Geosfera Indonesia
p-ISSN 2598-9723, e-ISSN 2614-8528
available online at : https://jurnal.unej.ac.id/index.php/GEOSI
Vol. 8 No. 1, April 2023, 61-82

https://doi.org/10.19184/geosi.v8i1.36694

Research Article

Emergency Response Demand and Supply: A GIS-Based Network Analysis For Fire Station's Service Coverage Delineation in Kano Metropolis, Nigeria

Sulaiman Yunus[1]*, Julius Afolabi Falola[1], Ibrahim Musa Jaro[2]
[1]Department of Geography, Bayero University, PMB 3011, Gwarzo Road, Kano, Nigeria
[2]Department of Geography, Ahmadu Bello University, Zaria, Nigeria
*Corresponding author, Email address : syunus.geog@buk.edu.ng

ARTICLE INFO

Received :
27 December 2022

Revised :
6 March 2023

Accepted :
10 March 2023

Published :
18 April 2023

ABSTRACT

Inadequate fire emergency response infrastructure and a lack of defined service coverage remain key barriers to timely fire disaster response. This study is applied research which employed geospatial techniques and aimed at examining fire disaster emergency response demand and supply relationships with the view to delineating service coverage and locating more facilities for optimum coverage in Kano metropolis. Locations of the existing fire stations and fire incidents (2009-2019) were gathered through GPS surveying. Network data set were generated. Nearest Neighbor and Network Analysis (origin-destination, service coverage and location-allocation) were conducted to determine emergency response demand and supply relationships, service coverage area delineation and identifying best site for allocating new facilities within the metropolis respectively. It was found that no clearly defined service coverage exist as emergency response supply takes more than 4-8 times the NFPA travel standard, and with a great deal of overlapping response patterns. New service coverage areas were proposed and best sites for 8 firefighting facilities identified for optimum coverage. It is concluded that emergency fire disaster response demand and supply relationships within Kano metropolis is imbalanced, with extensive recurrent demand especially within the core area served by overstretched and inefficient response supply. This, therefore, implies continuous exposure of lives and properties to the menace of fire disaster in Kano metropolis.

Keywords : Fire Facilities; Location-allocation; Response Demand; Response Supply; Service Coverage

INTRODUCTION

Fire has posed a substantial hazard to humans, the built and natural environment, frequently resulting in bodily and psychological damage, economic losses, pollution, and death (Yao et al., 2018). There were around 3.5 fires per 1000 inhabitants in the 31 countries studied in 2015 by IAFRS, resulting in 18,454 fatalities and more than 44,000 injuries (Brushlinsky et al., 2017). The "urban SDG" focuses on creating inclusive, secure, resilient, and sustainable communities, cities, and other human settlements. The goal is to protect those that are vulnerable by 2030, while also drastically decreasing fatalities, vulnerable people, and economic damages caused by disasters (including fire outbreaks) as a percentage of the global gross domestic product. As a result, governments offer fire response and rescue services as a fundamental public service to protect citizens' lives, property, and the built and natural environment from disasters like fires.

Proper resources allocation for prevention of fire and impact mitigation is essential for effective and dependable fire disaster management. Additionally, a significant issue is the geographic distribution of fire stations and the service coverage areas that are linked with them because it is essential for rapid emergency response. Most emergency response systems for fire disaster measure their effectiveness by how long it takes them to respond. The spatial distribution of demand and supply points within a network system influences response time (Shahparvari et al. 2020). A fire station's service coverage area is its responsibility zone or region, which is often determined based on demand and/or other specific factors. Each fire station has a unique coverage area that varies according to its location, street, residential density, landuse patterns, and other factors in the district (Adamu & Yunus, 2017). Furthermore, it is widely accepted that demand for emergency response services and the distribution of fire stations influences the sites for constructing new ones (Kanoun et al., 2010 ; Murray, 2015).

Challenges relating to fire disaster response demand and supply analysis, service coverage demarcation, and fire station siting (location allocation analysis) have been thoroughly investigated in numerous cities around the world using methodologies which integrate geographical information systems (GIS) with other methods (Yao et al., 2018). Some of the studies include, Chevalier et al. (2012) ; Aktaş et al. (2013); Xin & Huang (2013); Church & Li (2016); Dong et al. (2018), Nyimbili & Erden (2020); Ceyhan et al. (2012) ; Wuschke et al. (2013) ; Kiran et al. 2018; Kiran & Corcoran (2017); Zhibang et al. (2018); Wang et al. (2021); Mao et al. (2020); Chen et al. (2018) found that techniques like the p-median problem (PMP) was used to reduce the overall travel distance and time between fire stations and dangerous areas, hence improving access to locations where services are required. Long-established methods for determining service coverage include the location set covering problem (LSCP), the threshold coverage model (TCM), and the maximal covering location problem (MCLP) (Murray & Tong, 2009; Murray, 2013). Despite the fact that a variety of techniques were employed, the use of GIS allows for actual road network distance, which offers a more accurate travel time estimation than mare buffer distances (Catay, 2011; Oppong et al., 2017; Han et al., 2021; Yu et al., 2020); and spatial analytics, which provide a robust graphical approach representing space that enables the system of fire stations to optimally service their (Chhetri et al., 2017). Unfortunately, none of these techniques were applied to the response to an urban fire disaster in the city of Kano.

The NFPA response standards comprise of three defined time limitations which affect how fire and emergency medical services are delivered. NFPA 1710 proposes a 4-minute response time to help extinguish fires before they reach flashover, which occurs when the ambient temperature reaches between 825°F and 1,000°F between 4 to 10 minutes of initial ignition (ESRI, 2007). A post-flashover fire spreads and burns hotter than a flashover fire, hindering search and rescue operations across the rest of the building and requiring the dispatch of more firefighters to put out the fire. Although, NFPA (2010) and ESRI (2007) have proposed fire emergency response times based on the nature and behavior of fires while taking flash-over time into account, there has never been a universally prescribed cut-off. This is because different fire agencies have different cut-off distances that are influenced by variations in urban settings and available resources. For instance, a 5-minute impedance cut-off was suggested in Tehran, Iran, and Istanbul, Turkey, by Bolouri et al. (2018) and Aktas et al. (2013), respectively. Four minutes cut-off distance was used by Algharib (2011) in delineating the service coverage of fire stations in Kuwait and Kumasi, Ghana, respectively. However, in Sfax, Tunisia, Famagusta, Cyprus, and Padang, Indonesia, Kanoun et al. (2010), Kazemi et al. (2013), and Bahri (2016) employed an impedance cut-off of roughly 10 minutes. Erkut et al. (2001) and Ayuba et al. (2016) considered flashover time/NFPA standard of 4 minutes' drive, fire station locations, speed limits (Km/Hr), fire incident concentration, population density, and travel distances (minutes). Other elements, such as the city's population density, function, fire intensity, topography, and so on, may be considered in different areas depending on their unique characteristics.

Urban planners, researchers, disaster managers, and other stakeholders are very concerned about the recurrent fire disasters in the homes and markets of Nigerian towns (NEMA, 2006; Oladokun & Ishola, 2010). Kano Metropolis is not an exception to the damage this catastrophe has caused to nearly all landuse types, at varying intensities both spatially and temporally. This has led to an ever-increasing risk as well as the loss of many lives, injuries, and property that have cost billions of Naira. Studies on the subject have been carried out in various locations of Nigeria, utilizing a variety of methodologies and methods (Adamu & Yunus, 2016; Oladokun et al., 2012; Oladokun & Emanuel, 2014; Adekunle et al., 2016; Ogundele et al., 2013; Dogondaji et al., 2017). However, none of the prior studies especially in Kano metropolis have considered emergency response demand and supply relationships, service coverage delineation and location-allocation of new firefighting facilities for optimal coverage. Isa et al. (2016) attempted to define and propose service coverage areas for existing fire stations using buffer distances. In this study, due to the current challenges of fire disaster emergency response in the city, and with high recurrent fire disaster rate, three key issues are of interest: emergency response demand and supply relationships, service coverage area delineation and allocation of new facilities. Therefore, the objectives of this study are to; examine the spatial distribution pattern of historical fire incidents (response demand points from 2009-2019) and existing fire stations, determine the existing spatial service coverage (response supply coverage) of fire stations- based on the historic incidents, measure the existing emergency response demand and supply travel distances, redefine and delineate standard service coverage based on NFPA, and finally propose new facility locations for optimum fire emergency response demand and supply throughout the metropolis.

Conceptual Model of Fire Disaster Emergency Response Demand and Supply Relationships

Increasing fire disaster emergencies are driving extraordinary demand for effective response supply. Frequent fire disaster on various land uses within the Kano metropolis necessitated the need for efficient response system for fire disaster risk reduction. Response demand is simply the requirement for specialized assistance and services after a fire disaster to lessen the effects of an outbreak. On the other hand, response supply is the most spectacular phase of a fire disaster management and risk control (Ejikeme et al. 2012). It is the action that takes place instantly during and immediately after a fire disaster, which, if for any reason (technical or non-technical) delayed or prolonged, can surpass the power of responders and raise the enormity of an event. An indicator of how well an emergency response system is working is how quickly supplies are provided (Ganeshkumar & Remesh, 2010). Fire disaster response supply comprised of series of activities defined by time which commences when responders start their travel to the location of the emergency and ends immediately when they reach to the incident point (NFPA, 2003). When there is a need for emergency response, many different aspects, such as the availability and sufficiency of firefighters and equipment, knowledge, resources, and technological know-how, affect the type and quality of the supply.

The response demand and supply conceptual model sees time as central to determining the nature of the interaction between the response demand and supply relationships. Many factors such as access/travel distance, service coverage among others is embedded in time, and seen as the determinant of the efficiency of the relationships. However, when there is over response demand in the presence of inadequate personnel/apparatus, absence of service coverage area, technical problems among others, then there will be under response supply which translates to increased risk and exposure to the effect of fire disaster. Figure 1 depicts the systematic relationships between emergency response demand and supply on one hand and implication of over emergency response demand.

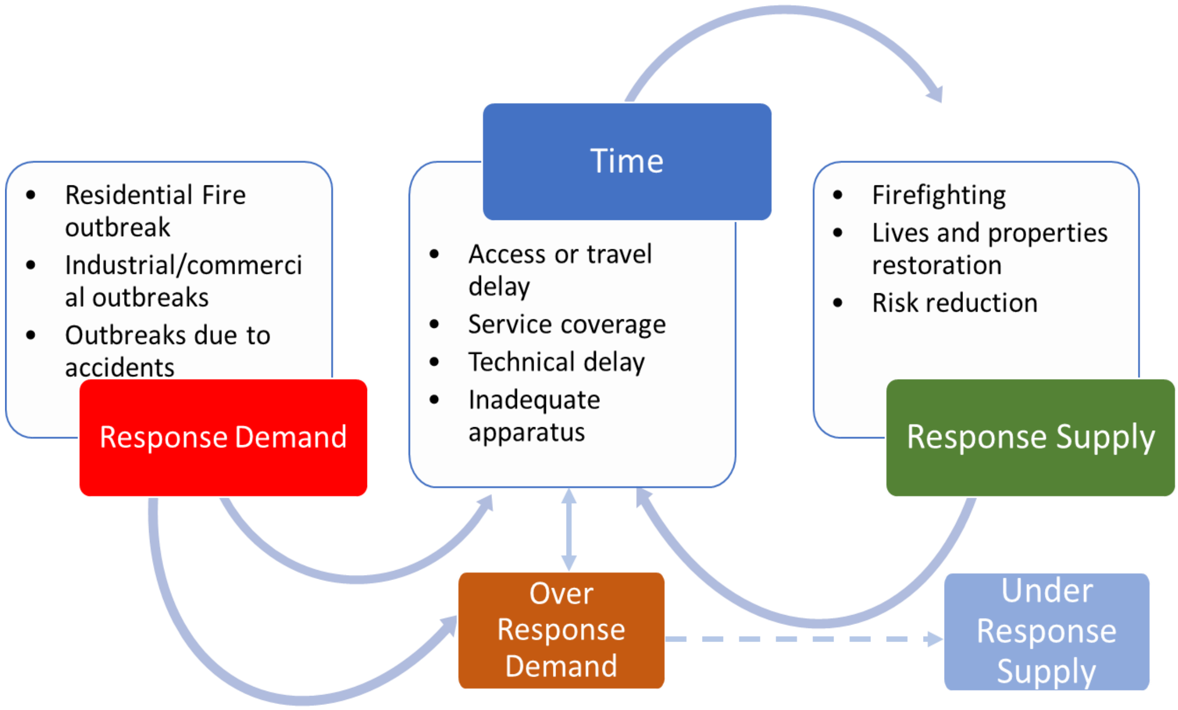


Figure 1. Conceptual model of fire disaster emergency response demand and supply relationships

METHODS

This research is an applied one which employed geospatial approach integrating quantitative and geospatial data types. Figure 2 describes and presents the various data kinds, sources, tools, and procedures for data gathering and analysis.

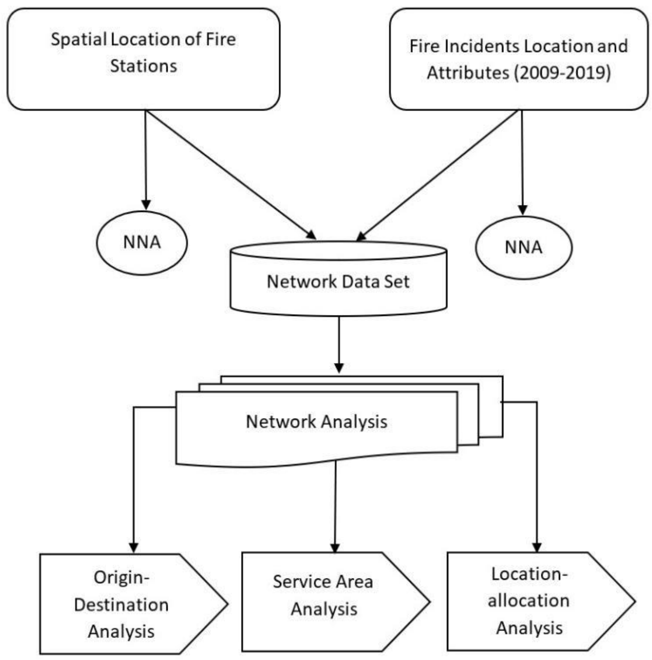


Figure 2. Flowchart of Methodology

Study Area

Kano is positioned between latitudes 11° 50' N and 12° 10' N, and longitudes 8° 25' E and 8° 40' E. It comprised of eight local government units including Fagge, Dala, Kano Municipal, Gwale, Tarauni and Nassarawa). Additionally, portions of Kumbotso and Ungoggo forms part of Kano metropolitan area (Maigari, 2016). The metropolis is around 499 km2 in size, with much of the urban area stretching outward from the region's center (Figure 3).

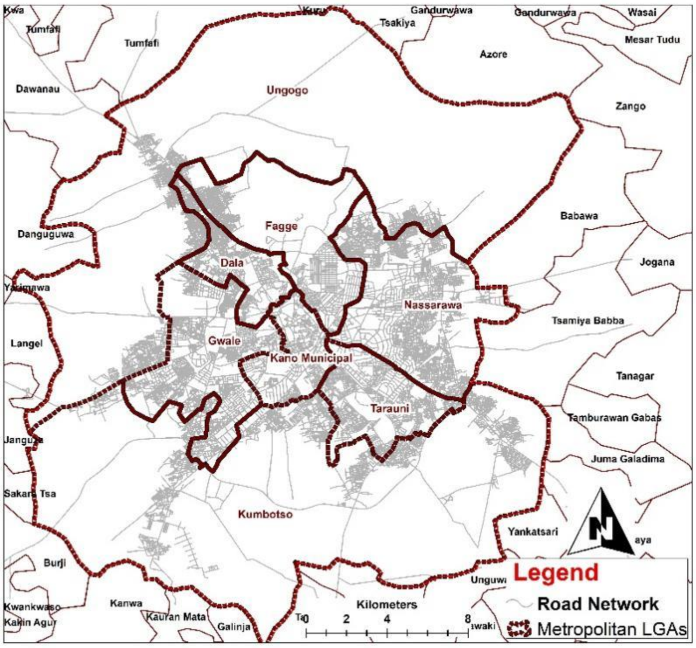


Figure 3. Kano Metropolis

By 2018, Kano metropolis is expected to have a population of 4, 331, 790, making it one of the West African subcontinent's urban centers with the highest economic and demographic growth (NPC, 2013). Good management is challenging due to the ongoing intensification of human activities, which worsens the environment and raises the danger of multiple tragedies (Barau et al., 2015; Yunus & Falola, 2022). The expansion of the metropolis has been credited factors including natural growth, immigration, the existence of educational institutions, the proximity of businesses and large markets, and the fact that it serves as the state capital (Ayila et al. 2014). Throughout the city, there is a wide range in the density of residential units. There are about 7,000 people living there every square kilometer. The six major LGAs (Dala, Municipal, Nassarawa, Gwale, Fagge, and Trauni) make up much of the urbanized area with population density of about 19, 000 persons per square kilometer over an area of roughly 145 square kilometers. According to reports, this region experiences the greatest fire outbreaks because of its high population density, intense socioeconomic activity, high demand, and consumption of a variety of energy sources throughout the year.

Kano Metropolis is susceptible to numerous calamities, both natural and man-made which has caused loss of lives, properties, and harm to the environment. While some strikes immediately, others take time to develop. Some of the disasters include flooding, dam collapsing/failure, collapsing of buildings, traffic and aviation accidents, explosions, riots, and fire disaster affecting commercial, residential, and industrial landuses. Urban fires are a serious problem in the city, where they frequently result in fatalities, serious injuries, and the damage of valuable property worth billions of Naira. Addressing frequent recurrence of fire disasters in especially highly populated areas of the metropolis remain a major challenge to urban planners, researchers, and other stakeholders. Consequently, the current research is being carried out.

Data Types and Sources

The daily records of each of the existing fire disaster emergency response stations within the metropolis were used to compile a fire disaster incident record (2009-2019) that included incident attributes such as date and time of occurrence, address, landuses affected, estimated damages (counts of structures/materials and monetary value), cause or trigger, turn-out and arrival time, duration of response exercise, and number of lives lost, among others. Because more than 80% of the existing fire stations were available (excluding Danladi Nasidi station) and the records were more readily available, accessible, consistent, legible (to some extent), and adequate, this period's incidents records were chosen (Table 1). A total of 4335 events were recorded and used to determine the existing response demand and supply pattern within the metropolis, and to also propose an updated one based on standards. The incidents' absolute location attributes (longitude and latitude) were acquired via GPS surveying in accordance with the addresses provided by the fire department's incident records. Similarly, the eleven (11) existing fire stations' location attributes (latitude and longitude) were also acquired. Road network data (vector format) with defined topology were extracted via on-screen digitization from a World View satellite image (2018) with a spatial resolution of 30 cm received from Kano Geographic Information System department (KANGIS). This allowed for the mapping of the spatial pattern of existing response demand and supply relationships and fire stations to enable delineating service coverage areas for each of the stations and allocation of more fire stations in places with deficiency of emergency response.

Table 1. Distribution and Counts of Historical Fire Incidents Responded to by the existing Fire Stations within Kano Metropolis (2009-2019)

Stations	Year(s)												
	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	Total	%
Bompai	32	23	31	34	17	13	26	26	17	38	13	270	6.2
Danladi Nasidi	NA	NA	NA	NA	NA	NA	NA	NA	NA	10	19	29	1
Government House	3	7	13	36	7	13	13	14	11	3	18	138	3
Gwale	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	0	0
Headquarters	246	84	98	80	87	66	296	204	199	233	157	1751	40
House of Assembly	NA	29	67	14	2	68	73	NA	12	20	71	356	8
Jakara	39	16	9	16	34	112	86	60	70	44	8	494	11
Kurna	32	28	45	61	28	69	11	3	51	21	17	366	8
Rijiyar Zaki	35	17	70	40	1	37	4	49	41	40	9	343	8
Sabon Gari	11	6	4	5	12	22	18	21	11	NA	NA	110	3
Sharada	4	30	1	NA	8	NA	69	70	150	137	9	478	11
Annual Total	402	240	338	286	196	400	596	447	562	546	321	4335	100.0

Data Collection Instruments, Techniques and Sampling Methods

Among the main data collection methods employed are the review of fire event records, GPS and electronic surveying, and geospatial data capture via on-screen digitization of road network data from World View satellite image (2018) to enable network analysis. To gather field data, a Global Positioning System (GPS) device was employed (GPS Garmin 86i). All the city's existing fire stations were purposefully selected since, in addition to housing professionals, they are legally responsible for fighting fires to protect people's lives and property. In addition, incidents from January 2009 to September 2019 were chosen to enable depicting the true nature of the problem and the analysis' findings to be generalized.

Data Analysis

Data analytics used in this study included Nearest Neighbor and Network analyses (service coverage and location allocation). In Nearest Neighbor Analysis, a nearest neighbor index was determined from the mean distance between each event location and its closest neighboring point. The analysis returns the observed and expected average distance, the z-score, nearest neighbor ratio and p-value. The statistical significance metrics indicate whether the null hypothesis should be accepted or rejected. However, the size of the research zone has a significant impact on the statistical significance of this approach. The null hypothesis for Average Nearest Neighbor asserts that "incidents or objects are randomly distributed." However, the nearest neighbor index is determined via the ratio between the observed and expected mean distances. The mean distance between neighbors is the anticipated distance in a fictitious random distribution. The pattern clusters when the index is less than one. However, if the index is more than 1, there is a propensity for dispersion. The spatial distribution of two crucial components in this scenario was determined using nearest neighborhood analysis (NNA). The first is the distribution pattern of response demand locations (fire catastrophe events) inside the study region, and the second is the number of fire stations already in use in the city.

Origin-destination analysis, which generates a matrix from many origins to multiple destinations, was used to determine emergency response demand and supply patterns as well as efficiency level, with respect to distance traveled and spatial coverage by each of the stations over the previous ten years. The returned matrix data includes the travel distance and time between each origin (in this case, fire stations) and each destination (incident location). The least amount of time (mins) or distance (km) required to travel from each origin to each destination is also taken into consideration while ranking the destinations that each origin connects to in ascending order. For each origin-destination pair, the optimum street route is found, and the trip times and lengths are saved as properties of the output routes. Even though straight lines are utilized for performance reasons, they never record straight-line distance but rather transit time and distance along the street network. Due to various inconsistencies, overlaps, and overstretching in the current response supply pattern, it was determined that none of the fire stations in the city have a well-defined service coverage area for the past ten years. Without any sort of guiding concept, they have been randomly responding to emergency demand points, which has led to the overall response system's inefficiencies. It is therefore required to redefine the service coverage considering the features of the city and in comparison, to an accepted benchmark (the NFPA standard in this case).

According to NFPA 1710, (2010), a city's total response time for a fire emergency should not exceed 4 minutes (240 seconds). This is due to the behavioral pattern of fire from the beginning to the end of its development stages. It is expected to be extinguished before it reaches the flashover stage, which usually occurs within 4-10 minutes from the ignition time. However, the longer the fire is allowed to burn, the more difficult it is to put out. Studies have established that fires advance and grow to become more difficult to extinguish every 17 seconds. This as a result leads to the suggestion that each station within the metropolis should have a designated service area that can be accessed within 240 seconds (NFPA standard) to allow for fire extinguishment within 4-10 minutes as also proposed by ESRI, (2007). To achieve this, Network analyst tool, and specifically service area analysis (ArcGIS 10.8v) was used to redefine and delineate new service coverage areas to enable emergency response supplies from the demand points by each of the 11 existing fire stations within 4 minutes. This was conducted using the criteria described in Table 2.

Table 2. Service coverage delineation and location-allocation criteria

SN	Criteria	Description
1.	Existing fire stations	Spatial distribution of the 11 existing fire stations in Kano metropolis
2.	Fire incident points	Spatial pattern of fire incident points/response demand points (2009-2019)
3.	Road network data	Road network shapefile with a well-defined topological relationship
4.	Road classes/categories	Primary, secondary, and tertiary roads
5.	Road lengths	Defined distance (in km) of all road categories
6.	Permissible speed limits	Speed limits of 70km/hr, 50km/hr and 30km/hr respectively as determined by the Federal Road Safety Corps (FRSC).
7.	Road distances	Road distance (computed from length and speed) per category based on permissible speed limit
8.	4 minutes drive	Service coverage distance travel delineation based on NFPA 1710 (2010)

The service coverage analysis enables detecting areas fully covered and those with response deficit. However, site allocation study was carried out utilizing the Network Analyst of the ArcGIS 10.8 v environment to enable optimal coverage throughout the city. The aim of this analysis is to determine the best places for a few fire stations to serve as many city residents as possible.

RESULTS AND DISCUSSION

Distribution Pattern of Fire Incident Locations (Response Demand Points) and Fire Stations in Kano Metropolis

The results indicated a Nearest Neighbor Index of 0.179, showing a clustered pattern of fire incident distribution (with an expected mean distance from each fire incident of 1004.52 meters and an observed mean distance of 180.02 meters). Unlike the findings of Chen & Yang (2018) who found more clustering of fire incidents within industrial and commercial areas in southern Taiwan, in this study, dominance and clustering of occurrences is on residential landuse, which accounted for around 72 percent of all fire incidents, (Figure 4). This finding implies that fire outbreaks occur sporadically at intervals of about 180m from an incident location in all directions, especially within the city core. This is similar to the findings of Isa et al. (2016) and Zhang et al. (2018) who identified incident concentration zones within the core areas of their study. This calls for immediate intervention. In contrast to the distribution of fire occurrences within the metropolis, fire stations are widely spaced, with a Nearest Neighbor Index of 1.69, resulting from an observed and expected mean distances of 3642.2 and 2150.7 meters respectively. This makes it difficult for existing fire stations to meet the ever-increasing emergency response demand, necessitating the placement of additional stations to ensure optimal coverage. On the contrary, while most studies use NNA to identify urban fire clusters, Ceyhan et al. (2012) employed exploratory and inferential methods for spatio-temporal analysis of fire clustering in parts of Ankara, Turkey. Moreover, Diggle's D-function was proposed for detecting residential fire clusters over time.

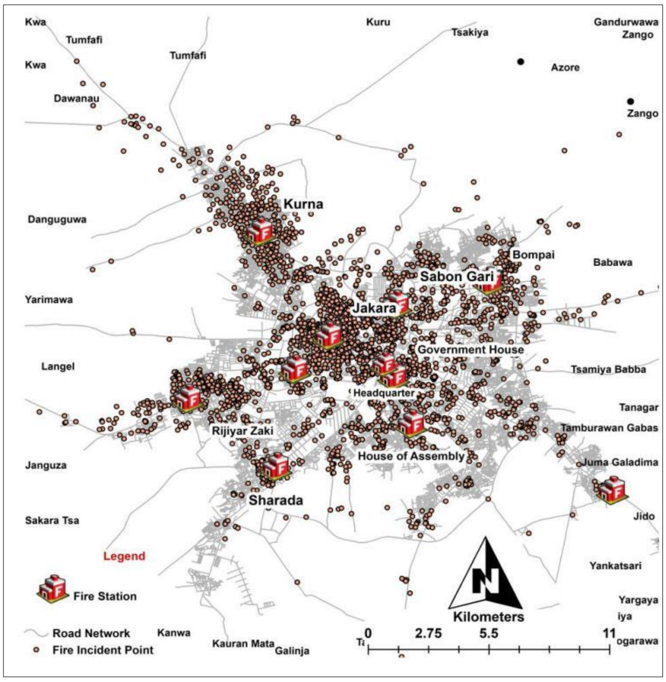


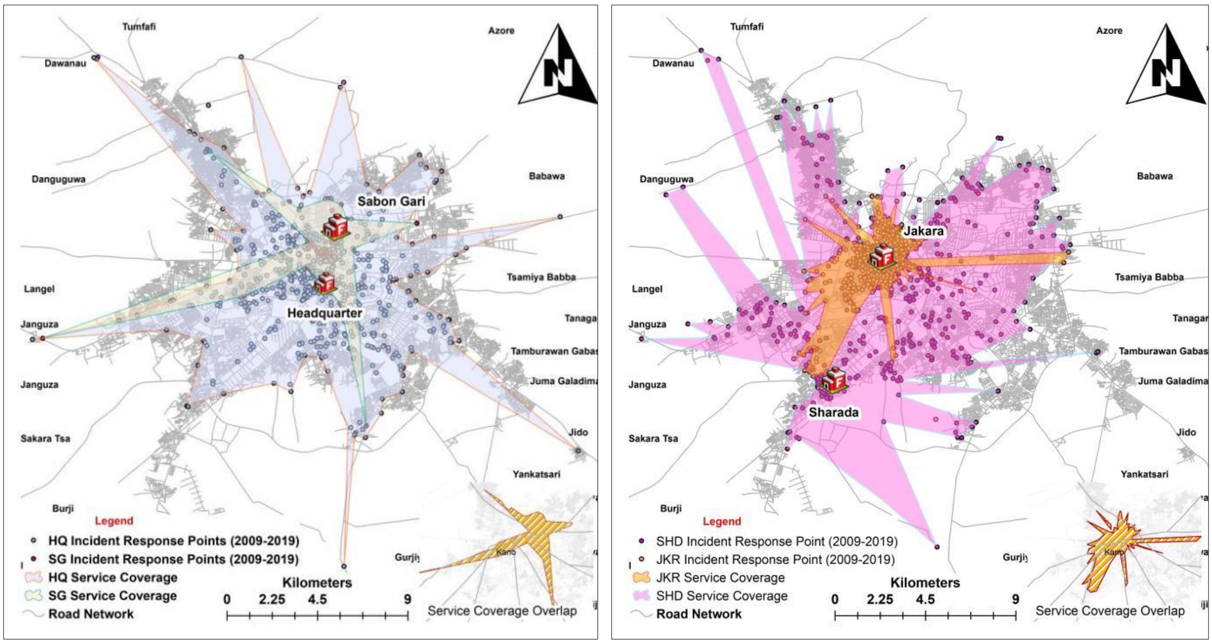
Figure 4. Distribution of fire stations and fire incident locations (response demand points) in Kano Metropolis from 2009 to 2019

With respect to the total number of demand points (4335) within the study period and the existing fire station, ratio analysis revealed that each station is expected to service around 394 demand points, regardless of distance coverage. However, because of many factors including lack of clearly defined service coverage area, fire incidence frequency, landues among others, there were variations in terms of the total incidents responded to and the spatial coverage areas. For efficiency, distance coverage is critical for rapid response, it must be considered when choosing the number of demand locations to be covered by each station. Other considerations include the number of firefighters, fire engines, extinguishers, fire suits, helmets among others.

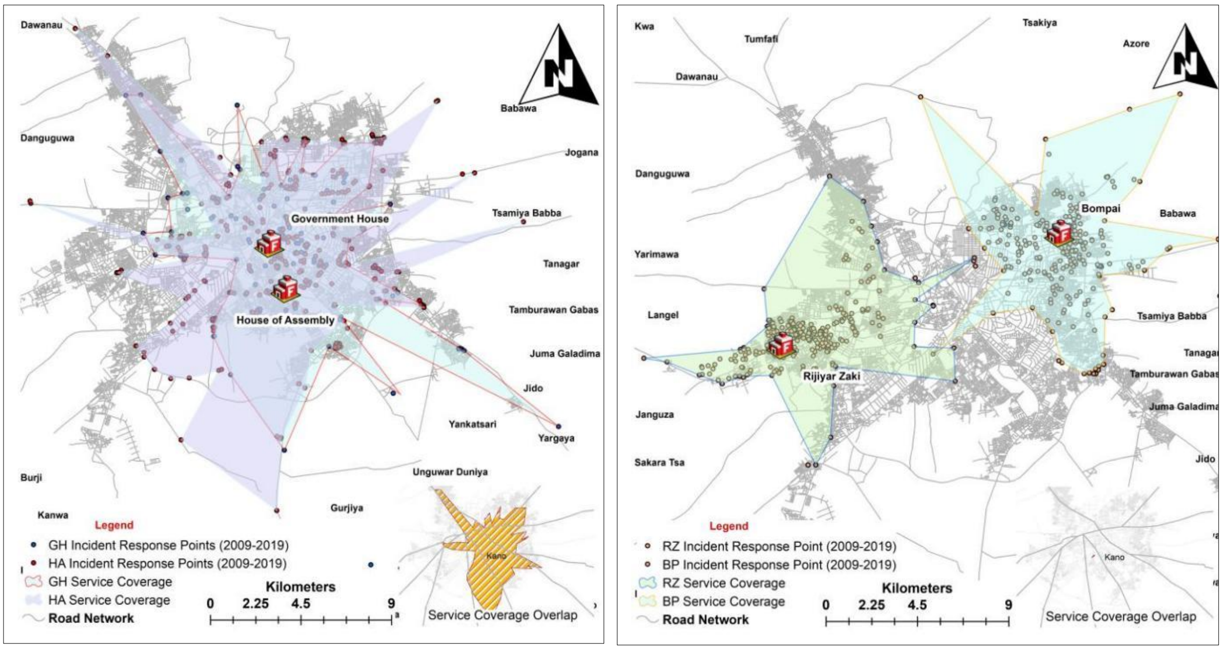
Delineation of the existing Service Coverage based on Historical Incident Response by the existing Stations (2009-2019)

Total fire incidents attended to by each of the stations (between 2009 and 2019) were mapped and used to delineate the spatial extent of the service coverage and the response demand and supply pattern by each of the existing fire station (Figures 5-9). The number and distribution pattern of incidents responded to were found to be uneven among the existing fire stations (Table 1), likewise their spatial coverage. According to the findings, the station at the Headquarter responded to about 40% of all fire incidents with a spatial coverage of about 95%. This is followed by Jakara and Sharada stations who responded to about 11% each of the incidents and with spatial coverages of about 50% and 93% of the total built-up area with the city respectively (Figure 6), with a great deal of overlap.

The House of Assembly and Government house stations responded to roughly about 8% and 3% respectively, and with spatial coverage areas of more than 80% and 75% of the metropolis' entire area with nearly 95% of the latter located within the former (Figure 7). Bompai and Rijiyar Zaki stations are complementary in that the latter covers the territory from the city's south-western outskirts to the city center, while the former covers the area from the city's north-eastern outskirts to the center, with a significant overlap in the center. These two stations, despite their vast service scope, are more systematically positioned than the others, but also over-stretched with a great deal of overlap into the areas of the headquarter, Kurna, Government House, House of Assembly stations (Figure 8). Due to the lack of a functioning fire truck and other station infrastructure, the Gwale station was inactive throughout the study period. Finally, the Danladi Nasidi station which was recently launched (2018) only responded to roughly 0.6% of overall events (Table 1).



Figures 5 and 6. Showing the Current Service Coverage Areas of HQ and Sabon Gari along with Jakara and Sharada Stations including their Respective Overlaps



Figures 7 and 8. Illustrate the Current Service Coverage Areas of the Governor's House and the House of Assembly, along with Rijiyar Zaki and Bompai Stations including their Respective Overlaps.

Others include Kurna and Headquarters stations, which have significant overlap of about one-third of Kurna covered by Headquarter station (Figure 9). This obviously indicates serious confusion, lack of consistency and misunderstanding of the system, all of which contributed to inefficiency in response, particularly in terms of travel distance. The results clearly depicts that none of the existing fire stations have a clearly defined and exclusive service coverage area, signifying that all stations have equal chances of responding to any incident in all parts of the metropolis. As a result, some stations are overburdened, while others are underused.

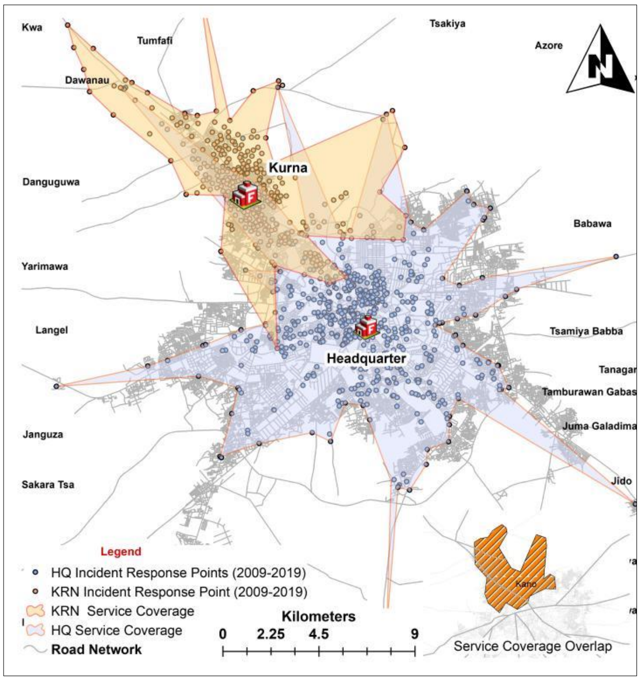


Figure 9. Overlap of existing fire service coverage in Kurna and HQ Stations

Table 2 presented the extents of prevailing service coverage and overlapping between pair of stations within the metropolis. From the result for example, the HQ and SG stations (Figure 5) covers spatial extents of about 145km² and 28.7km² respectively, with an overlap of about 25.1km². This signifies that about 89% of the service coverage area of SG is contained within that of HQ. Secondly, JKR and SHD stations covers service areas of about 24.9km2 and 172.7km2 respectively. This pair also have an overlap of about 24.2km2 accounting for about 98% of the service area of JKR station. In other words, the service area of JKR almost totally contained within that of SHD. This clearly depicts the level of redundancy within the prevailing response system. Only the service coverage areas between RZ and BP, KRN and DNSD stations has an insignificant overlap of about 0.03km2 and 0km2 respectively. Although most studies use geospatial methods for service coverage delineation, Yu et al. (2020) proposed a novel constrained Voronoi diagram for fire service area delimitation using datasets comprising street network and historical fire incidents.

Emergency Response Demand and Supply Distance Travel Patterns (2009-2019)

Based on the current situation, it takes the firefighters more than 4-8 times the ESRI (2007) and NFPA (2010) recommended travel distance standard of 4 minutes to attend to most of the fire incident situations within the metropolis. This, however, is unhealthy, and has and continuing to result to loss of numerous lives, injuries, and property destruction. Because the longer the time it takes to respond to a fire disaster, the more the risk level and the greater the magnitude of the consequence (Yunus, 2019). To clearly understand the response demand and supply situations that existed within the last decade, all the fire incidents responded to by each station along with the actual travel distances in minutes and kilometers were revisited and computed to determine those that were in accordance with the recommended travel distance (4 minutes), and those beyond. This is to enable proposing and delineating a more realistic service areas to avoid unnecessary overlapping and overstretching of the stations for optimal response coverage within the metropolis. Figures 10-13 depicts the emergency response demand pattern and supply relationships in terms of physical and time distances covered by each of the station to respond to each of the incident points. For easy understanding, time distance was categorized into three ranges starting from the minimum distance range (0-4 minutes) which is within the standard, to the maximum distances (above 20 minutes) which is about 4-8 times the standard.

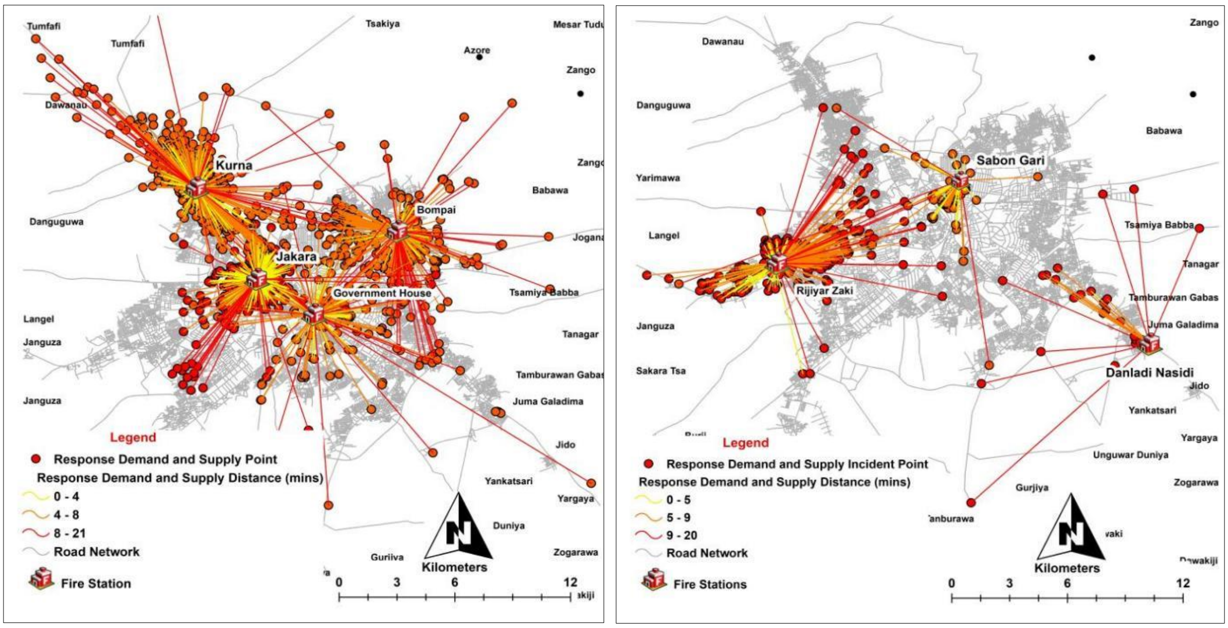


Figure 10 and 11. Emergency Response Demand and Supply Distance Range: (a) KRN, JKR, BP and GH stations (b) RZ, SG and DNSD stations

From Figure 10, about 39% of the incidents responded to by KRN, JKR, BP and GH stations were reached within 0-4 minutes' drive, 45% within 4-8 minutes and about 16% responded to within 8-21 minutes. This by implication signifies that more than 60% of the total incidents demand points were not responded to within the recommended time. This has significantly contributed to the resultant consequences experienced during the study period. However, on the other hand, only about 40% of the response demand points were serves within 4 minutes time thereby reducing the magnitude and people and properties exposure to fire risks within the area. Figure 10 depicts about 41% of the incident points responded to by RZ, SG and DNSD stations were within the recommended standard (0-5 minutes). However, 44% falls within response range of 5-9 minutes, and 15% within the range of 9-20 minutes. Many factors might account for the late response which also determined the magnitude of the incidents.

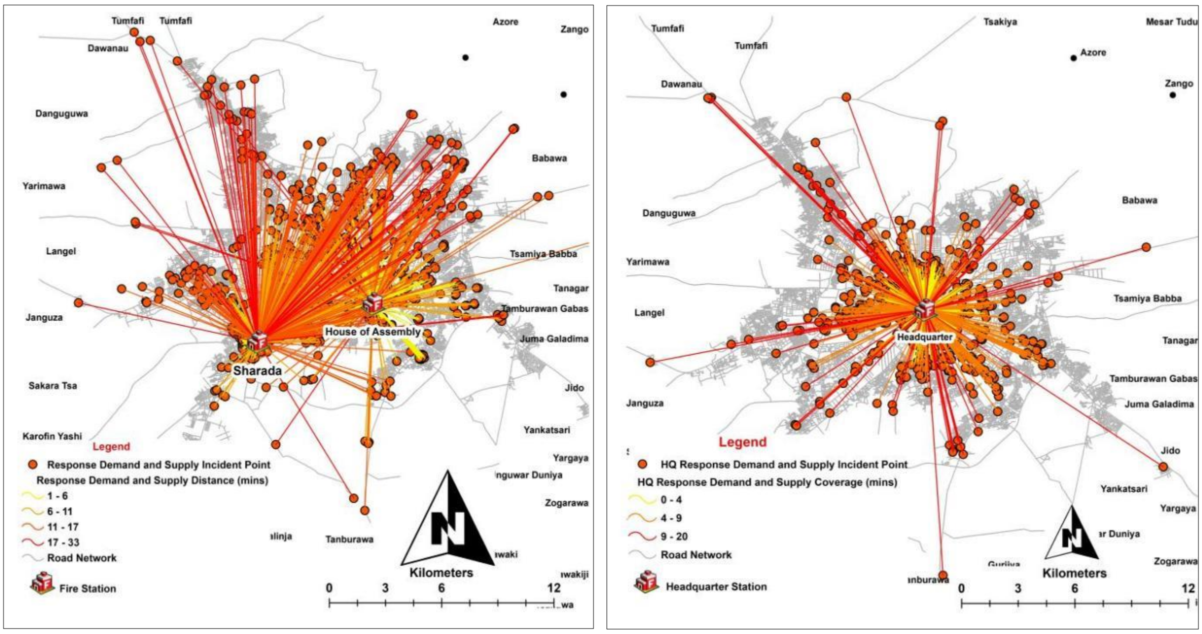


Figure 12 and 13. Emergency Response Demand and Supply Distance Range: (a) HQ station (b) SHD and HA stations

The HQ station (Figure 12), about 35% of the incidents were responded to very late (within 9-20 minutes). However, most of the incident responded to (about 47%) falls within the range of 0-4 minutes. In the case of SHD and HA stations, about 26% of the incidents were responded to within 17-33 minutes' drive (which is about 8 times the recommended distance). From Table 3, based on the previous distance coverage (time and length) by each of the station, the station at the headquarter responded to the highest number of incidents (1751) and has the highest distance coverage of about 2492.3 km and 3139.5 minutes. However, on the other hand, the least incident responded to, and distance coverage (in km and minutes) is by Danladi Nasidi station, which responded to only 29 incidents with a travel coverage of about 145.3km and 179.9 minutes.

Table 3. Response Distance Coverage and Overlaps by the existing stations (2009-2019)

SN	Station	No of Emergency Response Demand and Supply Points	Service Coverage (km^2)	Distance Coverage (km)	Time Coverage (mins)	Overlap Coverage (km^2)
1	Headquarters	1751	145	2492.3	3139.5	25.1
2	Sabon Gari	110	28.7	229.5	326.6	
3	Jakara	494	24.9	863.4	1168.9	24.2
4	Sharada	478	172.7	3391	4667.7	
5	Government House	138	106.6	571.9	718.9	80.8
6	House of Assembly	356	145.7	1900	2388.4	
7	Rijiyar Zaki	343	68.3	811.8	1098.2	0.03
8	Bompai	270	77.3	824.5	1258.1	
9	Kurna	366	72.7	1042.6	1462.9	0
10	Danladi Nasidi	29	63	145.3	179.9	
11	Kurna	-	72.7	1042.6	1462.9	58.7
12	Headquarters	-	145	2492.3	3139.5	

Service Coverage Area Redefinition and Delineation Based 4-minutes' Drive (NFPA Standard)

A four-minute travel threshold based on NFPA, (2010) and ESRI, (2007) was employed to determine the response service coverage for each existing fire station (Figure 14) as conducted by Oppong et al. (2017). This is to enable determining responsibility jurisdiction for the stations, and to estimate the expected gravity of emergency response demand and supply, and respective distance coverage. However, in this case, overlaps were not included in the service coverage delineation criteria to avoid redundancies as existed in the previous response system. Figure 14 and Table 3 shows that approximately 79 percent of total demand points (3411 demand points) are now accessible within a 4-minute drive of existing fire stations. However, just roughly 21% (924 points) of the total falls outside of the specified range. To achieve optimum coverage, this necessitates the need to position additional fire stations/facilities in strategic areas within the metropolis.

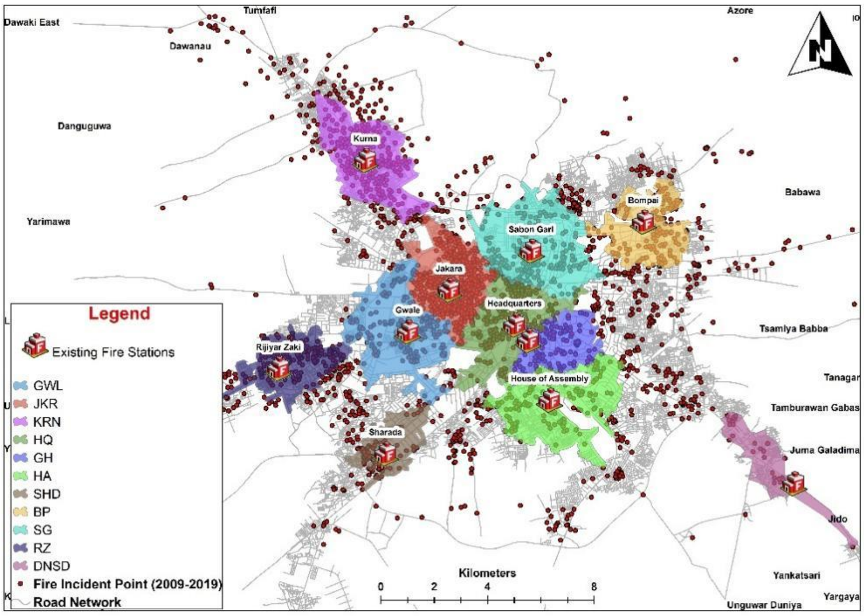


Figure 14. Proposed Service Coverage Areas Accessible within Four Minutes' Drive from all Directions

It is critical to note that in this case, with the newly proposed 4 minutes service coverage areas, the number of demand points and the supply distance coverage (minutes) of current fire stations changes depending on the demand points' closeness to the stations. From Table **4**, Jakara stations have the most demand sites (1635) within 4 minutes of driving in all directions, with a response supply distance coverage of roughly 2757.73 minutes. The stations at the Headquarters, Sabon Gari, and Kurna come in second, third and fourth with 322, 258 and 237 demand points, and response supply distances of 588.8, 502.6 and 549 minutes respectively. Due to the low risk of fire disaster because of low population density, the stations' location on the outskirts of the city for example Danladi Nasidi has the fewest demand points (about 35) and total response supply distance coverage of about 107.88 minutes. With this service coverage area, the existing stations can serve about 79% of the total incidents. However, about 21% remained unserved.

Table 4. Number of Response Demand Points Serviceable by the existing fire stations within a 4-Minute Drive.

SN	Name	Serviceable Demand Points	Total Distance (Minutes)
1	Gwale	224	440.13
2	Jakara	1635	2757.73
3	Kurna	237	549.45
4	Headquarters	322	588.82
5	Government House	136	281.58
6	House of Assembly	170	383.72
7	Sharada	48	140.45
8	Bompai	144	385.35
9	Sabon Gari	258	502.64
10	Rijiyar Zaki	202	412.91
11	Danladi Nasidi	35	107.88
	Total Served Areas	3411 (79%)	6550.66
	Total Unserved Areas	924 (21%)	

Location Allocation of Fire Stations/Facilities for Maximum Response Coverage

Because of the proportion of the unserved points within a reasonable distance drive, location-allocation analysis was undertaken to discover best sites to position more stations for optimum coverage within the metropolis, to alleviate demand strain on most of the stations within 4 minutes' drive. To determine the best sites, the analysis considers flashover time (4 minutes), demand points, fire station locations, road type and speed limits (km^2), fire incident concentration, and travel distances of 4 minutes apart from turn-out time (60 seconds). To locate new facilities, the analytic properties were set to optimize coverage, and a cut-off value of 4 minutes distance (based on NFPA and ESRI, 2007 standard) was used. Figure 15 shows the analysis' findings, which show places that are fully served as well as potential new locations for new response facilities to provide optimal response coverage.

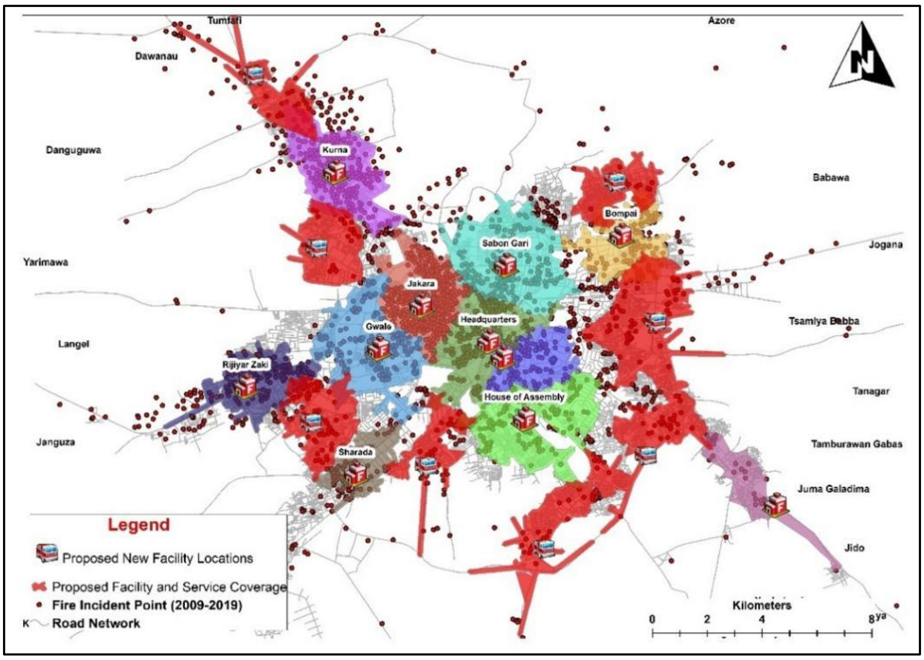


Figure 15. Proposed New Facility Locations and their respective Service Coverage Areas

Because the demand factor within 4 minutes' drive was deemed more vital in selecting the service coverage zones, the central section of the metropolis has been fully covered. And only those stations in the city center have a higher number of demand points than those on the periphery of the city. This is owing to the dense population and high frequency of fires in the city center. However, the existing stations only partially covered areas such as Hotoro, Dorayi Karama, Yankaba, Unguwar Dabai, Zaria Road, Eastern and Western byepass, Sharada, and Dandinshe, among others. The results of the location-allocation analysis suggested eight (8) areas where extra fire emergency response facilities should be located for optimum coverage. Table 5 shows the prospective sites' locations and characteristics. In a related study, Dong et al. (2018) used location-allocation analysis to recommend the site of four new fire stations in high-risk areas and major city routes.

Table **5**. Proposed Fire Stations/Facilities Locations based on Location-allocation Analysis

S/N	Street Address	Latitude	Longitude	Status
1	Mil-Tara, along Katsina Road	8.453	12.07	Required
2	Eastern Bye-pass Road	8.586	11.996	Required
3	Western Bye-pass Road	8.583	11.952	Required
4	Sheikh Ja'afar Road, Dorayi Karama	8.481	11.965	Required
5	Sharada Road	8.519	11.951	Required
6	Zaria road, adjacent to Sa'adatu Rimi College	8.55	11.922	Required
7	Brigade Axis	8.572	12.043	Required
8	Unguwar Dandinshi	8.475	12.022	Required

However, according to Table **6**, adding more stations to address response demand has not only relieved pressure on existing stations, but will also enhanced response coverage throughout the metropolis. Based on the foregoing, additional 18% of the demand points which were unserved by the existing stations are now accessible by the proposed stations within the required time, thereby making the total of 96%. The remaining unserved places that account for about 3% are usually low-density locations that often requires emergency response occasionally. These locations can be accommodated in the future as demand increases. Table 6 presents the number of expected demand points to be served by the proposed fire stations.

Table 6. Response Demand and Supply Points Accessible by the Proposed Fire Stations within 4 Minutes' Drive

SN	Station Name	Station Status	Count of Present Demand	Total Minutes (Present)
1	Mil-Tara, along Katsina Road	Proposed	117	288.83
2	Eastern Bye-pass Road	Proposed	121	17.71
3	Western Bye-pass Road	Proposed	102	48.90
4	Sheikh Ja'afar Road, Dorayi Karama	Proposed	112	222.44

SN	Station Name	Station Status	Count of Present Demand	Total Minutes (Present)
5	Sharada Road	Proposed	103	131.49
6	Zaria road, adjacent to Sa’adatu Rimi College	Proposed	89	81.67
7	Brigade Axis	Proposed	82	152.93
8	Unguwar Dandinshi	Proposed	74	177.43
			754 (18%)	

Based on the current response demand and supply pattern, the existing and proposed fire stations will be adequate to efficiently fulfill the increasing need for fire disaster response within the metropolis.

CONCLUSION

It is concluded that emergency fire disaster response demand and supply relationships within Kano metropolis is imbalanced, with extensive recurrent demand especially within the core area served by overstretched and inefficient response supply. One of the primary issues impeding the efficiency of the metropolis's response system is the lack of clearly defined service coverage zones by existing fire stations. Most of the fire stations are spatially overstretched, while others are left redundant due to great deal of overlaps. Depending on the incident concentration, the number of response demand points accessible by existing fire stations within a 4-minute drive varies dramatically, putting pressure on certain stations and easing pressure on others. As a result, new stations are required to improve the response system's coverage and efficiency. The study recommended that fire stations should rigorously adhere to the service coverage regions indicated by demand points and response supply coverage within a four-minute drive. This is to avoid redundancy and unsystematic responses and station overstretching. Also, the government should put into consideration positioning new fire stations/facilities in the proposed locations as soon as possible to ensure optimal response coverage throughout the metropolis.

ACKNOWLEDGMENTS

The authors sincerely thank the staff of Department of Geography, Bayero University Kano for their constructive criticisms and support.

DECLARATIONS

Conflict of Interest

The authors declare that in the research and preparation of this article, there are no conflict of interests related to certain organizations, institutions, and individuals or groups.

Ethical Approval

On behalf of all authors, the corresponding author states that the paper satisfies Ethical Standards conditions, no human participants, or animals are involved in the research.

Informed Consent
On behalf of all authors, the corresponding author states that no human participants are involved in the research and, therefore, informed consent is not required by them.

DATA AVAILABILITY
Data used to support the findings of this study are available from the corresponding author upon request.

REFERENCES
Adamu, Y. and Yunus, S. (2017). Spatio-temporal analysis of urban fire incidences at Abuja Phase1, Nigeria. *Nassarawa Journal of Tropical Geography, 8*, 1864-1874.

Akta¸s, E., Özaydın, Ö., Bozkaya, B., Ülengin, F., Önsel, ¸S., (2013). Optimizing fire station locations for the istanbul metropolitan municipality. *Interfaces,* 43, 240–255.

Algharib, S.M. (2011). Distance and coverage: An assessment of location-allocation models for fifire stations in Kuwait City, Kuwait. Ph.D. thesis. Kent State University.

Ayila, A. E., Oluseyi, F. O., and Anas, B. Y. (2014). Statistical analysis of urban growth in Kano Metropolis, Nigeria. *International journal of Environmental Monitoring an analysis*, 2(1), 50-56.

Ayuba, H. K., Aguocha, O., and Medugu, N. I. (2016). Fire vulnerability assessment of the Federal Capital City, *International Journal of Innovative Science, Engineering and Technology*, *3*(5), 39–46.

Bahri, S., (2016). 0-1 integer linear programming model for location selection of fifire station: A case study in Indonesia. *AIP Conference Proceedings*, AIP Publishing. p. 030004. https://doi.org/10.1063/1.4945062.

Barau, A. S. Maconacchie, R., Ludinc, A. N.M. and Abdulhamid, A. (2015). Urban morphology dynamics and environmental change in Kano, Nigeria. *Land Use Policy*, *42*, 307-317. https://doi.org/10.1016/j.landusepol.2014.08.007.

Bolouri, S., Vafaeinejad, A., Alesheikh, A., Aghamohammadi, H., (2018). The ordered capacitated multi-objective location allocation problem for fire stations using spatial optimization. *ISPRS International Journal of Geo-Information,* 7, 44. https://doi.org/10.3390/ijgi7020044.

Brushlinsky, N. N., Ahrens, M., Sokolov, S. V., & Wagner, P. (2017). World fire statistics.

Çatay, B. (2011). Siting new fire stations in Istanbul: A risk-based optimization approach. OR Insight, 24(2), 77–89.

Center of Fire Statistics Report, (2017). http://www.ctif.org/sites/default/files/ctif_report22_world_fire_statistics_2017.pdf, Accessed date: 30 September 2021.

Ceyhan, E., Ertuğay, K. and Düzgün, Ş. (2013). Exploratory and inferential methods for spatio-temporal analysis of residential fire clustering in urban areas. *Fire Safety Journal*, 58: 226–239. https://doi.org/10.1016/j.firesaf.2013.01.024.

Chen, C. & Yang, Q. (2018). Hotspot analysis of the spatial and temporal distribution of fires. Proceedings of the 4th International Conference on Geographical Information Systems Theory, Applications and Management (GISTAM 2018), pages 15-21. DOI: 10.5220/0006638600150021.

Chen, H., Cheng, T. and Ye, X. (2018). Designing efficient and balanced police patrol districts on an urban street network. Int. J. Geogr. Inf. Sci. 33, 269–290. https://doi.org/10.1080/13658816.2018.1525493.

Chen, Z.F., Li, J.W., Lu, F.X. and Li, Q. (2018). Optimizing location of fire stations and it' s enlightenments for Xiongan New Area. China Saf. Prod. Sci. Technol. 14, 12–17.

Chevalier, P., Thomas, I., Geraets, D., Goetghebeur, E., Janssens, O., Peeters, D., & Plastria, F. (2012). Locating fire stations: An integrated approach for Belgium. *Socio- Economic Planning Sciences*, 46(2), 173–182. https://doi.org/10.1016/j.seps.2012.02.003.

Chhetri, P., Kam, B., Lau, K., Corbitt, B., Cheong, F., (2017). Improving service responsiveness and delivery efficiency of retail networks. *International Journal of Retail & Distribution Management, 45* (3), 271–291. doi:10.1108/IJRDM-07-2016-0117.

Church, R., & Li, W. (2016). Estimating spatial efficiency using cyber search, GIS, and spatial optimization: A case study of fire service deployment in Los Angeles County. *International Journal of Geographical Information Science*, 30(3), 535–553. https://doi.org/10.1080/13658816.2015.1083572.

Dogondaji A. Z, Ojonugwa E., Ibrahim A. A., and Mustafa A. (2017). P-Center problem of fire stations in Sokoto Metropolis. *Asian Journal of Mathematics and Computer Research*, *18*(3): 143-151, 2017.

Dong X., Li Y., Pan Y., Huang Y., Cheng X., (2018). Study on urban fire station planning based on fire risk assessment and GIS Technology. *2017 8th International Conference on Fire Science and Fire Protection Engineering* (on the Development of Performance-based Fire Code). *Procedia Engineering, 211*, 124–130.

Ejikeme, J. O., Igbokwe, JI. I. and Johnson, N. G. (2012). Application of GIS for effective management of fire disaster in Onitsha", Nigerian Institute of Surveyors Technical Proceedings of General Meeting and Conference on Surveying Disaster Management and Global Warming held at Ilorin, Kwara State, June 25 - 29, 2012: 48 – 55.

Erkut, E., Fenske, R., Kabanuk, S., Gardiner, Q. and Davis, J. (2001). Improving the Emergency Service Delivery in St. Albert. *INFOR.* 39, 416 – 433.

ESRI (2007). GIS for Fire Station Locations and Response Protocol *An ESRI® White Paper January 2007.*

Fire Department of Ministry of Public Security (FDMPS) (2016). China fire yearbook (2016). in ChineseKunming, China: Yunnan People's Publishing House.

Ganeshkumar, B. & Ramesh, D. (2010). Emergency Response Management and Information System (ERMIS) – A GIS based software to resolve the emergency recovery challenges in Madurai city, Tamil Nadu. *International Journal of Geomatics and Geosciences,1*(1).

Han, B., Hu, M., Zheng, J. and Tang, T. (2021). Site selection of fire stations in large cities based on actual spatiotemporal demands: A Case study of Nanjing City. *ISPRS Int. J. Geo-Inf.* 2021, 10, 542. https:// doi.org/10.3390/ijgi10080542.

Isa, U. F., Liman, M. A., Mohammed, M. U., Mathew, O. S., and Yayo, Y. R. (2016). Spatial Analysis of Fire Service Station in Kano Metropolis, Nigeria. *IOSR Journal of Humanities and Social Science,* 21(9), 42–52. https://doi.org/10.9790/0837-2109014252.

Kanoun, I., Chabchoub, H., & Aouni, B. (2010). Goal programming model for fire and emergency service facilities site selection. INFOR*: Information Systems and Operational Research*, 48(3), 143–153.

Kazemi, M., Kunt, M.M., Aghayan, I., Larijani, R.J., (2013). Optimization model for fire station location based on GIS and Python: a case study in North Cyprus. *Applied Mechanics and Materials, Trans Tech Publ*. 330, 1059–1064.

Kiran, K. C & Corcoran, J., (2017). Modelling residential fire incident response times: a spatial analytic approach. *Applied Geography*, 84, 64–74. https://doi.org/10.1016/j.apgeog. 2017.03.004

Kiran, K. C., Corcoran, J., & Chhetri, P. (2018). Spatial optimisation of fire service coverage: A Case Study of Brisbane, Australia. *Geographical Research*, 56(3), 270-284. https://doi.org/10.1111/1745-5871.12288.

Li, X., Zhao, Z., Zhu, X. and Wyatt, T., (2011). Covering models and optimization techniques for emergency response facility location and planning: a review. *Mathematical Methods of Operations Research*, 74(3), 281–310.

Liu, N., Huang, B., & Chandramouli, M. (2006). Optimal sitting of fire stations using GIS and ANT algorithm. *Journal of Computing in Civil Engineering*, 20(5), 361–369.

Maigari A. I, (2014). Evolutionary trend, spatial distribution of, and issues associated with markets in Kano Metropolis: *Research on Humanities and Social Sciences.* 4(28) 2224-5766.

Mao, K., Chen, Y., Wu, G., Huang, J., Yang, W. and Xia, Z. (2020). Measuring spatial accessibility of urban fire services using historical fire incidents in Nanjing, China. *ISPRS Int. J. Geo Inf.* 2020, 9, 585. https://doi.org/10.3390/ijgi9100585.

Murray, A. T. (2010). Advances in location modeling: GIS linkages and contributions. *Journal of Geographical Systems*, 12(3), 335–354. https://doi.org/10.1007/s10109-009-0105-9.

Murray, A. T. (2013). Optimising the spatial location of urban fire stations. *Fire Safety Journal*, 62, 64–71. https://doi.org/10.1016/j.firesaf.2013.03.002.

Murray, A. T. (2015). Fire station siting. In H. A. Eiselt, & V. Marianov (Eds.). Applications of location analysis (pp. 293–306). *Springer International Publishing*.

Murray, A. T., & Tong, D. (2009). GIS and spatial analysis in the media. *Applied Geography*, 29(2), 250–259.

National Emergency Management Agency (2006). Industrial and Commercial Buildings Fire in Nigeria, NEMA, 2006.

National Fire Protection Association, NFPA (2010). Standard for the Organization and Deployment of Fire Suppression Operations, Emergency Medical Operations and Special Operations to the Public by Volunteer Fire Departments.

NFPA, (2003). Fire Loss in the United States, 2003

Nyimbili P. H. & Erden T. (2020). GIS-Based fuzzy multi-criteria approach for optimal site selection of fire stations in Istanbul, Turkey. *Socio-Economic Planning Sciences 71 (2020) 100860*, 1-13. https://doi.org/10.1016/j.seps.2020.100860.

Ogundele, J.A., Arohunsoro, S.J., Jegede, A.O., & Oni, B.B. (2013). Evaluating the operations of emergencies and disaster management agencies in Ekiti State, Nigeria. *Journal of Natural Sciences Research, 3*(15), 132-138.

Oladokun, V. O. & Ishola, F. A. (2010). A Risk analysis model for fire disasters in commercial complexes in Nigeria. *Pacific Journal of Science and Technology.* 11(2), 376-386.

Oladokun, V. O., & Emmanuel, C. G. (2014). Urban market fire disasters management in Nigeria: A Damage minimization based fuzzy logic model approach. *International Journal of Computer Applications.* 106(17), 975–8887.

Oladokun, V.O., Kolawole, A. & Emmanuel, C. G. (2012). Risk Analysis Models of Fire Accidents in Nigeria Commercial Complexes: A Fuzzy Logic Approach," in *Proceedings of NIIE 2012 Conference*, Benin.

Oppong, J.R., Boakye, K., Edziyie, R., Owusu, A.Y., Tiwari, C., (2017). Emergency fire response in ghana: the case of fire stations in Kumasi. 36, 253–261. https://doi.org/10.1080/19376812.2016.1231616.

Shahparvari S., Fadaki M., Chhetri P. (2020). Spatial accessibility of fire stations for enhancing operational response in Melbourne. *Fire Safety Journal, 117,* 103149. https://doi.org/10.1016/j.firesaf.2020.103149.

Wang, W., Xu, Z., Sun, D. & Lan, T. (2021). Spatial optimization of mega-city fire stations based on multi-source geospatial data: A Case study in Beijing. *ISPRS Int. J. Geo Inf*. 2021, 10, 282. https://doi.org/10.3390/ijgi10050282.

Wuschke, K., Clare, J. & Garis, L. (2013). Temporal and geographic clustering of residential structure fires: A Theoretical platform for targeted fire prevention. *Fire Safety Journal* 62, 3–12. http://dx.doi.org/10.1016/j.firesaf.2013.07.003.

Xin, J., & Huang C. (2013). Fire Risk Analysis of Residential Buildings Based on Scenario Clusters and its Application in Fire Risk Management. *Fire Safety Journal* 62, 72–78. http://dx.doi.org/10.1016/j.firesaf.2013.09.022.

Yao J., Zhang X., & Murray A. T., (2018). Location optimization of urban fire stations: access and service coverage. *Journal of Computers, Environment and Urban Systems*, 73, 184-190. https://doi.org/10.1016/j.compenvurbsys.2018.10.006.

Yu, W., Chen, Y., Chen, Z., Xia, Z., & Zhou, Q. (2020). Service area delimitation of fire stations with fire risk analysis: Implementation and case study. *Int. J. Environ. Res. Public Health. 17*(6). https://doi.org/10.3390/ijerph17062030.

yu, w., zhang, y., & chen, z. (2019). automated generalization of facility points-of-interest with service area delimitation. *IEEE access*, *7*, 63921-63935. https://doi.org/10.1109/access.2019.2916977.

Yunus, S. (2019). Response delay model: Bridging the gap in urban fire disaster response system. *International Journal of Humanities and Social Sciences*, *13*(12), 1463-1468.

Yunus, S., & Falola, J. A. (2022). Analysis of Spatio-Temporal Pattern, Causes and Consequences of Fire Disaster in Kano Metropolis, Nigeria. *Nigerian Journal of Environmental Sciences and Technology (NIJEST)*. 6(2), 478-492.

Zhang, X., Yao, J., & Sila-Nowicka, K. (2018). Exploring spatiotemporal dynamics of urban fires: A case of Nanjing, China. *ISPRS International Journal of Geo-Information*, *7*(1), 7. https://doi.org/10.3390/ijgi7010007.

Zhibang, X., Liang, Z., Ting, L., Zhonghui, W., Li, S. & Rongwei, W. (2018). Spatial optimization of mega-city fire station distribution based on Point of Interest data: A case study within the 5th Ring Road in Beijing. *Geogr. Sci. Prog*. 37, 535–546.