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Location–Allocation model applied to urban public services: Spatial analysis of fire stations in Mysore urban area Karnataka, India

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Abstract
Background: Urban fire is one of the most disturbing problems in modern times with the development of technology designed for fire prevention and suppression, they continue to damage life and properties.
Methods: Location-allocation model has been applied to find out the parts of the city having poor coverage. Potential sites were recommended wherefrom all demand points will be covered within a predefined impedance cutoff of time of five minutes as per the norms of Standard Fire Advisory Council (SFAC). The available sites to set up a fire station were identified using land use and land cover map that has been prepared from Landsat 8 satellite image were from agricultural land, wasteland land, follow land having area greater than 3 hectares were given as candidate (potential) sites.
Results: Within the travel time of five minutes the result indicates that 66.45 percent of city population in the Southeast and Southwest is un-served. Two scenarios have been adopted to fulfill the requirements of such emergency facility; by relocating the existing facilities and without relocating existing facilities. In both the cases nine fire stations are required to cover the entire city effectively.
Conclusion: Location allocation model provides the solution for spatial decision not to find the optimal locations for locating the emergency service facilities but also acts as tool to determine where and how many facilities are in need to fulfill the all requirements. Hence, it is advisable to adopt the second method that is, establishing six new fire stations without relocating existing three fire stations, which would be cost effective.

Keywords: fire stations, GIS, population, served area, time, distance, location-allocation

Introduction

Today fire has an important place among the causes of loss of life and property. It should therefore be intervened as soon as possible to eliminate the destructive outcomes. Effectiveness of the intervention is directly linked with instant access to the fire accident spots. Information Technologies (IT) that have developed rapidly in recent years are being used in fire relief management and the application of Geographic Information Systems (GIS) specifically, in fire accident management can achieve efficient results. Since GIS can analyze exhaustive spatial and non-spatial data it is highly effective in responding to spatial queries. Physical accessibility for fire service in an urban area is exceptionally important in spite of the hindrances like transportation that reflects the ease for travel. Accessibility is a combination of two elements: spatial location of a phenomena suitable destination, and the accessibility based on transportation network linking points on that surface [1]. The distance, travel time, transportation, and the associated cost are the geographical dimension's accessibility. Measures of access often focus on spatial location of service "supply" and the population "demand" in based on time and space [2]. The location-allocation models have been applied to form structural form of services of facilities to fulfill the demands in optimal way [3]. Location-allocation model is the process in which distribution of demands are taken into consideration to selects the optimal location for facilities from a set of available locations [4].

The demand and supply are the basic determinants of the optimal location and allocation of facilities [5]. The integration of GIS and location-allocation act as a tool for public facilities planning for developing a spatial decision support system [6]. The location-allocation models can be helpful for the spatial planners to choose the optimal locations of public facilities [7]. Location-allocation models are important in the location of new facilities as well as to evaluate and improve the efficiency of prevailing location decisions [8]. There are methodologies designed to place a limited number of stations [9] and others designed to place whatever number of stations necessary to address all demands [10]. Identifying and establishing fire station at an optimal location is one the important concerns of planners and researchers, especially in the cities where the population has been growing significantly [11, 12]. To achieve an effective and reliable emergency response system, the location of rescue facility plays a major role, the fatalities and disabilities caused by natural and manmade disasters can be significantly reduced through an effecting planning of location [13]. It is important to assure that; the fire stations are not only located at the place from where it can serve large area but also strategically placed so as to minimize the response time to accident spots [14]. There are several methods have been used to identify the suitable location for establishing facility canters by researchers [15, 16], among them Geographical Information System (GIS) based assessment method is popular in recent days [17, 18]. GIS provides real time simulation of transportation

network accompanied with high level of accuracy as it uses actual travel distance, speed of vehicle and time delays [19]. A GIS based analysis is likely to offer a straighter forward approach than conventional mathematical models [20]. Hence, the present study adopted GIS based approach to assess the location based emergency service of existing fire station in Mysore city, in which the service area of each fire station and unserved area is identified and suitable places for establishing new fire station and allocation of existing fire stations was assessed.

Study Area

Mysore is one of the popular cities in southern Karnataka located from 12°18'N to 12°30'N latitude and 76°39'E to 76°65'E longitude, and has an average altitude of 770 meters (2,526 ft.), covering 89.71 sq. km area. According to Census of India 2011, the city has been divided in 65 wards for administration purpose and the population of the city has been growing rapidly followed by spatial extension of settlements in all the directions. The city contains of three fire stations located at Saraswathi Puram, Bannimantap and Hebbal to secure the population from the fire incidents. Fire outbreak is a one of the major problems in the city which has been occurred often the number of fire incidences occurred in the city has been increasing over the years from 246 in 2003 to 416 in 2016. The cost of property damage also has increased from 4.1 million in 2013 to 11.24 million in 2016. Hence, the result of present study would help to understand whether the existing fire stations can cover entire city, if not what are the necessary steps to have to be taken to protect whole city.

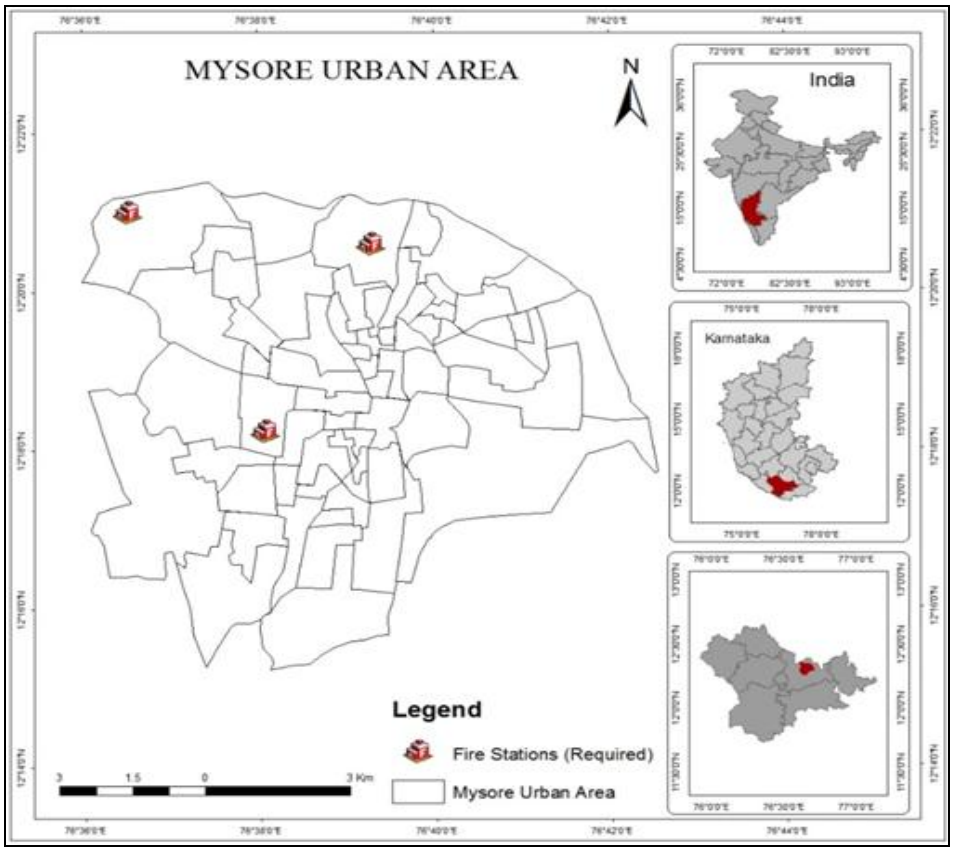

Fig 1: Study Area

Methodology

The methodology has been framed to examine three research questions as follow.

a) Which demand areas are not being served from existing facilities within the response time of 5 minutes?
b) Where are the optimal locations for placing an additional facility to address the unmet needs? And
c) What are the locations having appropriate building conditions, optimal distance, optimal time, population, facility capacity, optimal cost etc. in relation to fire station etc.

The present paper deals with the physical accessibility of fire stations to the different areas in Mysore urban area. To attain the objectives of the study, fire incident data was collected from 2003 to 2016 related to number/ prevalent of incidence. Location-allocation model has been applied to find out the parts of the city having poor coverage. Potential sites were recommended wherefrom all demand points will be covered within a predefined impedance cutoff of time of five minutes as per the norms of Standard Fire Advisory Council (SFAC). The available sites to set up a fire station were identified using land use and land cover Fig that has been prepared from Landsat 8 satellite image were from agricultural land, wasteland land, follow land having area greater than 3 hectares were given as candidate (potential) sites. The demand points were generated by converting the settlement area into vector format and centroid of each polygon were generated and their populations were assigned as weights. It is based on

the assumption that the population within the ward is equally distributed. Two scenarios have been adopted to fulfill the requirements of such emergency facility; by relocating the existing facilities and without relocating existing facilities. In both the cases nine fire stations are required to cover the entire city effectively. The drive time was assumed depending upon the vehicular traffic supposed to ply on the respective roads, road hierarchy, land use in the vicinity, road width, nature of road, traffic bottle necks, etc. and does not take into consideration traffic signals, because of permission to emergency vehicles to pass off in traffic signal points. The drive-time is valid only in the normal traffic conditions and it does not apply in circumstances where unexpected situations of traffic jams, or other barriers such as tree falling, road accidents, road blockades, etc. occur. The Standing Fire Advisory Committee (SFAC) recommendations for area, population and travelling time has been taken into consideration for the service area of fire station.

Results

The service area of existing fire stations in Mysore city was examined within the travel time of 5 minutes as indicted in Fig 2 and table 1.

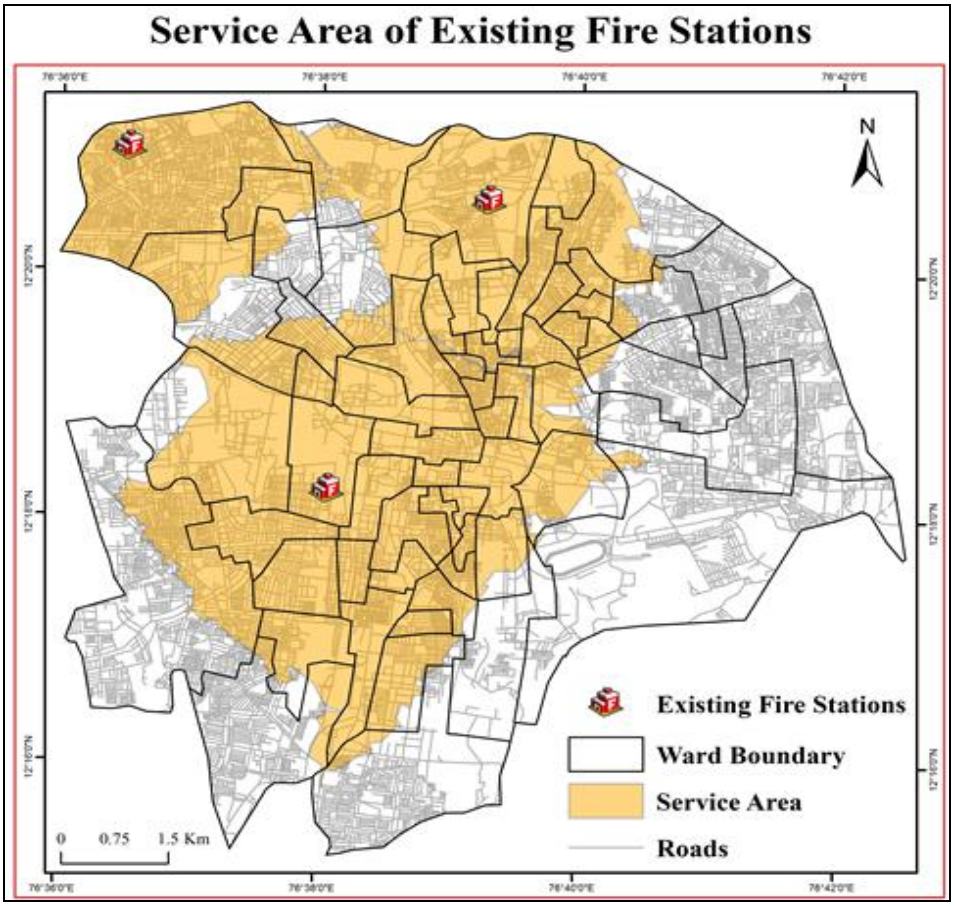

Fig 2

Table 1: Service Area of Existing Fire Stations within 5 Minutes within Mysore Urban area

Category	Population (%)	Area (%)
Served	33.55	57.91
Un-served	66.45	42.09
Total	100	100.00

The result of service area depicts that the existing fire stations serve 33.55 percent of population which is distributed over 57.91 percent area of the city within the time of 5 minutes. From the result it is obvious that the fire vehicle has to travel more than prescribed time to reach fire incidence in un-served areas, which may disastrous both in terms of life and property.

Location Analysis

As the result of service area indicated that the existing fire stations do not cover the whole city area, therefore it is necessary to make proper plan to protect the un-service area by establishing new fire stations. Two scenarios were used to establish new fire stations: Scenario 1 - establishing new fire stations by relocating existing fire stations and Scenario and 2 - establishing new fire stations without relocating existing fire stations. National Disaster Management Authority, Government of India 2012 guidelines (Basic Requirement for Setting Up A Fire Station, Annexure - 1B) has been followed to identify suitable site\sites to establish such facilities. In total, 81 sites were identified within city limit which are suitable to establish fire stations.

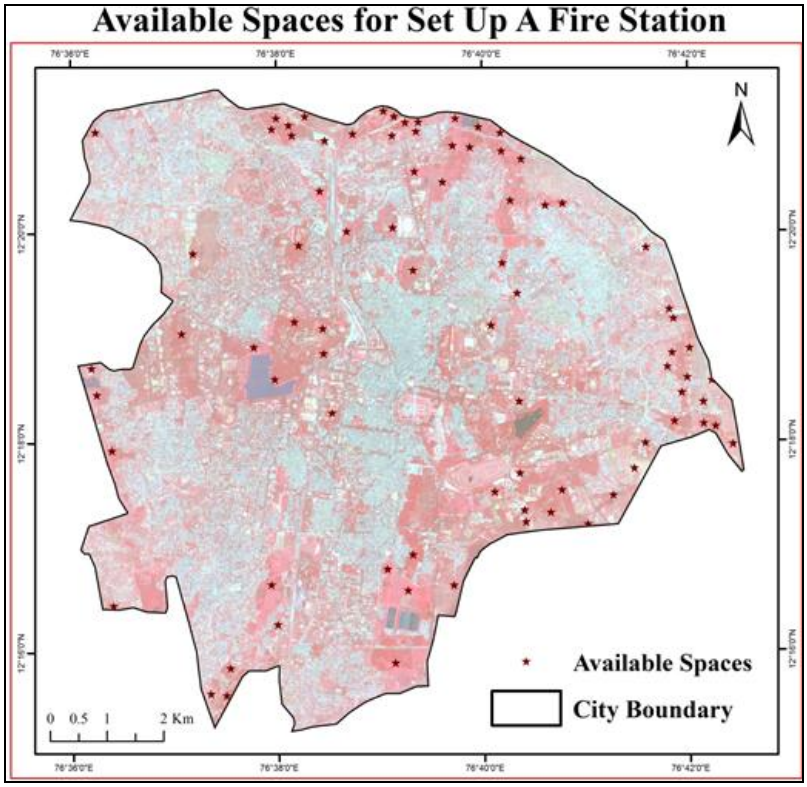

Fig 3

Scenario - 1

This scenario was carried out to establish new fire stations without considering existing ones at available 81 sites and settlements polygon centroids were generated as demand points.

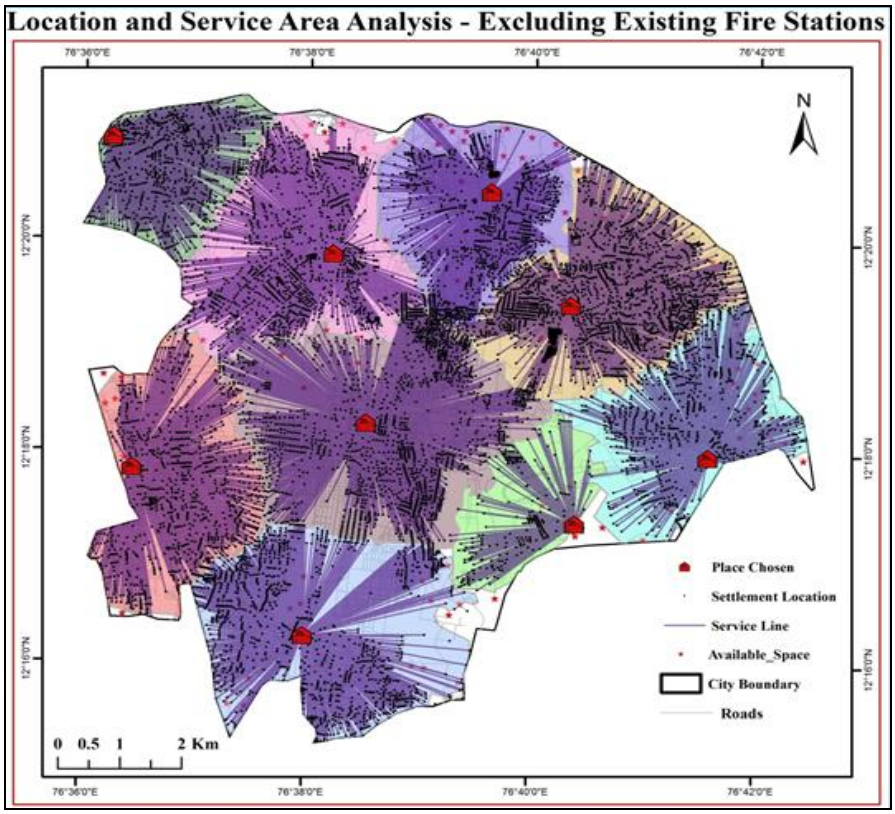

Fig 4

Table 2: A location–allocation model using travel time (in minutes) as impedance from proposed 9 fire station locations

Name	Facility Type	Number of settlement Polygons	Demand Weight (Population)	Total Time Travelled (Min.)	Total Weight Time (Min.)
Metagalli	Chosen	697	46022	2.76	1921.87
Rajendrarnagar	Chosen	1738	255219	3.14	5451.02
M.G Koppalu(Hebbal)	Chosen	559	10900	2.33	1302.15
Devaraja Mohalla(Jala Darshini)	Chosen	2386	358214	3.16	7530.40
Dattagalli	Chosen	498	17876	2.88	1433.93
Dattagalli South	Chosen	141	2510	2.79	394.04
Sriramapura(Madhuvana)	Chosen	1343	153623	2.92	3922.46
Kurubarahalli	Chosen	202	16434	2.80	566.33
Kurubarahalli East	Chosen	795	32264	2.73	2170.50

The result indicates that, among 81 potential sites 9 sites were chosen as suitable sites. These sites serve all the demand points within the travel time of five minutes. It was discovered that out of these nine potential sites (Table 2) Dattagalli South had the lowest allocated demand and Devaraja Mohalla (Jala Darshini) had the highest allocated demand.

Scenario - 2

Second scenario was implemented without relocating existing fire stations and to establish new facilities at available 81 sites to serve all the demand points.

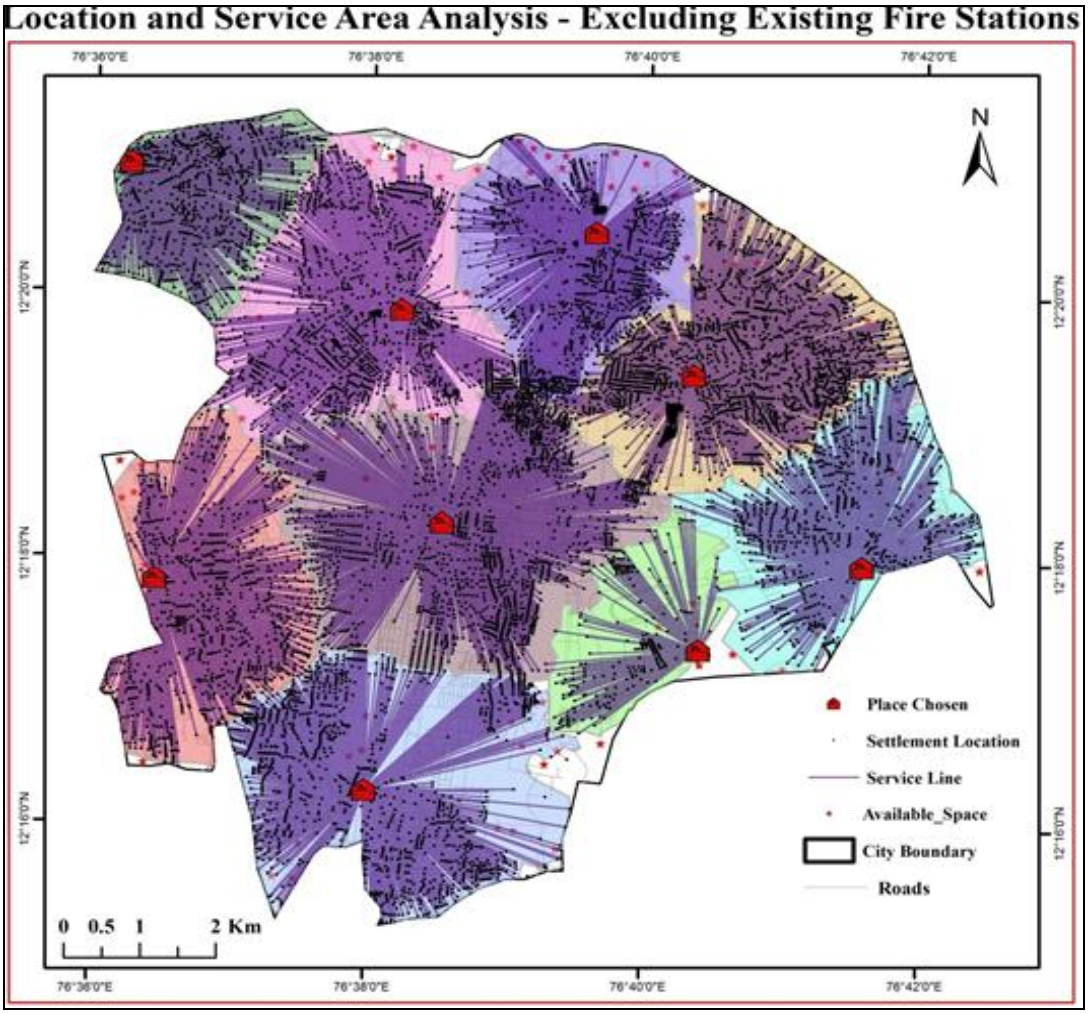

Fig 5

Table 3: A location–allocation model using travel time (in minutes) as impedance from proposed 9 fire station locations without relocating existing facilities

Name	Facility Type	Number of settlement Polygons	Demand Weight (Population)	Total Time Travelled (In Minutes)	Total Weight Time (In Minutes)
Manasagangothri	Chosen	1168	100065	2.51	2930.72
Dattagalli	Chosen	240	4272	3.28	787.82
Srirampura Madhuyana	Chosen	1190	120844	2.80	3329.79
Kurubarahalli	Chosen	304	17368	2.58	785.41
Kalayangirinagar	Chosen	819	74260	2.59	2123.40
Gayathripuram	Chosen	2124	276614	2.49	5289.28
Hebbal	Required	761	22118	2.41	1833.82
Bannimantap	Required	751	108415	2.53	1901.99
Saraswathipuram	Required	1002	169106	2.89	2900.48

The result shows among the available locations 6 locations were chosen for in addition to existing fire stations to cover all the demand points within the travel limit of five minutes. When the 6 additional (chosen) locations for the potential fire station facilities were included within the model, (Table 3) the results indicated that the potential site for the fire station in Dattagalli had the lowest allocated demand with just 240 settlement polygons and a total of approximately 4272 people allocated to it. It was discovered that in spite of the inclusion of the other 6 potential facilities the existing fire station of Saraswathipuram still had the highest allocated demand for its CKD healthcare service Both the scenarios indicate that the city requires nine fire stations to serve the all demand points. Therefore it is advisable to adopt second scenario i.e., to establish additional 6 new fire stations without relocating existing 3 fire stations, which would be cost effective.

Conclusion

This paper proposed a method of gradual optimization of urban fire station plan based on GIS location allocation model. The analysis revealed that the fire stations in the study area are less in number with intent of its maximal coverage within the minimum impedance time concerned. Emergency services need to be planned in such a way that it caters to most areas/locations within quickest possible time as the fire service mission is to protect life and property from fire. The main goal of the spatial planners around the world is the selection and finding the optimal site for facilities. Location allocation model provides the solution for spatial decision not to find the optimal locations for locating the emergency service facilities but also acts as tool to determine where and how many facilities are in need to fulfill the all requirements. The location - allocation model helps planners to locate facilities and also to support them in taking a decision about where to locate facility or facilities inside a chosen location. The result of both analyses revealed that, a total of nine fire stations are required to cover the entire city within 5 minutes. Therefore, the present study suggests adopting second method that is establishing 6 new fire stations without relocating existing fire stations which would be cost effective.

Acknowledgement

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