyala Governorate

District in Diyala	**Population**	**Number of current fire stations**	**Number of unserved population**	**The overall need for centers**	**Deficit in the number of centers**
Baquba	294,337	3	258,334	25	22
Kanaan,	48,403	1	36,403	4	3
Bani Saad	136,077	1	12,4077	11	10
Buhraz,	54,174	0	54,174	5	5
Al-A'abarh	83,604	0	83,604	7	7

Note: The population data was collected from (https://cosit.gov.iq/ar/pop-main/manpower) under the approval of the Directorate of Civil Defense in Diyala Governorate

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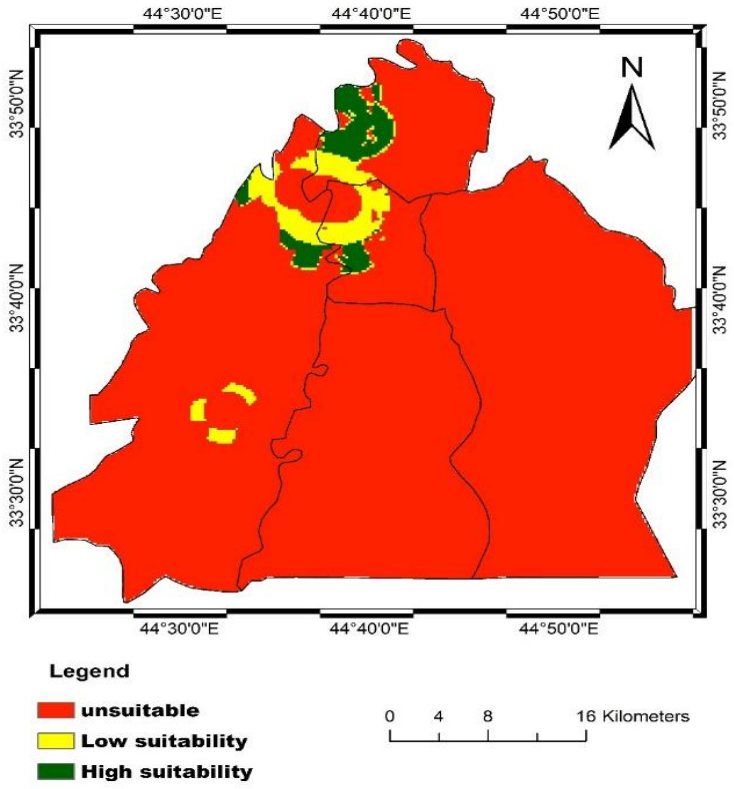

Fig. 4. Suitability map using fuzzy overlay

4. CONCLUSIONS

This study intended to select a suitable location for a new fire station in Baquba District Eastern Iraq based on five criteria layers using ArcGIS 10. The suitability model was built using GIS-based on five criteria layers, which are roads, hospital, existing fire stations, population, and police stations. All the values converted to a uniform scale from 0 to 1, where 0 represents unsuitable while 1 represents suitable place. Then these layers were combined to produce the suitability map. This step is conducted using the Fuzzy overlay method. Accordingly, the suitability map has been generated that divided the study area into three classes namely: unsuitable (red color), low suitability (yellow color), and high suitability (green color). Specifically, it can be stated that two areas of Al-A'abarh northern of Baquba and Buhraz southern of Baquba are the most preferable places to construct a new fire station based on the five criteria applied.

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Conflicts of Interest
The author declares that he has no known conflict of interest, competing financial interests, or personal relationships that could have appeared to influence the work reported in this paper.

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