International Journal of Civil Engineering and Technology (IJCIET)
Volume 9, Issue 7, July 2018, pp. 936–947, Article ID: IJCIET_09_07_098
Available online at http://www.iaeme.com/ijciet/issues.asp?JType=IJCIET&VType=9&IType=7
ISSN Print: 0976-6308 and ISSN Online: 0976-6316

ASSESSMENT AND DEVELOPMENT OF THE SPATIAL COVERAGE OF FIRE SERVICE IN NASIRIYAH CITY BY USING GEOGRAPHIC INFORMATION SYSTEMS (GIS)

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ABSTRACT

The rapid increment in population growth and in the urban area of cities necessitates the evaluation of the fire service within cities from time to time as it is concerned with the protection of the population and their private property and the protection of state property. The success of fire service depends mainly on the speed of the fire truck reaching the scene and the performance on field to reduce losses to a minimum ratio. The objective of study is utilizing the applications of GIS to assess the efficiency of spatial coverage of the fire service in Nasiriyah city and spelling out the necessary measures to increase coverage at the short and long term. The coverage is first evaluated according to the service ranges currently applied by the government departments responsible for the fire service. The obtained results are compared to the coverage based on service radius .The study suggests the service polygon method to determine areas where the fire service can reach in (4 minutes) or less. The main conclusions of the study is that the assessment of the coverage using a radius of service equal to (2.5 km) corresponds to the characteristics of the road network in the study area, but the findings of coverage using the suggested service polygon method is more accurate and closer to reality. The number of fire stations available within the area of study is sufficient at the current time, but poor distribution has provided typical coverage for only 60% of the areas in need of fire service.

Key words: GIS, Fire station, Coverage range, Service radius, Service polygon.

Cite this Article: Murtadha S. Satchet, Ameer H. Muhammad-Ali, Yousif H. Khalaf, Abbas S. Jaber and Sajad K. Wanas, Assessment And Development of the Spatial Coverage of Fire Service in Nasiriyah City by Using Geographic Information Systems (GIS), International Journal of Civil Engineering and Technology, 9(7), 2018, pp. 936–947.
http://www.iaeme.com/IJCIET/issues.asp?JType=IJCIET&VType=9&IType=7

TERMINOLOGY

- Service Range (Coverage Range): the boundary of a certain area served by one or several fire stations, which might be of a regular or irregular shape. Coverage range is determined by different standards according to the characteristics of cities.
- Service Radius: is the value of the coverage range radius for a full circle.
- Response Time: the time consumed by a fire truck to travel from the fire station to the scene (Wheel start to wheel stop) [1].
- Fire Path: The route taken by the fire truck on the road network from the fire station to the scene.

1. INTRODUCTION

The distribution of firefighting centers requires comprehension of a set of factors affecting their performance and level of efficiency such as the road network, the maximum speed, the breadth and size of roads and other characteristics that influence the movement of fire trucks. The land uses and the distribution of population should be well defined so that fire stations can be allocated in accordance with the characteristics and size of these spatial variables. The propagation of the fire station sites can be efficiently planned by aid of the latest technologies, like Geographic Information Systems (GIS), which is characterized by its ability to record and store all geographical variables that affect the service required and to be processed and analyzed statistically and spatially to determine the best fire station sites [2-4].

By reviewing the previous related studies, a study conducted to analyze the planning characteristics of the distribution of fire stations in Dammam by concentrating on the distance between the centers, the number of population served and the time needed to reach the fire. The study found that the distribution of firefighting centers in Dammam with a concentrated pattern in the city center closely to the high population density. The study suggested redistributing the firefighting centers in different places of the city [5]. While in Saudi Arabia, there was is a study showed the deficiency of planning in the distribution and establishment of civil defense centers by observing the response time, which was considerably long (10 - 18) minutes [6]. In another study for the spatial analysis of the distribution of fire extinguishing services in AL-Mansoura city using geographic information systems (GIS). The study revealed that the propagation of fire extinguishing sites in AL-Mansoura city was harmonious but did not supply equal service in all regions of the study area [7], and there are two similar studies in Riyadh and Makkah [8,9]. For assessing the distribution efficiency of emergency services in Makkah based on the response time and a service radius of (2 km) as a local standard, there was a study suggested the use of spatial information systems to reduce response time to a large extent [10]. At the same year, the US environmental research institute [11] defined the abilities of GIS in supporting the planning operations carried out for emergency situations and its importance in determining the spatial distribution of firefighting centers. The study adopted the standard of the response time to determine the positions of firefighting centers.

At local level, several researches were conducted in this field. In Mosul city, the efficiency of the spatial distribution of fire stations had been examined according to local and international standards. The study revealed that there are large areas of the city that are not covered by the fire service and at the same time there is an overlap in the service area in other parts of the city. The study suggested a service radius of (2.3 km) and a response time of (4 minutes) [1]. Another study was conducted in the same city, discussed the use of geographic information systems in determining the current and ideal range of fire stations in the city. The study showed that the application of local standards in determining the number of fire stations is not realistic and the recommendations were to set a service radius of (3 km) and a response time of (2 minutes) per (1 km) [12].

In this paper, Nasiriyah city was selected as a study area. Nasiriyah city, the center of Thi-Qar governorate, is located in the southeast of Iraq on the Euphrates River. It is the fourth largest populated city after Baghdad, Basra and Mosul. The Euphrates River divides the city into two parts, a northern part called Al-Jazeera side and a southern one called Al-Shamiyah side (Figure 1). The area of the municipal borders of Nasiriyah city is (184 km^2) of which (98 km^2) barren land and (86 km^2) distributed to many sectors (residential, industrial and orchards) which need the fire service. There are five fire stations in Nasiriyah city, which are divided on the two parts of the city: *Sumer, Rtal, Al-Nu'man, Al-Shamoukh, and Ur* . The first three stations are located in Al-Jazeera side, while the fourth and fifth stations are located in Al-Shamiyah side [13].

Figure 1 A map shows study area location and the distribution of the existed five fire stations

According to the Iraqi urban housing standards, a fire station should be available for each neighborhood, or for each 110 hectares area of the city, or for every 12,000 inhabitants [14]. When applying the standard of residential neighborhood, the study area needs 57 fire stations with a total of 57 residential neighborhoods and this number is very large and unrealistic, whereas applying the standard of area, the total area which need the fire service within study area is 8600 hectares (86 km^2) which requires more than 78 fire stations and this number is also large and impractical. However, by exploiting the population standard, the population of Nasiriyah city is 455,700 according to 2010 census [15] and by applying the equation (1)

below (the formula for computing the population growth rate), the current population (for 2018) can be estimated for Nasiriyah city as follow:

$$P_o = P_T (1 + r)^n \quad (1)$$

Where:

P_T: The population's approximate number in the study year (2018).

P_o: The population's actual number in the latest census year (2010).

r: The population growth rate.

n: Number of years between P_T and P_o

By adopting the expected population growth rate (2.7%) for the years after the previous census of Iraq and especially Nasiriyah city (Source: Census of the population, buildings, and families in 2010: The Central Bureau of Statistics–Ministry of Planning), P_o = 563,953.

Thus, the number of the fire stations should be provided in the city for year 2018 is 47, and this number is also large. On the other hand, the spatial coverage criteria that are mentioned in Iraqi standards, assume a response time of (10 minutes), and a service radius (1.2 km) but these standards are contradictory since they specify a small radius and suggest a large arrival time. These results assure the unreliability of such local standards, which has been confirmed by several studies and research [1,12].

2. METHODOLOGY

After the collection of land cover data and road network for the study area and the spatial identification of the sites of the fire stations and the service ranges currently applied, the geo-database for the fire service was built. The methodology of assessing the spatial coverage of the fire service has passed through several steps (Figure 2) as follows:

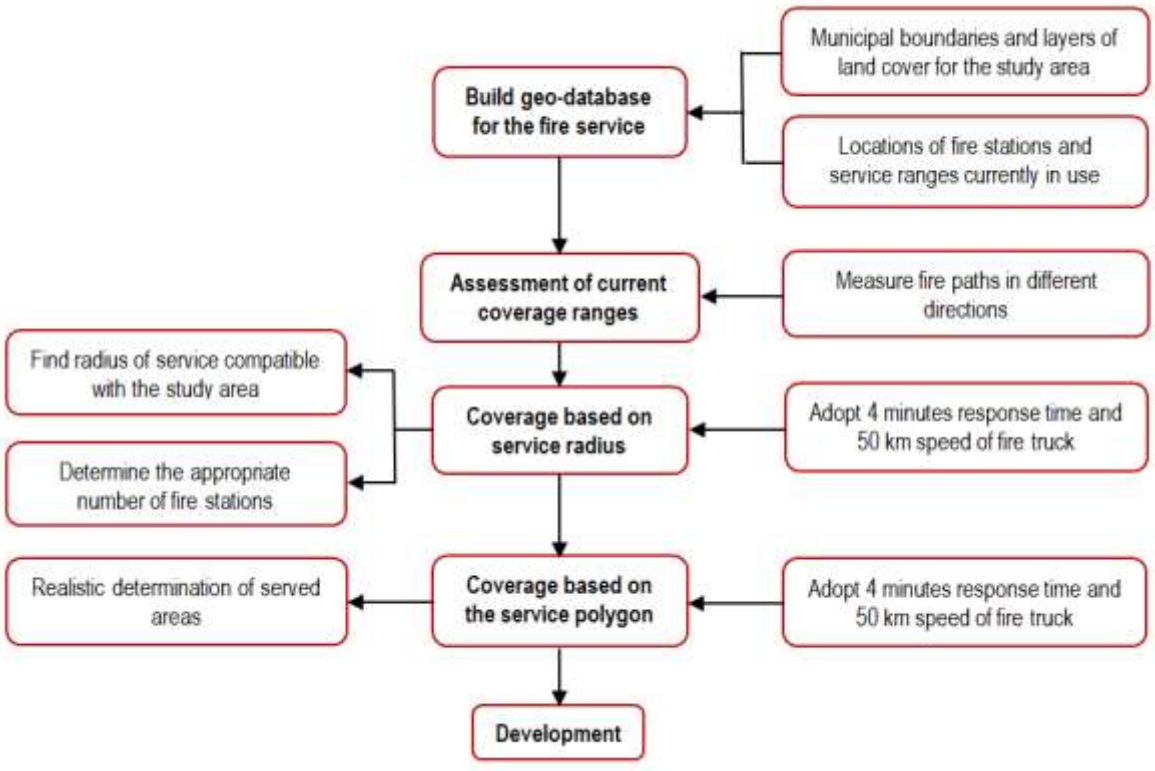

Figure 2 Methodological framework for assessing the spatial coverage of the fire service

2.1. Assessment of Current Coverage Ranges

The coverage ranges of fire stations which currently applied in the study area by government agencies responsible for civil defense are based on the distribution of residential neighborhoods of the city to fire stations, without paying attention to the extent to which response time has been achieved. In order to evaluate the efficiency of those ranges, the tools of ArcGIS-10.5 software were used to track and measure the lengths of the fire paths that the fire truck can drive in different directions through the city road network from the fire station to the currently coverage limits (Figure 3).

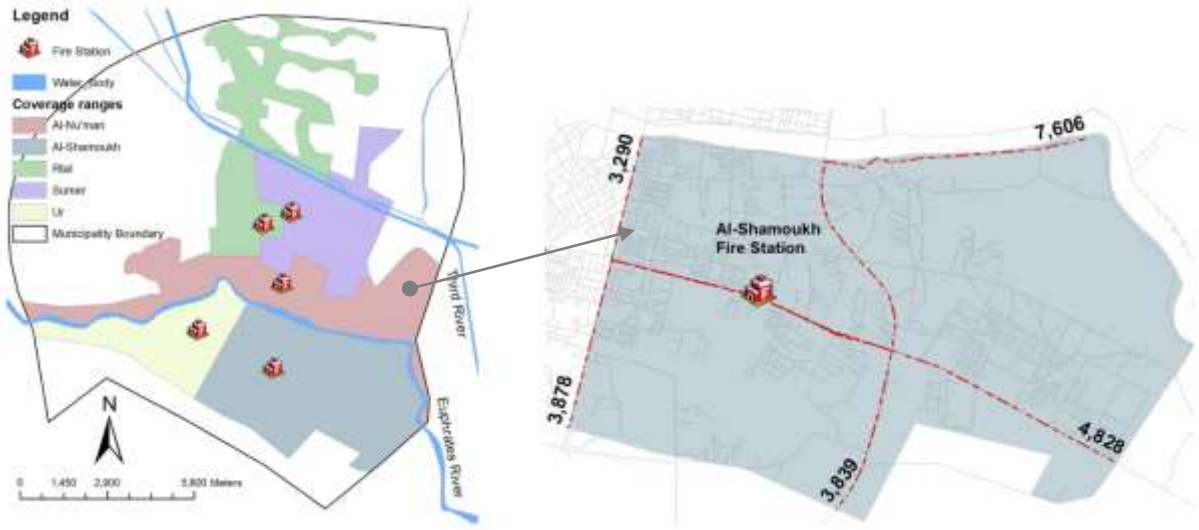

Figure 3 The possible fire paths to the limits of current coverage range

2.2. Coverage Based on Service Radius

Many studies in evaluating the level of service of fire stations depend on the service radius of each station through the distribution of the station's activity according to a radius specifying the area covered by the fire service [1,12]. The value of this service radius relies on several factors, the most important of which are the nature of the area, the capacity of the roads, and the paths of fire truck and its speed. All these factors affect the time of arrival to the accident area [16]. In order to determine the appropriate radius of service for the study area, a response time of (4 minutes) was adopted and (50km/h) to the speed of the fire truck [1,5]. Thus, the distance travelled by the fire truck during the (4 minutes), equals (3.34 km) which forms the winding path of the fire truck on the road networks starting from the fire station to the accident site. Winding pathways (3.34 km) in length with variant directions, have been delineated in ArcGIS, then the displacements of these paths are found to estimate the service radius of current fire stations (Figure 4).

2.3. Coverage Based on the Service Polygon

By utilizing the existing network of roads in the study area and the sites of the five fire stations, the study proposed the principle of service polygon. The service polygon is produced by connecting the ends of the paths travelled by the fire truck in different directions from the fire station at a distance of (3.34 km) (equivalent to 4 minutes response time) or less at the ends of the available road network (Figure 5). This polygon provides more practical coverage of areas that a fire truck can reach through the city's road network and consequently, it gives more precise and realistic results in calculating the coverage area. Also, this polygon forms a unified coverage area for all fire stations available in the city, in other words, any fire accident that is expected to occur inside this polygon has a distance of less than or equal to (3.34 km)

from any of the available fire stations, therefore, the service polygon deals with the city as a one unit.

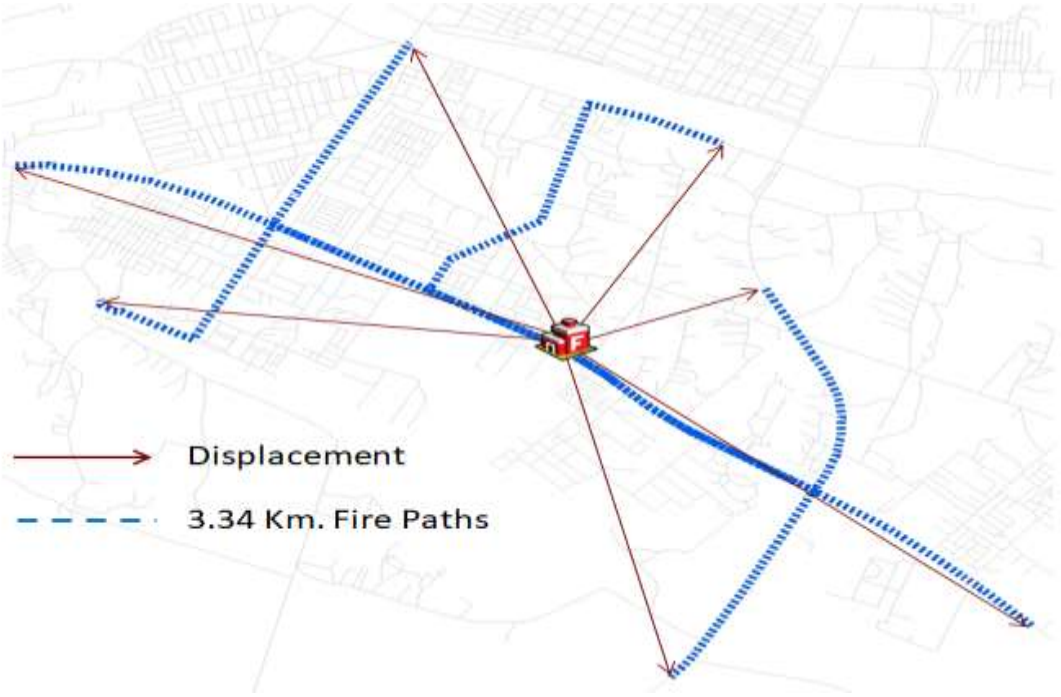

Figure 4 Shows the method applied to compute the service radius

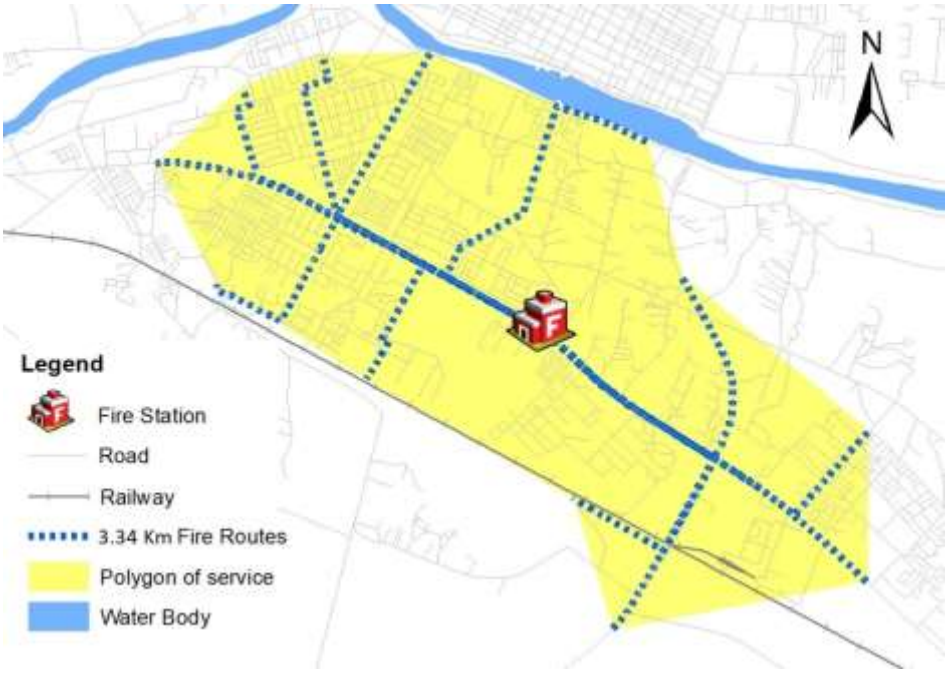

Figure 5 Shows how to build the service polygon

3. RESULTS AND DISCUSSIONS

The assessment results of coverage ranges currently applied in the study area showed there are some extreme areas far from the fire stations long by distance which consume more than (4 minutes) to be arrived and other areas which are never reachable due to the lack of connectivity with the city transport network. For example, the coverage of Al-Shamoukh fire station extends to areas away from the fire station by more than (5 km) and may reach to more

than (7.5 km) and the coverage limits of Al-Nu'man Fire station extends to a distance of (10 km) and so is the case for the remaining coverage ranges currently applied (Figure 6). The current fire service also showed that firefighting centers are not in the middle of their coverage; there may be a fire accident close to a fire station, but it is within the scope of another fire station, which is more distant from the scene and therefore takes longer to reach the site which leads to further losses.

The current distribution of fire stations and their coverage ranges is limited to providing an ideal service for the entire study area, particularly with the expansion of urban area in the city, which will generate pressure on the fire stations and therefore the service provided will be less efficient over time.

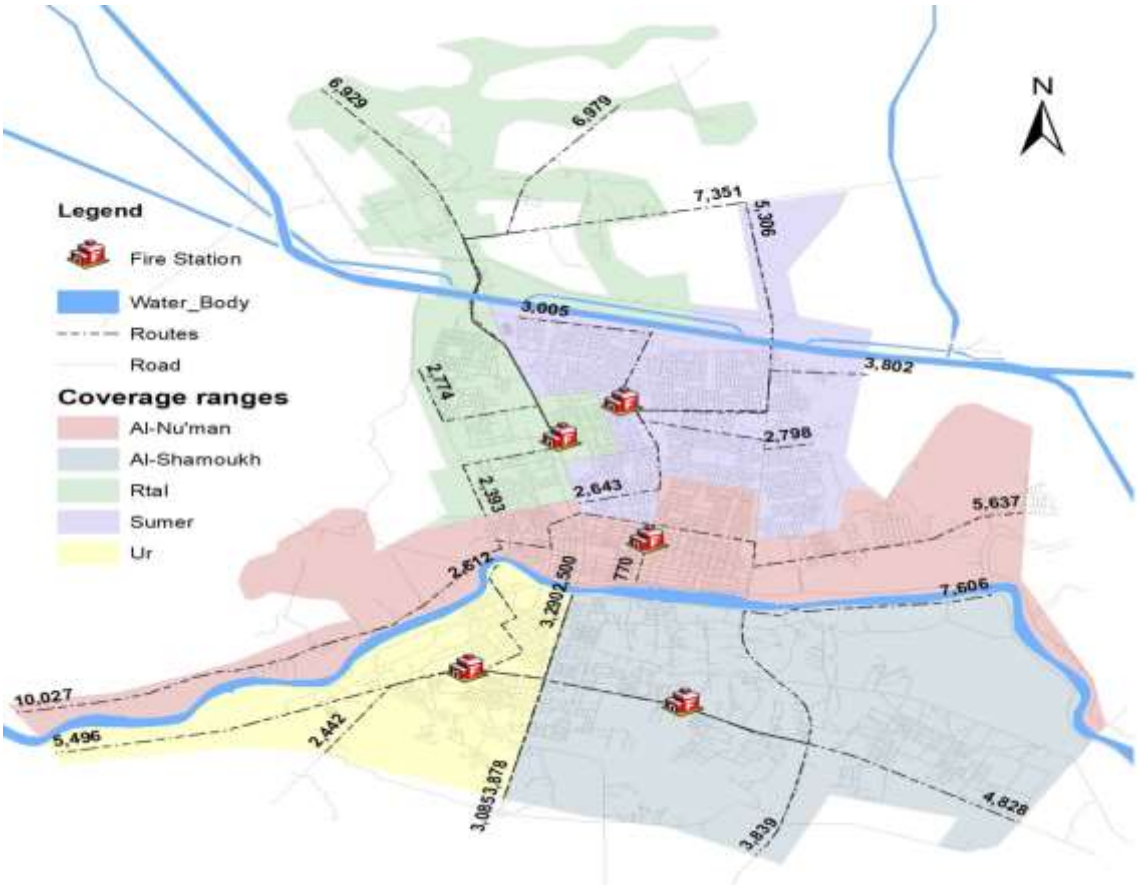

Figure 6 Lengths of fire paths according to current coverage ranges

The coverage computations using the service radius were applied to the five fire stations within the study area and the table (1) shows the values of the service radius of each of them and its notable that the value of (2.5 km) represents the radius average of the fire service that coincides to the characteristics of the area and will be dependent on the subsequent calculations of this study.

Table 1 The service radius of each fire station

NO	Fire stations	Service Radius (km)
1	Al-Shamoukh	2.500
2	Ur	2.480
3	Rtal	2.570
4	Sumer	2.580
5	Al-Nu'man	2.330
	Radius average	**2.452 km ≈ 2.50 km**

The area of the single coverage circle with a radius of (2.5 km) equals (19.6 km^2). Thus, the theoretical total of five coverage circles is (98 km^2). However, the practical results for the (2.5 km) service radius using ArcGIS-10.5 software (Figure 7) indicate the following:

- Total area of coverage is (58.2 km^2) due to overlap in the coverage ranges resulting from the convergence of the fire stations sites.
- The overlap areas equal to (28.4 km^2) or 49% of the total coverage area.
- The total coverage area serves 62% of the areas that currently need fire service within the study area.
- The total coverage area includes 8% of the barren areas.
- The five fire stations are adequate for standard coverage at present but lack the appropriate allocation.

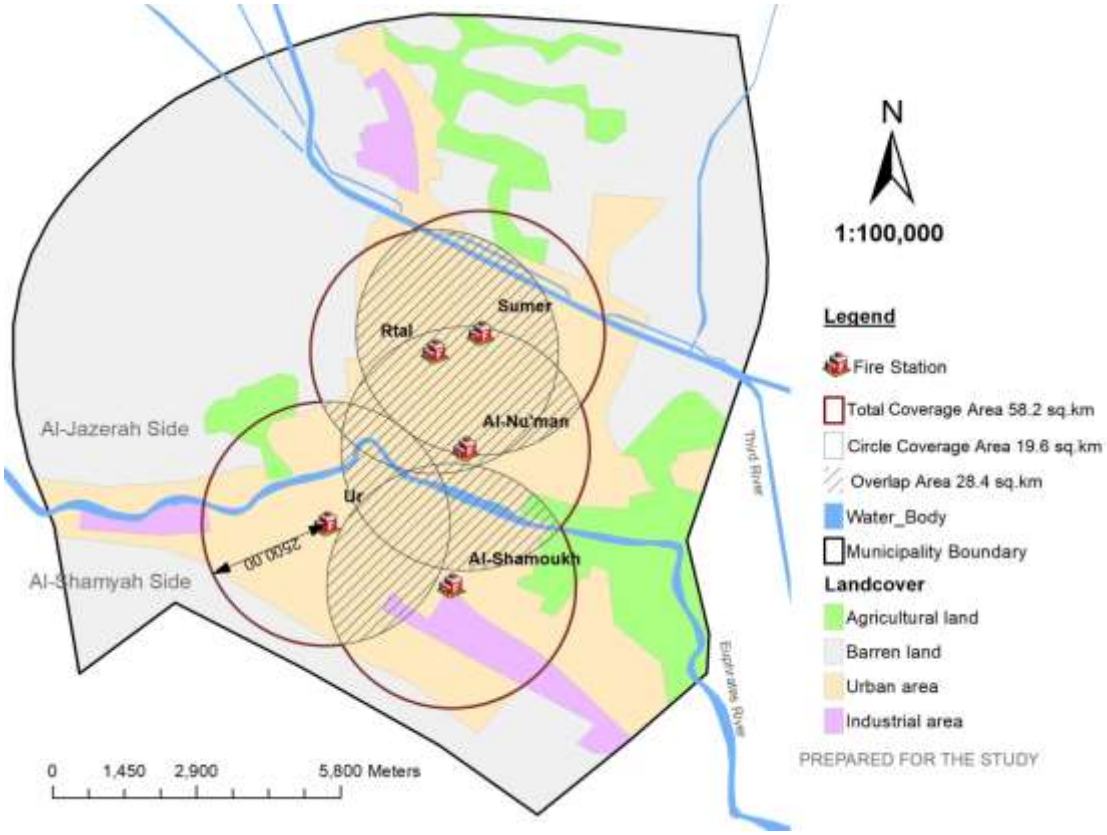

Figure 7 Coverage using service radius

When applying the service polygon proposed by the study on the current sites of the fire stations (Figure 8), the following observations may be made:

- The total coverage area within the boundary of the polygon is (46.4 km^2) which constitutes about 54% of the areas that need fire service at the moment.
- All areas inside the polygon are connected to the city road network so fire trucks can reach anywhere in less than or equal to (4 minutes).
- Polygon service does not cover barren areas.

The results of the above methods show that the coverage of the polygon service (54%) is less than coverage using the service radius (62%). This is due to the fact that the latter includes in its coverage some barren areas and those not connected to the road network, and

this indicates that the coverage of the polygon service is more accurate and closer to reality. In both cases, however, more than 40% of the city's urban areas need more than (4 minutes) of response time. From this we conclude that the selection of the current fire station sites was not according to the correct criteria served, and in order to increase the efficiency of these centers, the positions of some of them should be changed to reduce the overlap and increase the served areas.

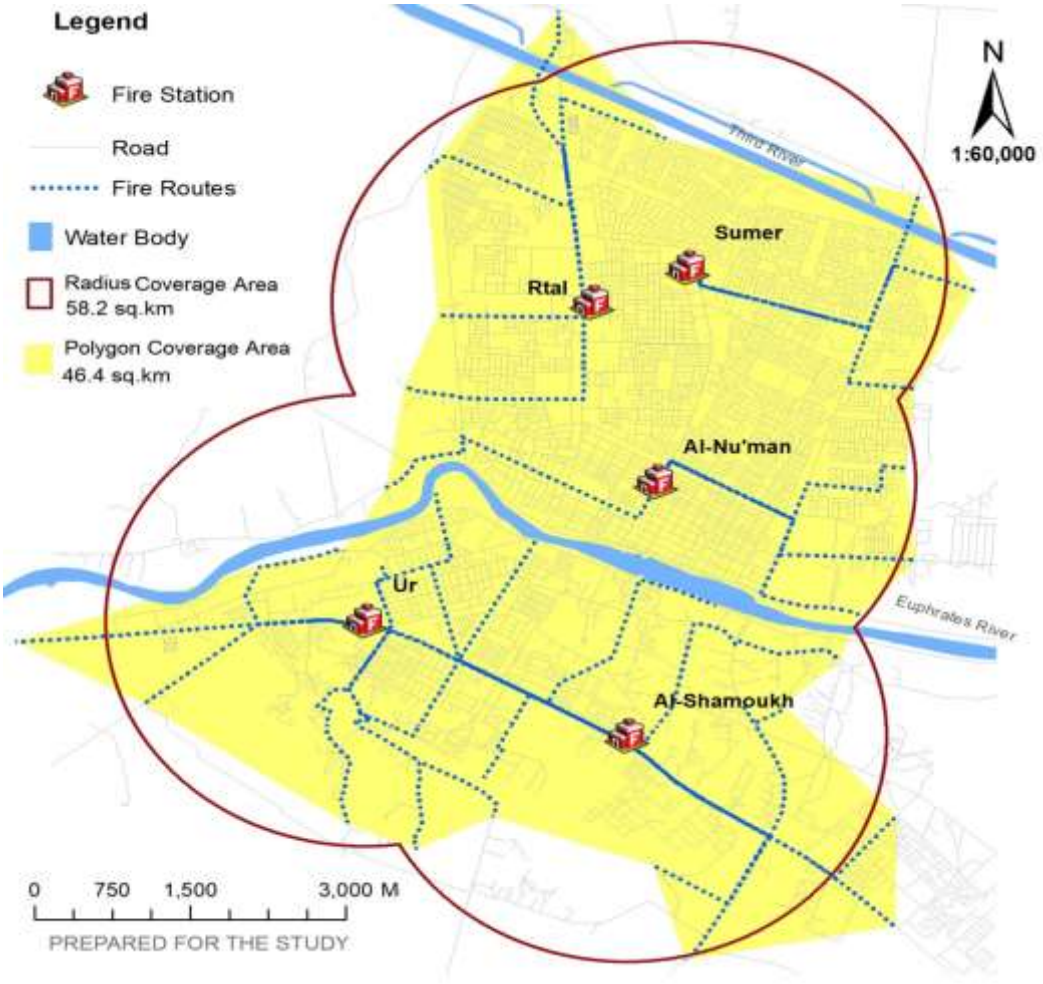

Figure 8 Coverage using service polygon

4. SOLUTIONS

In the immediate term, the following manipulations can be carried out for the purpose of increasing the efficiency of the fire service provided within the study area:

- Moving the site of Al-Shamoukh fire station from the current position in the (Al-Shamoukh neighborhood) to an distance of 1800 m south-east along the highway to the new site proposed by the study at the beginning of Al-Iskan neighborhood.
- Relocating the site of Rtal fire station (at Al-Mualemeen neighborhood) by moving a distance of 3550 m northward along the highway to the new location near the industrial neighborhood.
- Distributing three patrols of fire trucks in the eastern and western parts of the city with an agricultural nature, especially in the summer season, which is full of forest fires.

By reconstructing the service polygon according to the above treatments (Figure 9), the total area of coverage was (78.5 km^2), which constitutes about 91% of the areas that currently need the fire service. In the long term, the study area requires at least five new fire stations to be added to the old five centers so that they can provide enough coverage for all the land within the basic design of (184 km^2).

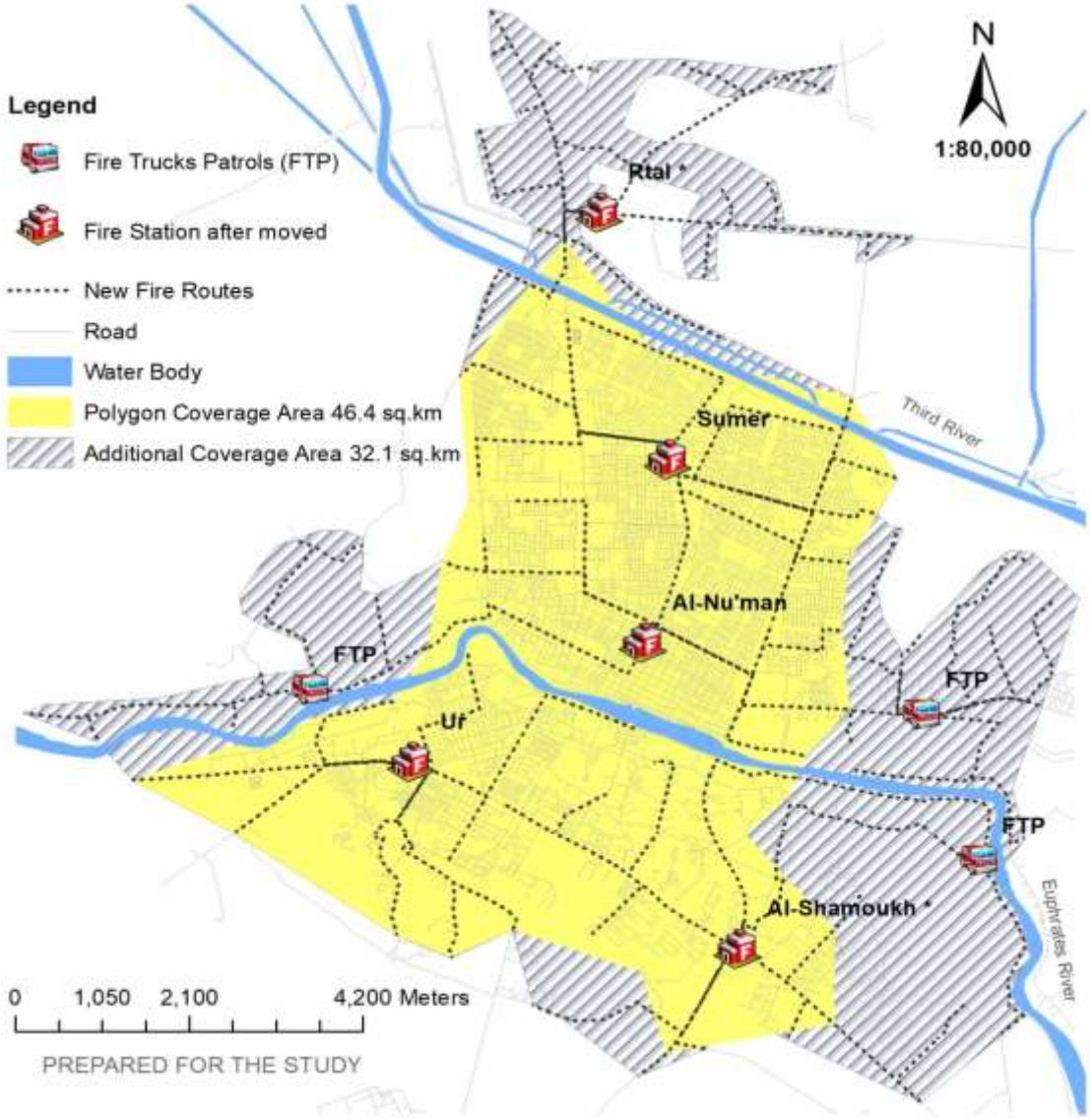

Figure 9 Service polygon coverage after conducted the proposed manipulations

5. CONCLUSIONS

- The five fire stations are adequate for standard coverage at present but lack the appropriate distribution.
- The coverage range of the fire service currently applied does not meet the standard response time (4 minutes).
- A service radius of (2.5 km) was found to be compatible with the characteristics of the road network in the study area (using a speed of 50 km/h for the fire truck and 4 minutes response time).
- The proposed service polygon is more accurate and closer to reality in determining the standard coverage areas.

- There are 40% of areas requiring fire service within the study area fall outside the standard coverage.
- The efficiency of the fire service can be increased by changing the location of Al-Shamoukh and Al-Rtal fire stations and adding three fire patrols in the east and west of the study area.
- In the long term, the study area needs at least (5) additional stations to cover the municipal borders area.

ACKNOWLEDGMENTS

The author extends special thanks Thi-Qar University for providing the necessary instruments and software to complete this study. In addition, the following Iraqi government offices are gratefully acknowledged for their data support:

- Directorate of Nasiriyah Civil Defence, Ministry of Interior, Iraq.
- Directorate of Nasiriyah Municipality, Ministry of Municipalities, Iraq.
- The Central Bureau of Statistics, Ministry of Planning, Iraq.

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