EMERGENCY FIRE RESPONSE IN GHANA: THE CASE OF FIRE STATIONS IN KUMASI

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Comprehensive emergency management and response is crucial for disaster prevention and health emergencies. However, in African countries with an abundance of natural disasters and a rising surge in cardiovascular and obstetric emergencies, little research exists on emergency response. This study examines the fire emergency response in Kumasi Metropolitan Assembly (KMA), Ghana's second largest city. We use Geographic Information Systems (GIS) tools including location -allocation modeling to evaluate the existing system of fire facilities, identify gaps in service, and suggest locations for new fire stations to maximize population coverage. Our results show that fire stations within KMA are poorly distributed and large portions of the metropolis are underserved, a situation that is partly responsible for the huge losses of lives and property during fire outbreaks.

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CHAPTER 1

INTRODUCTION

Comprehensive emergency management and response systems are crucial for disaster prevention and mitigation of casualties, yet little research exists on emergency response in African countries, particularly for fire outbreaks. Responding to emergencies such as disease and fire outbreaks is a dilemma for most developing countries. A timely and effective response to different emergency events is vital. However, emergency response systems are either inadequate or non-existent. Consequently, minor incidents or events become emergencies that threaten public safety, health, and welfare. In comparison to developed nations, casualties resulting from emergencies in developing nations are costly and more damaging. The lack of resources in developing countries coupled with their low capacity to prepare and respond are major limitations (Sena & Woldemichael, 2006). Even where resources are available, poor coordination among the various emergency response agencies limits their effectiveness.

Emergency response challenges faced by public health systems in developing countries include financial resources, understaffing, and poor infrastructure (Kruk, 2008). A robust health system includes a financing mechanism, a well-trained and adequately paid workforce, reliable information on which to base decisions and policies, and well-maintained facilities and logistics to deliver quality medicines and technologies (European Parliamentary Research Service, 2015). A lack of adequate health infrastructure is an impediment to responding to health emergencies. Hence, a quality health infrastructure is valuable in itself, enabling quicker responses to health emergencies. Furthermore, access to emergency care has been a major problem in most developing countries. This is often due to poor transportation or the unavailability of ambulance services, as is the case in Ghana (Adamtey et al, 2015). According to the Ministry of Health in Ghana, the national ambulance service in collaboration with the Ghana National Fire Service (GNFS) aims at providing accessible 24-hour ambulance service nationwide in the case of any emergency (MOH, 2008). However, in Ghana as in many developing countries, little consideration has been given to optimizing the availability of these agencies in the occurrence of an emergency.

In addition to health emergencies, fires are another emergency that developing countries continue to face. Responding to fire emergencies is of great importance as responding to health emergencies. The longer it takes for the fire department to respond to a fire incident, the higher the loss incurred in terms of property, health, and lives. Ghana has been plagued by increasing and disastrous fire emergencies, particularly over the last few years. Accra and Kumasi, its two largest cities, have experienced an unprecedented number of fire outbreaks with excessive property damage amounting to several millions of dollars. In 2013 alone, the GNFS reported a total of 5,489 fire outbreaks in Ghana, with 1,128 injured persons and 213 deaths, leading to a total cost of about 18 million US dollars (Graphic Online, 2014). Effective emergency management and response, for example through the efficient placement of fire service facilities, could prevent or mitigate such losses. In Ghana, a systematic evaluation of the geographic coverage of the emergency response of fire stations remains to be done. While geographic variation in response time is a crucial measure of the efficiency of emergency response and management, this has not been addressed. This is the gap we seek to fill.

This study examines the emergency fire response system in Kumasi, Ghana’s second largest city. It uses GIS tools and spatial analysis to evaluate the geography of existing fire stations and identify spatial gaps in coverage. Using predefined response times, this study evaluates the performance of the GNFS and answers the following questions: What is the total area covered for the predefined response times? What is the total population covered? After this evaluation of the performance of the current system of fire stations, the study identifies priority locations for siting additional fire stations to improve fire service coverage according to predefined standard response times. This study proposes that the poor distribution of fire stations is partly responsible for the huge losses in life and property damage.

CHAPTER 2

LITERATURE REVIEW

2.1 The Economic and Human Losses of Fire Outbreaks in Ghana

In the last decade, fires have occurred in Ghanaian government agencies, market sites, hospitals and industries, resulting in significant losses in terms of lives and property. Each year, there is an increase in the number and severity of fire outbreaks. According to the GNFS, Ghana recorded 1,986 fire outbreaks in 2006 (Aziz, 2007). In the first quarter of 2013, approximately 2,201 fire outbreaks were reported leading to an estimated US $8 million loss in property damage (Appiah, 2013). The number had increased to a total of 4,171 cases by the end of 2013 with at least 65 deaths (Mordy, 2013). Between January and September 2016, the country further lost approximately US $21 million in property damage (Peacefmonline.com, 2016), a 50% increase from the total cost of items damaged in 2015. In the first quarter of 2016, the GNFS reported the Ashanti region as the region with the highest reported cases of fire incidences (Anane, 2016). This clearly indicates an increase in the incidence of fire each year.

In 2009, portions of the ministry of foreign affairs, the government agency responsible administratively and executively for the initiation, formulation, co-ordination, and management of Ghana's Foreign Policy, burned down (ghanaweb.com, 2016). Several key historical documents including some dating back to the independence of Ghana were lost as a result of the fire incidence. The Central Medical Stores of the Ghana Health Service (GHS) in Tema, which houses medical supplies for distribution to medical facilities nationwide, was destroyed by a fire in the early parts of 2015. An estimated US$81million of medical supplies and equipment was lost (Pharmaceutical Society of Ghana, 2016). Another major fire disaster in recent years was the fire outbreak that consumed the GOIL filling station at the Kwame Nkrumah Circle in Accra in 2015. Over 150 people, including women and children, lost their lives. (Gadugah, 2016). In the latter part of 2016, the country was hit by yet another major fire at the Ghana International Trade Fair Centre resulting in six deaths (Ibrahim, 2016).

The locations that have experienced the most fire outbreaks in recent years, causing fear and panic in the public, are market sites. These are typically crowded places, often with wooden structures, substandard electrical wiring, and outdated electrical appliances. The Kumasi central market which is considered the largest open air market in West Africa (Storr, 2008) has experienced a series of fire outbreaks. In 2012, a fire outbreak there resulted in over 150 shops being burned. In February 2014, more than 500 traders were rendered jobless as a result of another fire in which 300 shops were burned down, destroying merchandise and food items (Dapatem, 2014). In March 2016, over 100 shops and stores were totally destroyed during yet another the fire outbreak (Ghana News Agency, 2016). Adding to the list of major fire incidences is the fire that gutted portions of block B of Unity Hall at Kwame Nkrumah University of Science and Technology (KNUST) in 2014. In all, a total of ten rooms on the sixth floor of the eight-story building were burned (Dapatem, 2014).

2.2 Factors Leading to the Incidence of Fire

At the neighborhood level, socio-economic factors are one of the common drivers of fire. (Federal Emergency Management Agency, 1997). Predominant among the socio-economic factors are lack of parental presence, low education, and inadequate income. Jennings (1996) emphasized socio-economic factors as powerful indicators of fire.

At the individual level, risk factors such as carelessness, smoking, alcoholism, lack of education, and drug abuse contribute to fire (Miller 2005). Smoking continues to be the leading cause of residential fire fatalities in the United States (USFA, 2011). In Canada, the leading known cause of fire related deaths is carelessness on the part of smokers (Health Canada, Regulatory Proposal Consultation Paper, 2002). Similarly, in the United Kingdom, the careless disposal of cigarettes and cigars by smoker's accounts for almost half the accidental fire deaths in residential areas (Holborn, 2003). In Ghana 75% of fires are caused by smoking, while 15% attributed to lack of education and 10% to accidents (Ghana News Agency, 2010).

Low income people are more likely than affluent people to indulge in activities that might lead to fire occurrences, such as living in overcrowded houses, and not equipping their houses with fire prevention items such as sprinklers and fire detectors (Wood, 1972). In addition, low-income people are more likely to have malfunctioning wiring or appliances, and to encounter barriers to escape in the cause of a fire. Furthermore, low-income people are likely to live in dilapidated buildings made of sub substandard materials. In Ghana, one of the main causes of fire is the use of poor electrical materials (Anaglatey, 2015). Likewise, most of the electrical wiring is done by individuals with minimal or no electrical knowledge.

Low education level is also a known predictor of fire incidences (Federal Emergency Management Association, 1997). Individuals who are well educated are able to foresee the danger of fire in addition to knowing what to do in the event of a fire outbreak. Moreover, individuals with a higher level of education are likely to equip their homes and surroundings with fire preventive equipment's such as fire extinguishers, and fire blanket to aid in the response to a fire incidence (Comolotti, 2004). In a study conducted in a community in Queensland, Wood (1990) investigated the level of individuals' awareness and preparedness in relation to fire. His findings revealed that fire safety awareness had a direct impact on level of preparedness. When people are unware of the negative impact of fire, they disregard the importance of having fire prevention equipment in place to minimize the loss of lives and property. Hence, there is a need to increase awareness of the negative effects of fire outbreaks.

Other causes of fire in Ghana include criminal acts such as arson (Andoh, 2016), political sabotage (Ayarkwa et. al., 2010) and frequent electrical interruptions. In recent years, one of the major causes of fire outbreaks in Ghana is gas leaks leading to explosions. Most gas stations are situated in crowded neighborhoods in Ghana. As a result of this, any gas explosion leads to huge losses in lives and property. Most of the gas explosions are caused by negligence on the part of individuals. In Ghana, acts such as arson is also to blame for the frequent fire outbreaks. Individuals seeking to destroy and cover up evidence of theft and massive fraud have deliberately set up these fires (Ghana Business News, 2016). They sometimes also do this to cause fear and panic in the public for no reason. Some of the fire outbreaks attributed to arsonists include the fire that engulfed the Central Medical Store in 2015, and market fires that have hit the Kokomba Market, the Makola Market and the Kumasi Central market (ghanaweb.com 2015). Another reason for the actions of arsonists is to deliberately sabotage the government in power (Ayarkwa et al, 2010).

2.3 Ghana National Fire Service

The Ghana National Fire Service (GNFS) was established in 1963 with its primary aims being firefighting, extinguishment, and rendering humanitarian services (GNFS official website). Other functions include the organization of public fire education programs, rescue and evacuation services for those trapped by fires, or other emergencies, as well as the organization and training of volunteer fire squads at the community level. By the year 2011, the GNFS had 6,699 personnel in total with 4,682 males and 2,017 females (GNFS Annual Performance report, 2013). In the Auditor General’s performance on the preparedness of the GNFS 2013, the GNFS had 132 fire stations sited in 116 districts out of the 170 in the country. This leaves 54 districts without fire stations rendering its citizens vulnerable to fire outbreaks.

The lack of logistical preparations for fighting fire outbreaks makes it difficult for the GNFS to perform its responsibilities. Such logistics include protective gears, state of the art fire tenders, and fully equipped fire stations. Inadequate training facilities that ensure that fire personnel of the GNFS are abreast of the knowledge and skills needed to fight fires are a setback to the GNFS in carrying out their operations. Also, the lack of cooperation between the GNFS and other stakeholders such as the Ghana Water Company Limited (GWCL), the police department and ambulance services limits the operations of the GNFS. For example, efficient coordination between the GNFS and the GWCL would ensure that fire hydrants are put in accessible locations and that water is available when needed.

2.4 Emergency Management and Response

Over the past few decades, cities within both the developed and developing world have come to terms with crisis situations arising from both man-made and natural disasters. Of greater importance to a community's ability to respond to a disaster is its emergency management capacity (Carafano et al., 2007). This comprises its available resource capital and its ability to effectively mobilize such capital to maximum effect (Bryson & Crosby, 1992). A lack of preparedness, response, and success when it comes to disaster response is typical of most developing countries. (Lin Moe & Pathranarakul, 2006). The initial stage of any emergency response is seen as very vital to bringing normalcy back as quickly as possible (William et al, 2000). According to Fling (1996), the initial setting up of a critical control center, the facilitating of mutual aid between the emergency services, the establishment of a cordon management system, and the formulation of communication structures constitute part of the initial elements of an emergency response. When disasters occur, governments and communities must respond.

Emergency response is handled in a structured way in developed countries. In Great Britain, response to disasters is organized at the local level, where knowledge of available resources is most complete and a coordinated response is possible (Kapucu, 2009). Disasters are dealt with by the emergency services: police, ambulance and fire services. In Canada, emergencies are managed first at the local level for example, by first responders such as medical professionals and hospitals, fire departments, the police, and municipalities (Public Safety Canada, 2016). Local authorities who need assistance request it from provincial or territorial governments. If an emergency escalates beyond their capabilities, the province or territory may seek assistance from the federal government. In the United States, the Federal Emergency Management Agency is in charge of emergency management. Each state also has an appointed emergency management office. The majority of incidents are handled by states and local authorities independent of federal involvement. When federal disaster management is necessary, the military is the primary coordinator and source of manpower (Ricardo, 1998).

2.5 Emergency Response in Ghana

To ensure a reduction in losses resulting from disasters, especially in developing countries, the International Decade for National Disaster Reduction (IDNDR) was declared (Housner, 1989). The main goals of this project included sharing methods for assessing, predicting, preventing, and mitigating natural disasters with nations around the world. In keeping up with the objective of IDNDR, Ghana established the National Disaster Management Organization (NADMO) in 1996 with the passage of parliament Act 517 (Oteng-Ababio, 2012). NADMO is the government agency charged with providing disaster response and recovery assistance by coordinating the activities of all the organizations involved in disaster management (NADMO official website). Some of the disasters NADMO responds to include flooding, fires for which fire emergency response operations need support, and disease outbreaks (NADMO annual report, 2011).

NADMO's objectives include being in a position to provide the first line of response in times of disaster, ensuring disaster prevention, and reducing the impact of disasters on society (National Disaster Management Organization official website). Despite these responsibilities, the organization has failed the country (Oteng, Ababio 2013, p. 9). Amongst the many reasons for its shortcomings are staff shortages, transportation, and financial constraints. The vision of NADMO is to reduce risk to people and especially the poor and disadvantaged from the effects of environmental and human induced hazards. Agencies that NADMO collaborates with in performing its duties include the police service, ambulance service, and the GNFS.

2.6 Response Time as a Major Component in Any Emergency Response Framework

An effective response time is vital in any form of emergency such as car crashes, fire outbreaks, disease epidemics or emergency medical responses. It is the determining factor between life and death for those involved. Response times also determine the extent of loss of lives and property in the event of an emergency. Hence the shortest possible response time is necessary to minimize the loss in lives and property. A reduction in the response time would possibly lead to a decrease in morbidity in addition to an improvement in the survival for many injured (Blackwell, 2002). In the emergency medical services care, an important measure of quality is response time (American Ambulance Association, 1994)). This is the amount of time that it takes for emergency responders to arrive at the scene of an incident after the emergency response system was activated.

2.7 Fire Response Time

While it is important that fire stations are properly situated to maximize coverage, they must also be strategically placed to minimize response times to fire scenes (Liu et al, 2006). A fire department's response time is the length of time it takes a fire truck to arrive at a fire scene starting from the time the call was made to the fire department (Flynn, 2009). Toregas et al. (1971) used response time as the main parameter in determining a facility location problem. The maximum time or distance that separates a user from his closest service is crucial. Once a response time is specified, there must be a fire station allowing for response within the time specified. The selection of an optimum number of fire stations and their best location in relation to each other plays an important role in minimizing the total loss from a fire (Hogg, 1968). Hogg (1971) further demonstrates how the time elapsed between a call for emergency service and the arrival of the responding unit is an important measure of an effective emergency service system.

Response time is a critical component for a successful response to any emergency (Blackwell et al, 2002). According to the Commission on Fire Accreditation International (2000), response time is the main determinant for the allocation and distribution of resources to meet the goals and objectives of a community's master fire protection plan. An important factor in fire station response time is its centrality of location and easy access to the incident site. In the Unites States, the National Fire Protection Association (NFPA) Standard 1710 requires fire departments to respond to structure fires within four minutes, a rule that all cities in the country must comply with. (Flynn, 2009). In Ghana, the stipulated target response time for the GNFS is also 4 minutes. However, according to a performance audit report by the Auditor-General, the GNFS arrives at fire scenes in an average of 12 minutes and 30 seconds (GNFS, 2013).

2.8 Location-Allocation Modeling

Decision makers often need a decision support tool for siting facilities based on several criteria at their disposal. This is where the capabilities of location-allocation modeling are needed. Location-allocation models are generally applied to the configuration and location of service facilities to satisfy demand in optimal ways (Ghosh & Rushton, 1987). Location-allocation modeling finds the optimal locations for siting one or more facilities to service a given set of demand, taking into account constraints such as the number of facilities available, their cost, and the maximum impedance from a facility to a given point. Travel distance or travel time can be an impedance. Furthermore, in the location-allocation process there is the simultaneous selection of optimal locations and allocation of demand (Drezner, 1995). Due to the complexity of such decision support systems, location-allocation problems require efficient heuristic solutions (Densham & Rushton 1992).

Emergency response is one sector that has benefited from the decision support capabilities of location-allocation modeling (fire and ambulance services). Other sectors that make use of location-allocation models include waste disposal sites, libraries, hospitals, schools and retail sites. Furthermore, Toregas et al. (1971) demonstrated the benefits of using location-allocation models for finding the optimal locations of emergency facilities. In the health sector, location-allocation models provide a framework for optimizing the spatial accessibility of public health services (Rahman & Smith, 2000). Oppong and Hodgson (1994), demonstrated how accessibility to health facilities in the Suhum District in Ghana could be improved without additional facilities using location-allocation models (Oppong & Hodgson, 1994). Toregas et al. (1971) demonstrated the benefits of using location-allocation models for finding the optimal locations of emergency facilities. The research provided both the number and the locations of the fire stations that can cover all demand points within the response time requirement. They also showed the benefit of applying location-allocation models to support decision making for locating new fire stations. In another study to evaluate the current distribution of fire stations in Dubai, Badri et al. (1998) applied location-allocation modeling. One of the major goals of their work was to provide acceptable decision support to the city authorities for selecting the optimal locations for new fire stations.

2.9 Maximum Coverage Problem

The Maximum Coverage Problem seeks to find the optimal locations for a fixed number of facilities that cover as many demand as possible within the impedance cutoff. In other words, this model seeks to maximize the total number of covered demand within a threshold of service distance or time by locating the candidate facilities. This means that the facility that is located where the density of demand is high has the advantage of being selected first. Balcik et al. (2008) used the maximum coverage problem to consider facility location decisions for a humanitarian relief chain responding to quick onset disasters. They determined the number and locations of distribution centers in a relief network and the amount of relief supplies to be stocked at each distribution center to meet the needs of people affected by the disasters.

Thus, this model is an appropriate one for selecting the optimal location for fire stations in the study area because fire stations are often needed to reach demand locations within a specified response time.

2.10 Research Objectives

Aim 1. Examine the geography of the existing fire stations in the study area

The geographic distribution and number of existing fire stations determine the response time to a fire incident. Whereas some sub-metropolitan areas of the KMA have fire stations sited within their boundaries, others do not. Sub-metropolitan areas that depend on fire stations located elsewhere face poorer coverage, meaning increased response times and increased fire damage. To address this aim, this study answers the following questions:

1. What is the total area covered under the predefined response times in each sub-metropolitan area?

2. What is the total population covered in each sub-metropolitan area?

Aim 2. Identify priority locations for siting additional fire stations to maximize population coverage

In the event of a fire outbreak, the total population within the specified coverage distance of a fire station is a crucial determinant of the total lives lost. In this study, we assume that siting fire stations in areas with high population will facilitate prompt response and reduce loss of lives. Given the current system of facilities, we need to identify potential new fire station sites that will increase the overall efficiency of the existing system the most by increasing the population covered. To address this aim, this study answers the following questions:

1. How does relocation of existing fire stations improve coverage?

2. How many new fire stations should be added to the current system and where should they be located to improve coverage the most?

CHAPTER 3

STUDY AREA AND METHODOLOGY*

3.1 Study Area

KMA is the most populated and industrialized among the 27 districts in the Ashanti region. The metropolis shares boundaries with the Kwabre East and Afigya Kwabre Districts to the north, the Atwima Kwanwoma and Atwima Nwabiagya Districts to the west, the Asokore Mampong and Ejisu-Juaben Municipalities to the east, and Bosomtwe District to the south. According to the 2013 Ghana statistical service report, KMA has an estimated population of 2,035,064 people and an annual growth rate of about 5.4 % (Ghana Fire Service, 2010). Women constitute 52.2% of its population while men represent 47.8%. Out of the total population, approximately 63% are aged 15-64, normally referred to as the work force. KMA is further divided into 10 sub-metropolitan areas, namely Asawase, Asokwa, Bantama, Kwadaso, Manhyia, Nhyiaeso, Oforikrom, Suame, Subin, and Tafo. Major economic activities in the city occur at the Central Business District (CBD), the Central Market—the largest open air market in West Africa—and the Adum Shopping Centre. I addition, there are other minor markets in the metropolis. Kumasi is the second largest city in Ghana and the capital city of the Ashanti region. It experienced the highest frequency of fire outbreaks in Ghana for the period 2011-2013 (see Figure 3.1).

* Parts of this chapter has been previously published earlier in part or in full, from Oppong, J. R., Boakye, K., Edziyie, R., Owusu, A. Y., & Tiwari, C. (2016). Emergency fire response in Ghana: the case of fire stations in Kumasi. *African Geographical Review*. Reproduced with permission from Taylor and Francis Group Publishing.

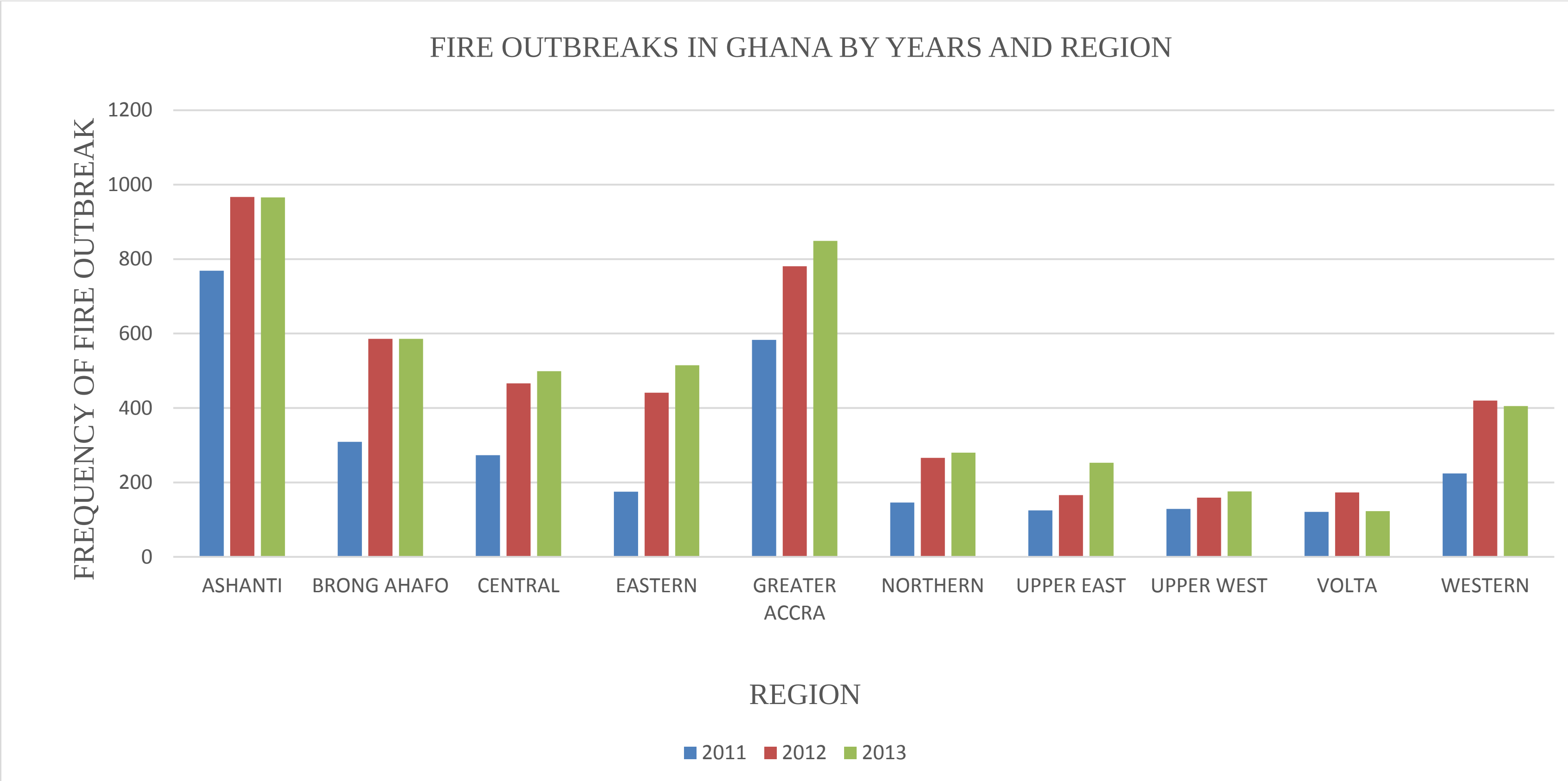

Figure 3.1. Frequency of Fire Outbreaks in Ghana (Figure reproduced from Oppong, J. R., Boakye, K., Edziyie, R., Owusu, A. Y., & Tiwari, C. 2016) (Source: Ghana National Fire Service Statistics)

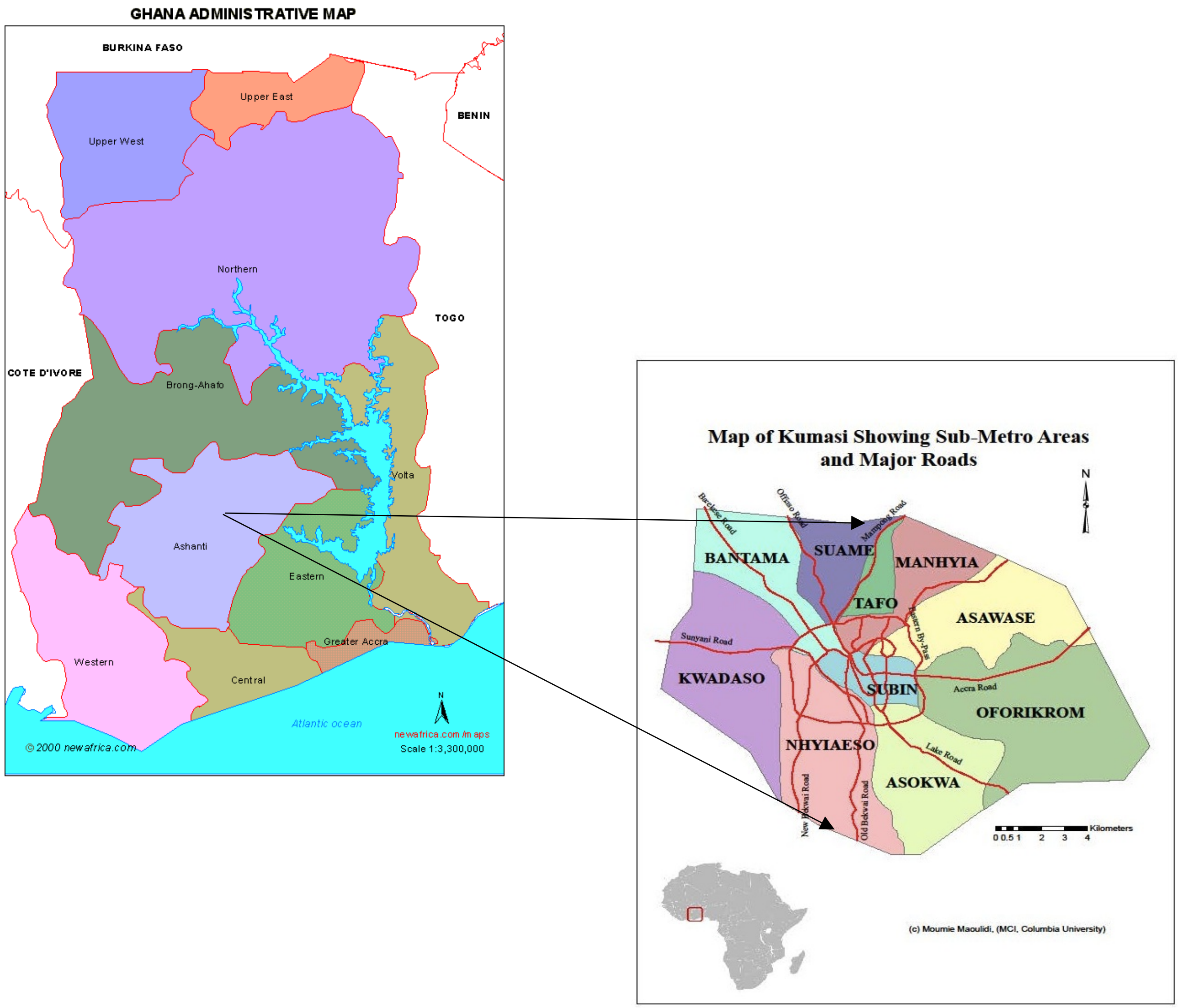

Figure 3.2. Study area (Source: MCI, Colombia University) (Figure reproduced from Oppong, J. R., Boakye, K., Edziyie, R., Owusu, A. Y., & Tiwari, C. 2016).

3.2 Data and Methodology

The X and Y coordinates of the existing fire stations were obtained using a handheld GPS (see Table 3.1). In addition, a GIS layer consisting of street centerlines and the boundaries of the 10 sub-metropolitan areas was created using ArcGIS 10.3 software. The land use / land cover dataset came from the Kwame Nkrumah University of Science and Technology environmental science department. This dataset was in a raster format and was already classified into the following land use categories: built up, grass, water, bare ground and forest. The built-up area was extracted from the land use dataset, and used as the basis for any further analysis. The total population count in each sub-metropolitan area was obtained from the 2010 population and housing census made available through the Ghana Statistical Service (Ghana Statistical Service, 2012).

Table 3.1. Coordinates of Fire Stations in the Kumasi Sub-Metropolitan Area (Table reproduced from Oppong, J. R., Boakye, K., Edziyie, R., Owusu, A. Y., & Tiwari, C. 2016)

Fire Station	Sub-metropolitan area	X	Y
Kumasi Regional Headquarters Fire Station	Asokwa	656651.6	735184.6
Kumasi Metro Fire Station	Oforikrom	656639.8	739294.4
KATH Fire Station	Bantama	651386.7	740578.8
Magazine Fire Station	Suame	651775.3	743259.5
Manhyia Fire Station	Manhyia	653203.7	741142.3
KNUST Fire Station	Oforikrom	657583.8	739118.3

The built-up area defined the service area for fire response. In this study, it is assumed that the built-up areas have higher chances of fire incidents compared to areas with other types of land use. Vector data are appropriate for performing area analysis. Hence, the clipped built-up area, which came in a raster format, was converted to a vector format prior to analysis. A cross-sectional analysis was conducted on the study area based on the following response times: 4, 5, 8, 10, and 15 minutes. According to the GNFS operational standards and International Association of Fire Fighters Guidelines (IAFF), the stipulated target response time for the GNFS is 4 minutes (GNFS, 2013).

Thus, the 4-minute response time was used as one of the pre-defined response times. Not only is this the standard response time for the GNFS but also for the National Fire Protection Association (NFPA) in the United States, according to Standard 1710 (Flynn, 2009). The remaining standard response times (5, 8, 10, 15 and minutes) were used to illustrate differences in coverage, particularly in the face of the current traffic conditions in Kumasi.

To determine the covered areas using the predefined response times, a speed limit of 9.32 mph was used, which was the average speed limit during the peak period in KMA, according to a 2004 report by Ghana's Department of Urban Roads. The peak speed limit was used to create a worst-case scenario given the narrow roads, and traffic congestion in the municipality. To compensate for individual street networks with no speed limits, the 9.32 mph speed limit was assigned to all the street networks. Next, the service areas for each existing fire station were created. To do this, the traveling time on each line segment was calculated using the length of each street segment and the speed limit of that segment. Topology was also performed on the street file to correct for errors including points that overlap and those that are not connected.

In this study, the New Service Area function within the network analyst extension in ArcGIS desktop 10.3 was used. This function creates service areas around any location. It creates a region around a point that encompasses accessible streets given a specified impedance. Hence this function was used to create service areas for each fire station under the predefined response times. The service area is defined as a region around any fire station that encompasses all accessible streets within a specified impedance. Impedance in this study is defined as time. Because this study focused its analysis of the built-up area, only the service areas that surrounded the built-up areas were considered. The percentages of built up areas covered by each fire station in each sub-metropolitan area were calculated using the equation below.

$$\frac{\text{Sum of service area of each fire station in a sub - metropolitan area}}{\text{Total built area of that sub-metropolitan area}} * 100$$

This study applied the maximum coverage model, one of the location-allocation models available in ArcGIS Desktop to identify strategic locations for siting new fire stations to maximize coverage. A set of demand and potential facility sites were created to use in the maximum coverage model. The study area was gridded into a cell size of 1km using the fishnet feature in ArcGIS. This created a feature class containing a net of rectangular cells. The Centroid of each cell was generated to give a point feature. A total of 377 points were generated. Point features are required in order to utilize any of the location-allocation models in ArcGIS. Out of the points generated, 177 points were located in the built up area. The 177 points were used as potential facility sites. The same 177 points were used as demand points in this study. The variables of built-up areas and the population in each sub-metropolitan area were combined to create a new variable. Previous studies have suggested that the combination of these two variables creates a new measure that can be a strong candidate for influencing fire station locations (Schillin et al, 1980). The new variable created was assigned to the centroid of each cell.

The maximum coverage model was applied to the six existing fire stations to evaluate them how relocation may improve population coverage. This model was also used for the selection of locations for additional fire stations to maximize population coverage. Before the maximum coverage model was used, each demand point was weighted according to its total population. The demand points with larger populations have a higher chance of attracting a fire station to be sited nearby. The total population that would be served after relocating the fire stations was computed. A spatial selection was performed using the select by attribute tool in ArcGIS to select demand points that intersect the service area. Because each point represents a population, the selected points were summed and percentages computed to determine the percentage of the new population served. These calculations were made for all the predefined response times. The equation below was used to compute the new population served after relocating the existing fire stations.

$$\frac{\text{Sum of all points selected}}{\text{Total population in built up area}} * 100$$

The maximum coverage model was again used to identify the optimal number and locations for siting additional fire stations to cover the most demand. The 177 points and the six existing fire stations were used as potential facility points. This resulted in a total of 183 potential facility points to serve 177 demand points. Each time the model was run, a new fire station location was chosen in addition to the six existing ones. This new location was selected to maximize coverage when added to existing locations. This was done for only the 10- and 15-minute response times until the addition of any fire station did not add any significant increase in population in coverage. Service areas for the locations of the selected sites were then created. In order to compute percentages for the total population covered after the addition of a new fire station, a spatial selection was made for the demand points that intersected the service area. The equation below was used to determine the new percentage of the population covered after a new fire station is added.

$$\frac{\text{Sum of total population covered by service areas for selected fire station}}{\text{Total population for built up area}} * 100$$

CHAPTER 4

ANALYSES AND RESULTS[†]

4.1 Distribution of fire stations in the Kumasi Metropolis

Figure 4.1 and Table 4.1 shows the current geographic distribution and number of fire stations in the study area. Only 5 of the 10 sub-metropolitan areas have fire stations. These are the Manhyia, Suame, Asokwa, Oforikrom, and Bantama sub-metros. While each sub-metro area has only one fire station, the Oforikrom sub-metropolitan area has two – KNUST and the Kumasi metro fire stations which are approximately .6 miles apart.

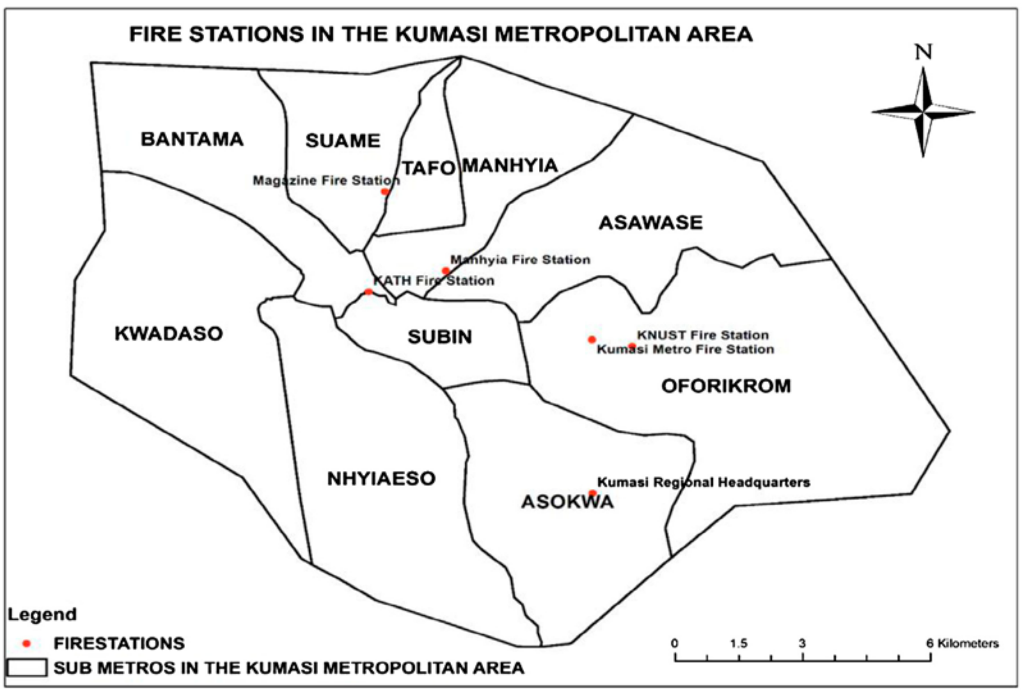

Figure 4.1. Fire Stations in the Kumasi Metropolitan Area (Figure reproduced from Oppong, J. R., Boakye, K., Edziyie, R., Owusu, A. Y., & Tiwari, C. 2016)

Interestingly, most fire stations are located in the central and eastern part of the study area away from the more populous areas. Surprisingly, the most populous sub-metropolitan area

[†] Parts of this chapter has been previously published earlier in part or in full, from Oppong, J. R., Boakye, K., Edziyie, R., Owusu, A. Y., & Tiwari, C. (2016). Emergency fire response in Ghana: the case of fire stations in Kumasi. *African Geographical Review*, Reproduced with permission from Taylor and Francis Group Publishing.

according to the 2010 population and housing census, Asawase, (Table 4.2) does not have a fire station. Apart from the regional headquarters fire station which is located in the central part of the Asokwa sub-metropolitan area, all the fire stations are located close to the outskirts of each sub-metropolitan area. Assuming that the original fire stations were located centrally with regard to the sub-metropolitan areas they serve, the city and its sub-metros may have grown spatially in ways that the original planners did not anticipate.

The explanation for this configuration of fire stations lies in the historical growth of KMA. The Kumasi metro and KNUST fire stations are both located in the older part of the city centered on Adum. Peripheral expansion began from the most central location (Adum) particularly towards the north and west. As a result, the distribution of population within the 10 sub-metros is skewed towards the Asawase, Manhyia, Bantama, Kwadaso, and Suame sub-metropolitan areas (Ghana Statistical service, 2010 National Population census). Regardless of the explanation, the current configuration of fire stations makes it difficult to cover the city effectively and may produce unnecessarily much higher response times and a greater risk of loss in the event of a fire outbreak.

Table 4.1. Number of Fire Stations in Each Sub-Metropolitan Area (Table reproduced from Oppong, J. R., Boakye, K., Edziyie, R., Owusu, A. Y., & Tiwari, C. 2016)

Sub-metropolitan area	Number of Fire Stations
Asawase	0
Asokwa	1
Bantama	1
Kwadaso	0
Manhyia	1
Nhyiaso	0
Oforikrom	2
Suame	1
Subin	0
Tafo	0

Table 4.2. Population in Each Sub- Metropolitan Area (Table reproduced from Oppong, J. R., Boakye, K., Edziyie, R., Owusu, A. Y., & Tiwari, C. 2016)

Sub-Metropolitan Area	Total Population
Kwadaso	251215
Nhyiaeso	134488
Subin	174004
Asokwa	140161
Oforikrom	303016
Asawase	312258
Manhyia	152225
Tafo	146024
Suame	161199
Bantama	260474

Source: Ghana Statistical Service (2012). 2010 Population & Housing Census. *Summary Report of Final Results*

4.2 Evaluating the Spatial Distribution of Covered and Uncovered Areas

In Figure 4.2, the total area in each sub-metropolitan served by the existing fire stations is shown. Figure 4.3 shows lack of coverage for most parts of the study area. Obviously, the immediate surroundings of fire stations receives the most coverage. The sub-metropolitan areas with no fire stations experienced little or no coverage even within the 15 minutes response time. Approximately 50 percent of the study area is shown to lack coverage within a 15 minutes response time. The areas lacking maximum coverage as seen are mostly the outskirts of the study area where there are no fire stations.

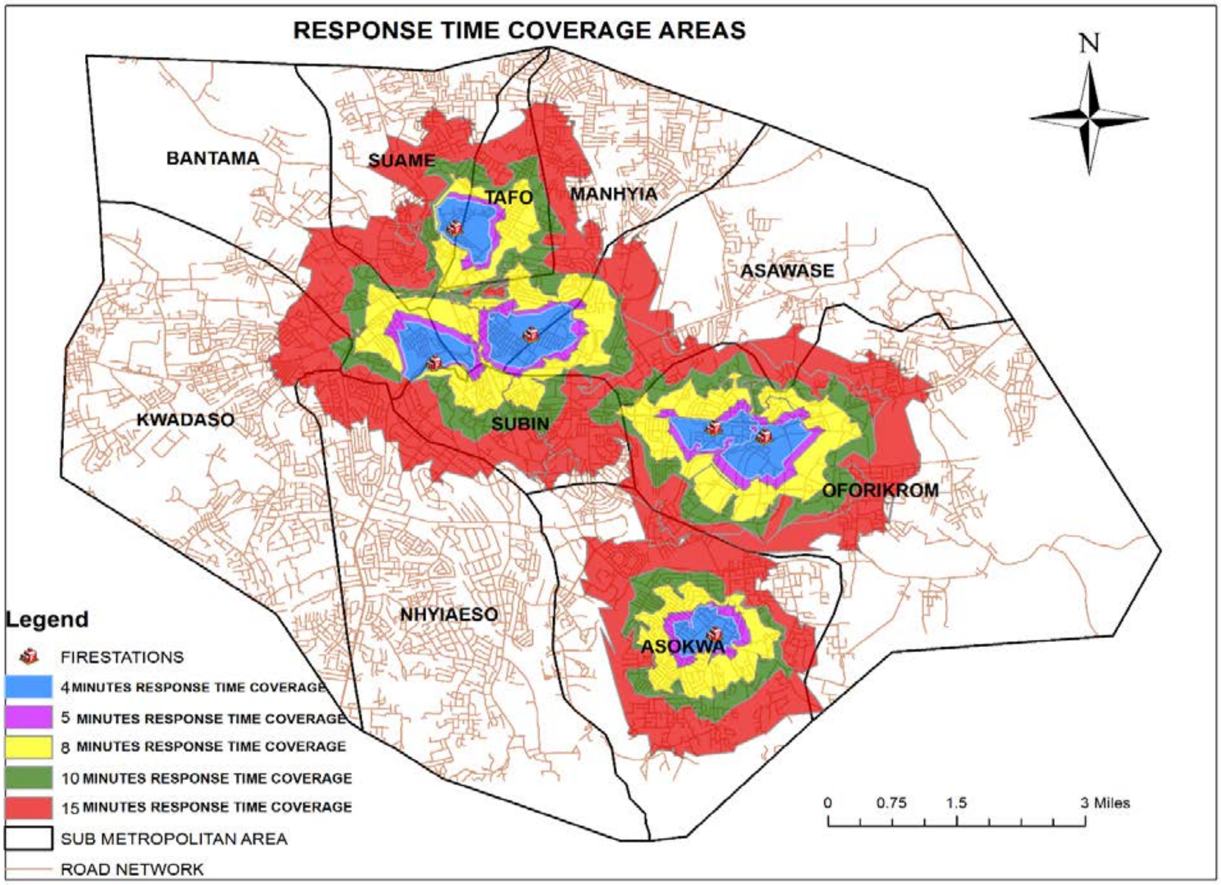

Figure 4.2. Response Time coverage areas (Figure reproduced from Oppong, J. R., Boakye, K., Edziyie, R., Owusu, A. Y., & Tiwari, C. 2016)

Table 4.3 shows the percentage of total built up area served under the pre-defined response times. Clearly, the GNFS has failed to achieve its target response time of 4 minutes. Also, no sub-metropolitan area is able to attain a 100% coverage given the current configuration of fire stations within the 4 minutes response time. Kwadaso and Nhyiaeso sub-metropolitan areas have the least coverage with 0% while Tafo has the highest coverage with 12.3% within 4 minutes. As a matter of fact, the remaining sub-metropolitan areas have less than a quarter of their areas within four minutes response time. Notable improvements in coverage occurred with increasing response time. For example, in the Asawase sub-metropolitan area, total area covered increased from 4% to 34%. Despite this huge increase, the Asawase sub-metropolitan area failed to achieve a 100% coverage.

Manhyia sub-metropolitan area also increased coverage from approximately 12% to 79% from a response time of 4 to 15 minutes. Nevertheless, the Manhyia sub-metropolitan area also failed to achieve a 100% coverage. The sub-metropolitan area with the highest coverage for a 15 minutes response time was Tafo. Tafo had 79.3% of its area covered under the existing configuration of fire stations. Again, the existing configuration fails to achieve a 100% coverage for this sub-metropolitan area.

It is also important to realize that the Kwadaso and Nhyiaeso sub-metropolitan areas are the most poorly covered. The Nhyiaeso sub-metropolitan area, for example, has 0 % coverage for the 4, 5, 8, and 10 minute's response times. However there was 9.15% coverage for a response time of 15 minutes. Kwadaso sub-metropolitan area has 0% coverage for the 4, 5 and 8 minutes response time. However, there is a 0.5% increase in coverage for a 10 minutes response time. This further increased to 6.6% within a 15 minutes response time which was less than 10%.

Table 4.3. Percentage of Total Built Area Served Under the Pre-Defined Response Times (Table reproduced from Oppong, J. R., Boakye, K., Edziyie, R., Owusu, A. Y., & Tiwari, C. 2016)

Sub-metropolitan area	4 Minutes	5 Minutes	8 Minutes	10 Minutes	15 Minutes
Asawase	4.07	4.87	10.45	16.62	34.4
Asokwa	3.94	13.2	18.77	25.5	57.2
Bantama	5.01	5.9	12.26	19.6	50.9
Kwadaso	0	0	0	0.5	6.6
Manhyia	8.94	18.94	25.71	45.22	75.3
Nhyiaso	0	0	0	0	9.1
Oforikrom	5.25	11.8	25.64	43.49	72.1
Suame	1.8	2.78	6.69	10.22	19
Subin	0.9	8.42	20.51	46.25	64.3
Tafo	12.3	16.98	35.26	52.1	79.3

4.3 Relocation of Fire Stations.

The existing fire stations were relocated to maximize population coverage using the predefined response times. Figures 6-10 shows new locations of fire stations to maximize population coverage. The new fire stations locations selected by the models are relocated mostly in the north central part of the study area reflecting the population concentration. Also, some of the sub-metropolitan areas which initially had fire stations lost theirs to other sub-metropolitan areas. For example, the Asokwa sub-metropolitan area lost its fire station for the 4, 5, 8, and 10 minutes response times while Asawase, which initially had no fire station had one located after the relocation process.

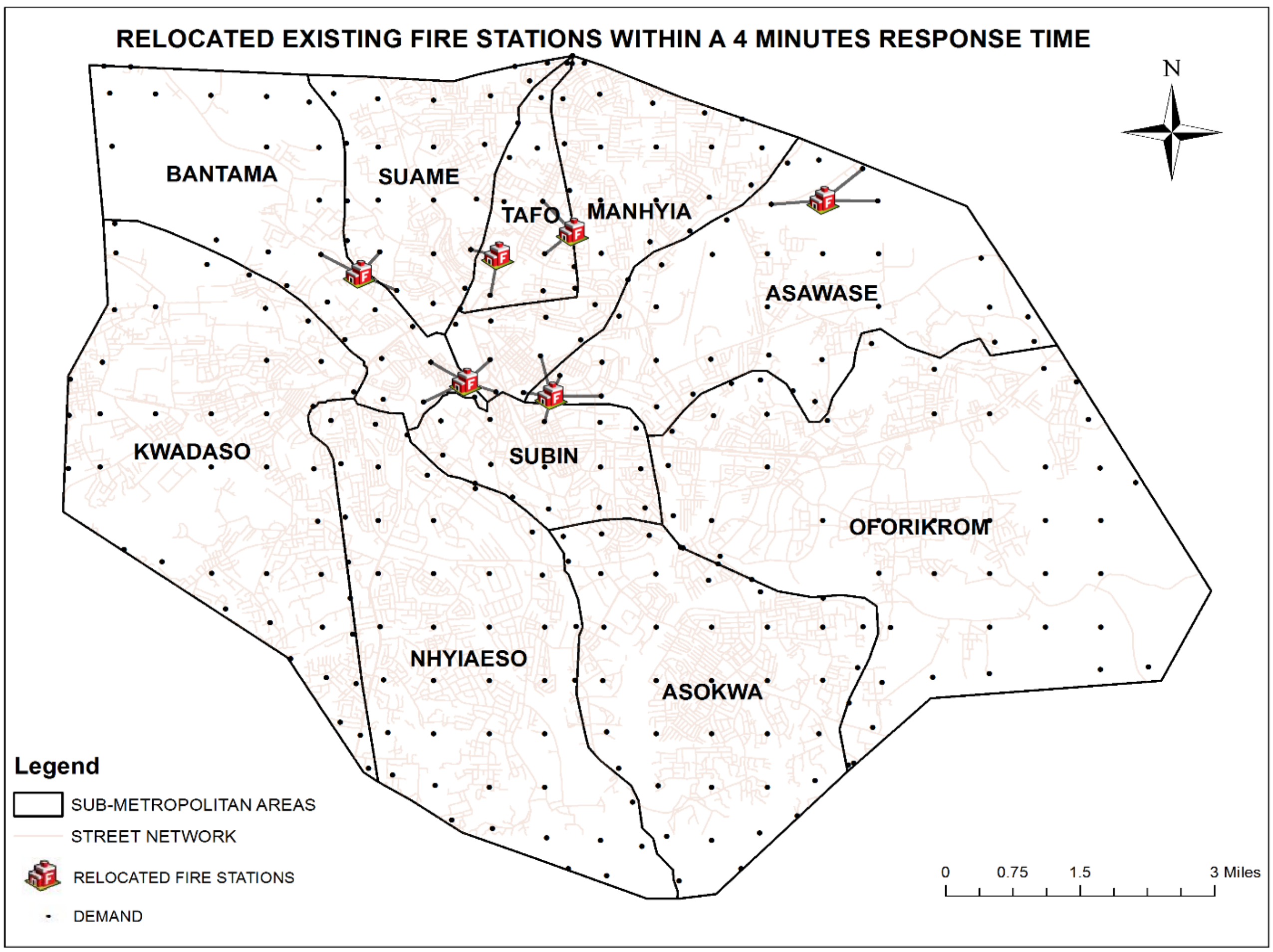

Figure 4.3. Relocated Existing Fire Station within a 4 Minutes Response Time

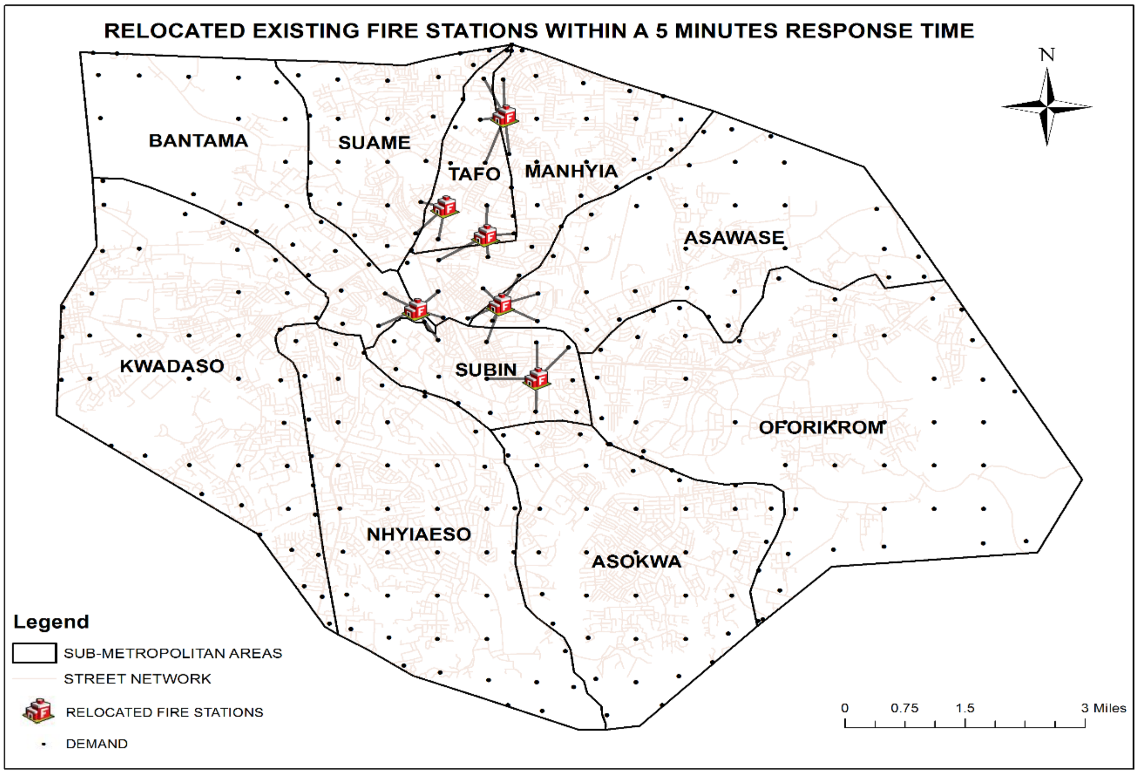

Figure 4.4. Relocated Existing Fire Stations within a 5 Minutes Response Time

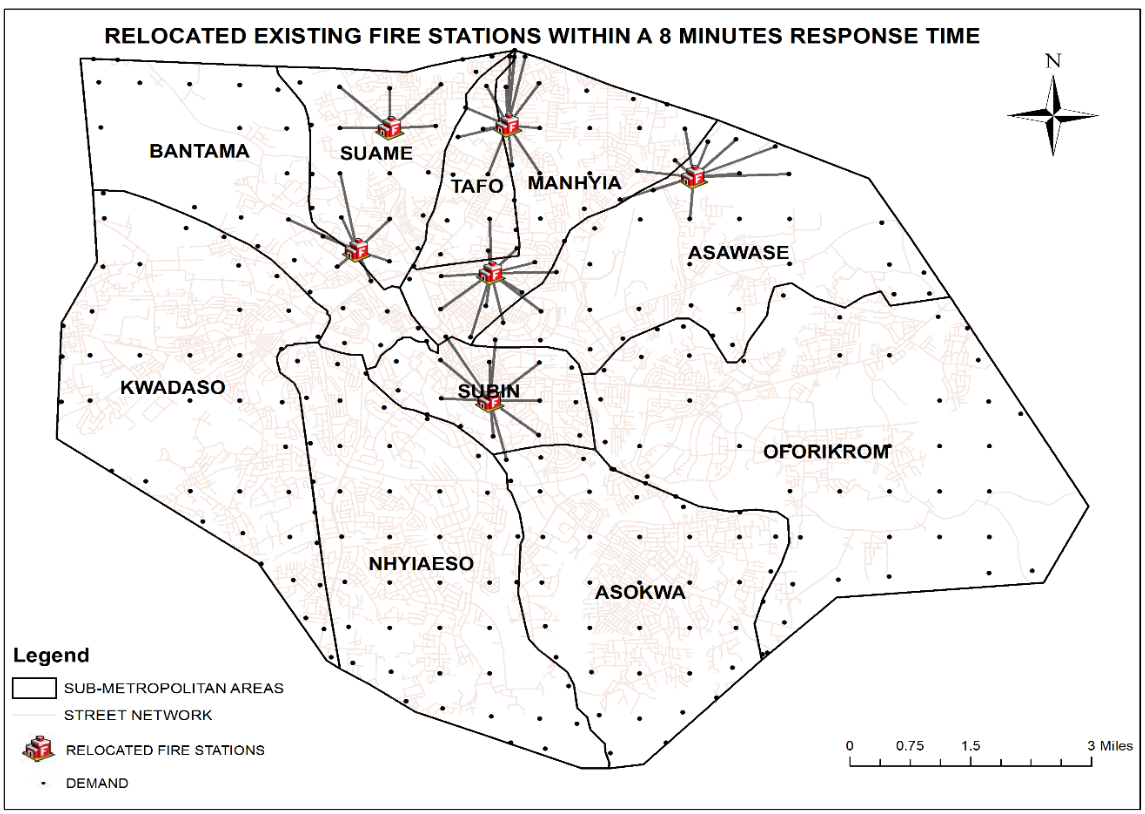

Figure 4.5. Relocated Existing Fire Stations within a 8 Minutes Response Time

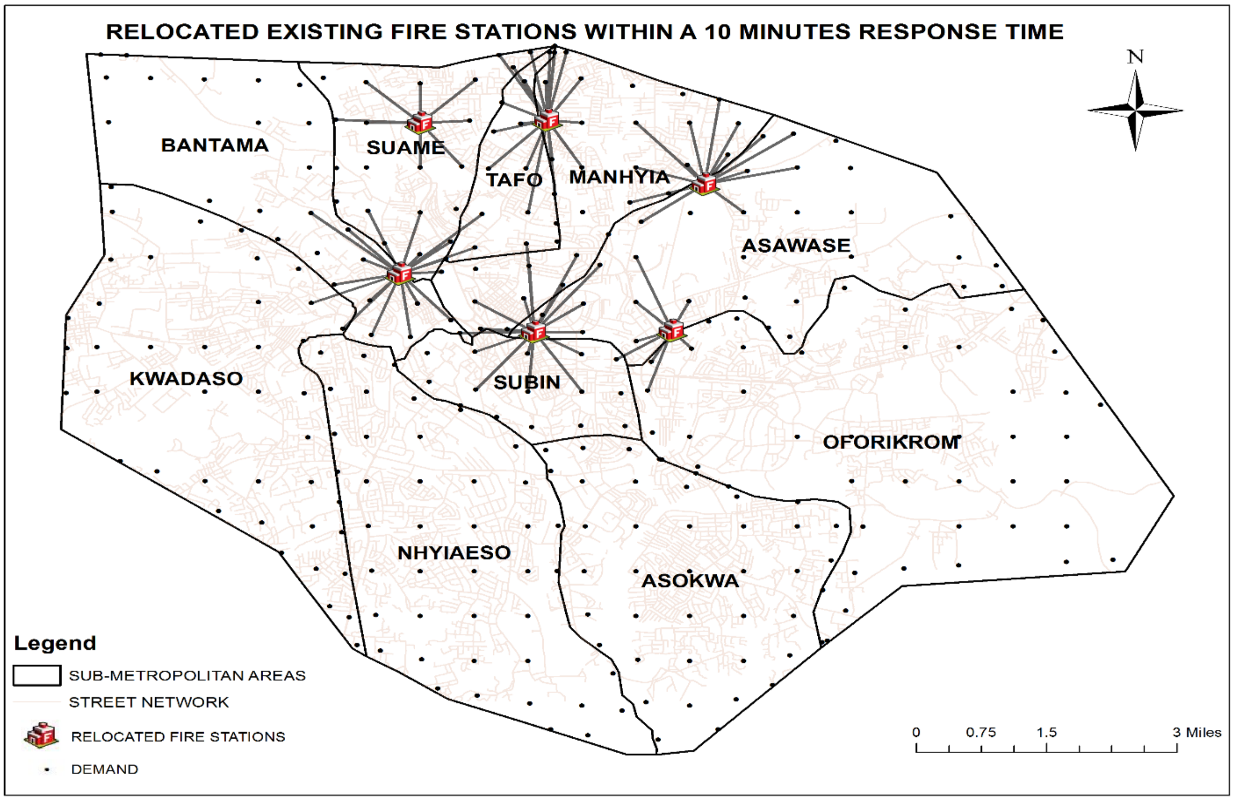

Figure 4.6. Relocated Existing Fire Stations within a 10 Minutes Response Time

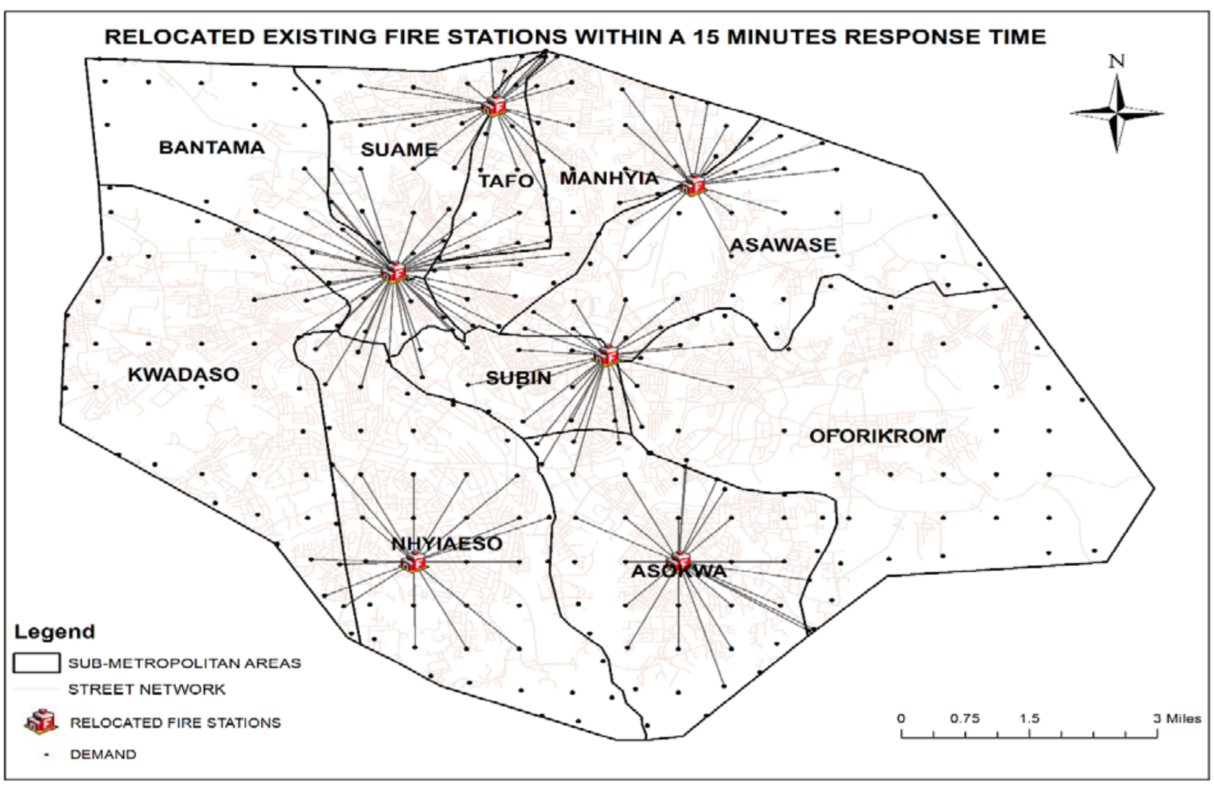

Figure 4.7. Relocated Existing Fire Stations within a 15 Minutes Response Time

4.4 Locations for additional fire stations

This study identified locations for new fire stations to maximize population coverage. Because the 4, 5, and 8 minutes response time looks unachievable by the GNFS, this study used only the 10 and 15 minutes response time for this part of the analysis. Figure 4.9 shows the location for siting 5 additional fire stations within a 10 minutes response time. From the map, the model selects a location in the Bantama sub-metropolitan area for siting an additional fire station for a 10 minutes response time. For the siting of two additional fire stations, locations in the Bantama and Asokwa sub-metropolitan areas were chosen. For three additional stations, locations in the Bantama, Asokwa, and Tafo sub-metropolitan areas were selected. Fire stations were iteratively located until an additional fire station added no significant coverage in terms of population.Similarly, the addition of new fire stations for a 15 minutes response time located fire stations in almost all the sub-metropolitan areas. Figure 4.10 shows the location for siting 5 additional fire stations for a 15 minutes response time. From the map, the model selects a location in the Manhyia sub-metropolitan area for siting an additional fire station for a 15 minutes response time. For the siting of two additional fire stations, locations in the Bantama and Asokwa sub-metropolitan areas are selected. For three additional stations, locations in the Bantama, Asokwa, and Tafo sub-metropolitan areas are selected. Fire stations were iteratively located until an additional fire station produced no significant increase in terms of population covered.

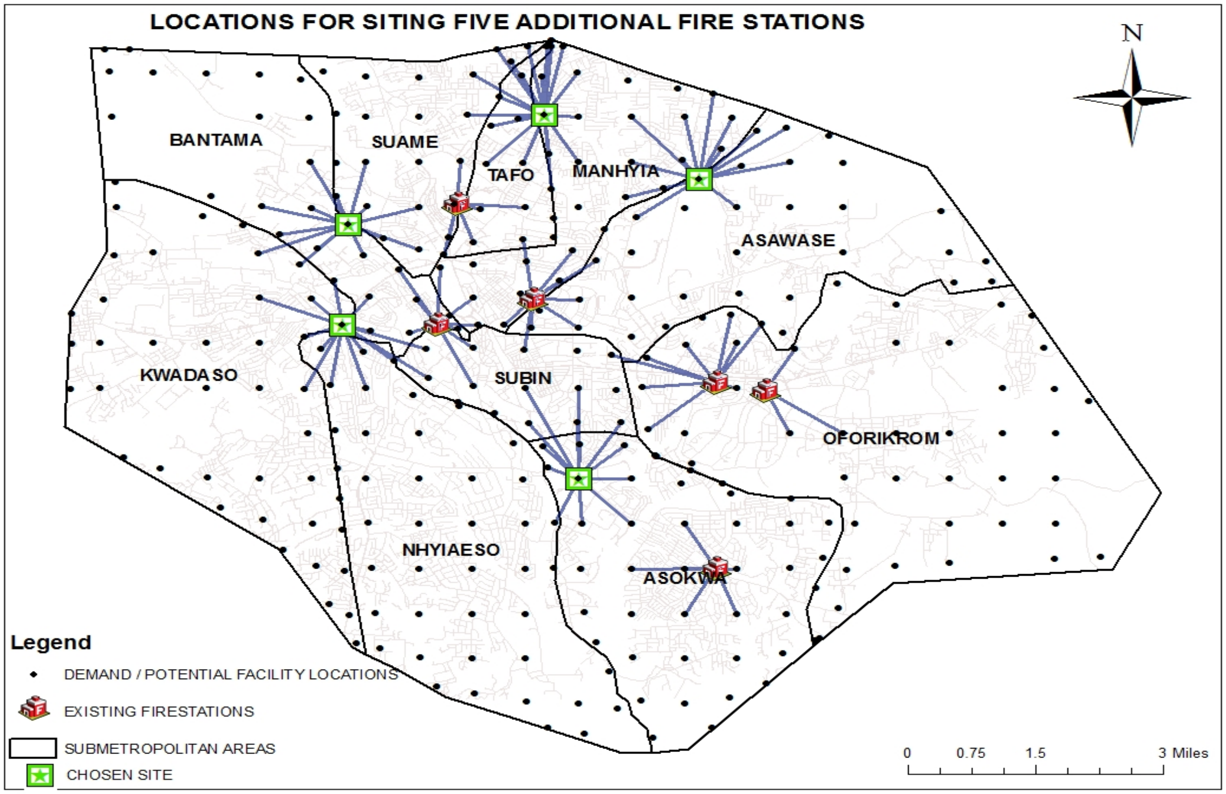

Figure 4.8. Location for Siting 5 Additional Fire Stations within a 10 Minutes Response Time

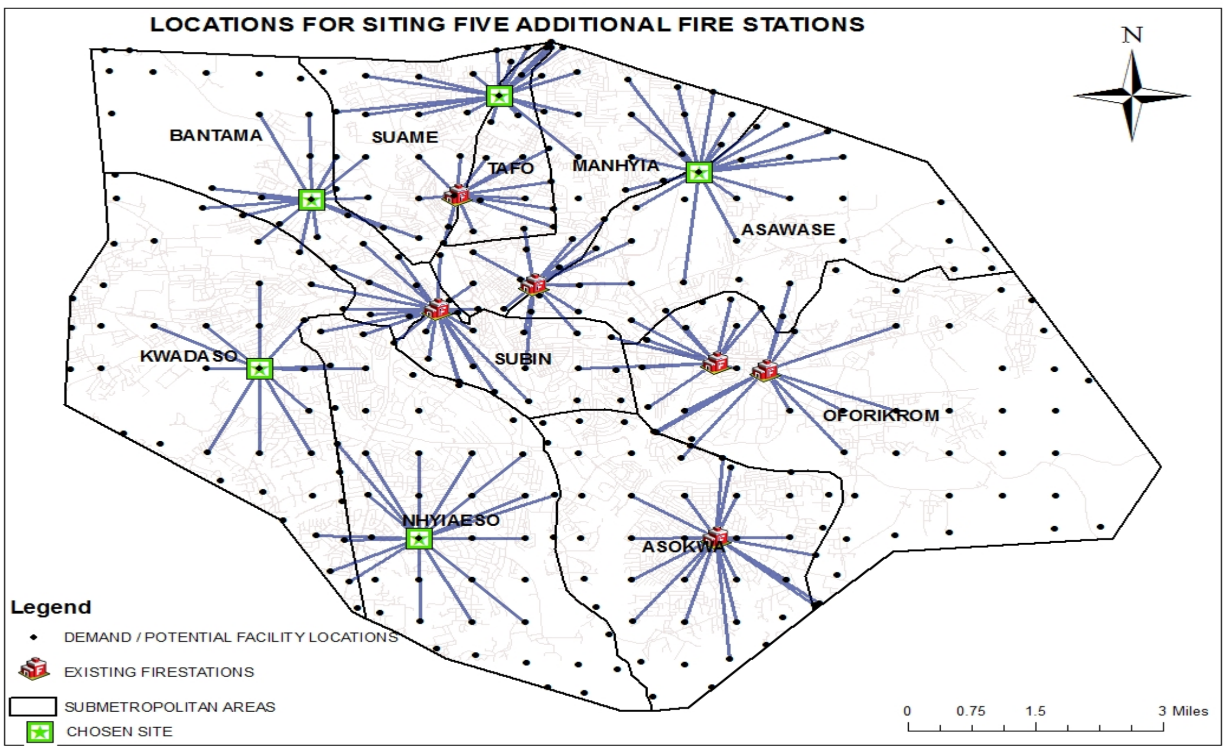

Figure 4.9. Location for Siting 5 Additional Fire Stations within a 15 Minutes Response Time

4.5 Population Served After Relocation of Fire Stations

This section presents results of population served after relocating the existing fire stations. From Table 4.4, the total population served for a 4 minutes response time, the target of the GNFS is 48,253. This represents approximately 3% of the total population in the study area, leaving approximately 97% of the population in KMA uncovered in the event of a fire outbreak. The percentages of population served for 5, 8, 10 and 15 minute response times are 4.7%, 16.2%, 20% and 39.5% respectively. As a matter of fact, for a 15 minutes response time, less than 50% of the population is served under the existing system of fire stations.

Table 4.4. Population Served Under the Existing Fire Stations

Response time (mins)	Population Served	% Population Served
4	48253	2.8
5	79712	4.7
8	277037	16.2
10	342990	20
15	675747	39.5

Relocating the current 6 fire stations would significantly improve coverage (Table 4.5). For example, there is approximately 6% increase in the population served for a 4 minutes response time after fire stations are relocated. Similarly, population served increased by 10.4%, 8.7%, and 16%, and 8.7% increase in the population served for 5, 8, 10, and 15 minutes response times respectively. This increase in population is due to the new location of fire stations in densely populated areas

Table 4.5. Population Served After Relocation of Fire Stations

Response Time (mins)	Population Served	% Population Served
4	143202	8.4
5	258699	15.1
8	426455	24.9
10	616962	36.1
15	824815	48.2

4.6 Population Covered After Adding Additional Fire Stations.

This study used only the 10 and 15 minutes response times to determine the locations for siting additional fire stations. Table 4.6 shows the population covered after adding additional fire stations within 10 minutes response time. There is a 2% increase in the population served after the addition of one fire station to the existing ones. Subsequently, there is a 13%, 18%, 21%, 23%, 26%, 27% increase in the population served after the addition of fire stations respectively. Most importantly, 50% of the population is served after the addition of 9 stations. The population served further increases to 52 % after adding 10 fire stations. From Figure 4.11 and Table 4.6, the addition of any fire station after the 10th fire station results in less than 1% increase in population served.

The same can be said for the population covered after adding additional fire stations. The existing fire stations serve approximately 39% of the population for a 15 minutes response time. However, after adding one fire station, there is a 6% increase in the population served (see Table 4.7). Similarly, there are increments in population served as more fire stations are added. For a 15 minutes response time, a population coverage of 50% is achieved after adding three more fire stations. Approximately 75% of the fire population is served when the 10th fire station is added. From Figure 14 and Table 4.7 the addition of any fire station after the 10th one results in less than 1% increase in population served.

Table 4.6. Population Covered for a 10 minutes response time

Number Of Fire Stations	Population Covered	% Population Covered	% Increase in Population Covered
6	342990	20.05	
6+1	380515	22.25	10.94
6+2	498468	29.15	30.99
6+3	576535	33.72	15.66
6+4	664178	38.84	15.20
6+5	704620	41.21	6.09
6+6	749974	43.86	6.44
6+7	796072	46.55	6.14
6+8	820260	47.97	3.04
6+9	860233	50.31	4.87
6+10	896959	52.45	4.29
6+11	913827	53.44	1.88
6+12	927199	54.22	1.46
6+13	940332	54.99	1.42
6+14	953503	55.57	1.40

Table 4.7. Population Covered for a 15 minutes response time

Number of fire stations	Population Covered	% of population served	% Increase in Population Covered
6	675747	39.5	
6+1	785998	45.9	16.32
602	844712	49.40	7.47
6+3	948974	55.50	12.34
6+4	1035026	60.53	9.07
6+5	1118441	65.41	8.06
6+6	1172746	68.58	4.86
6+7	1222676	71.50	4.25
6+8	1253324	73.29	2.51
6+9	1281727	74.95	2.26

6+10	1294288	75.69	0.98
6+11	1314412	76.87	1.55
6+12	1322346	77.33	0.64
6+13	1332093	77.90	0.74
6+14	1342353	78.52	0.77

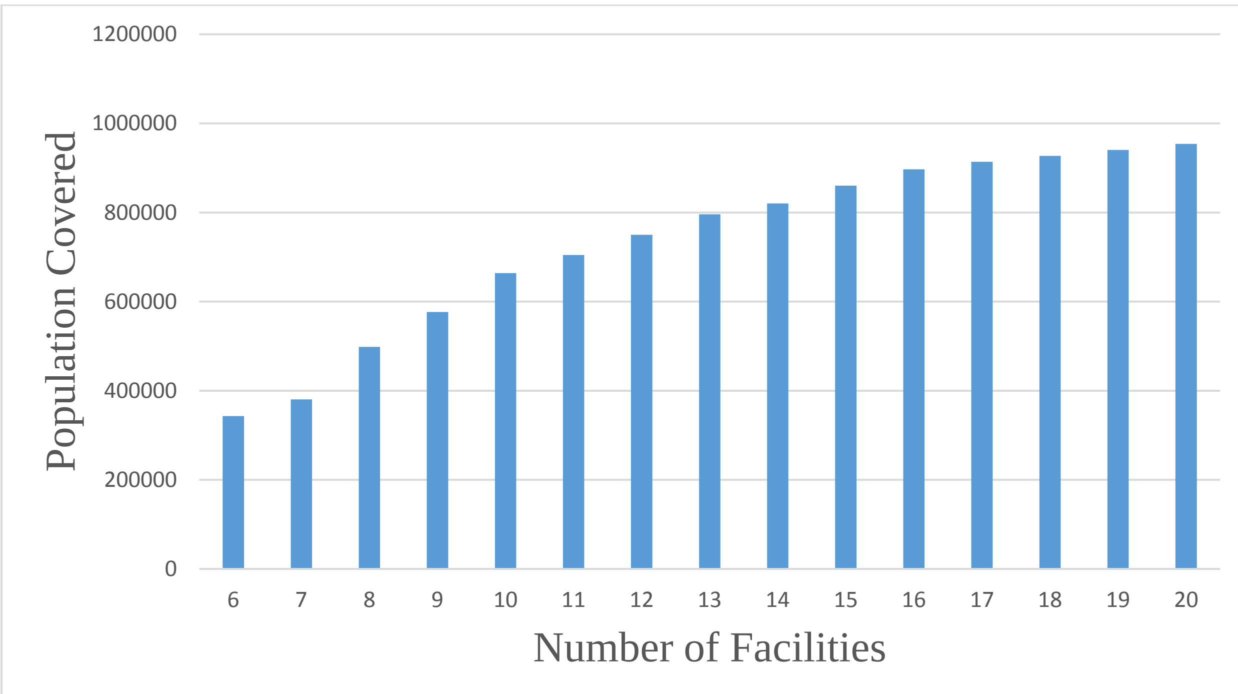

Figure 4.10. Trade off Curve for Additional Fire Stations for a 10 Minutes Response Time

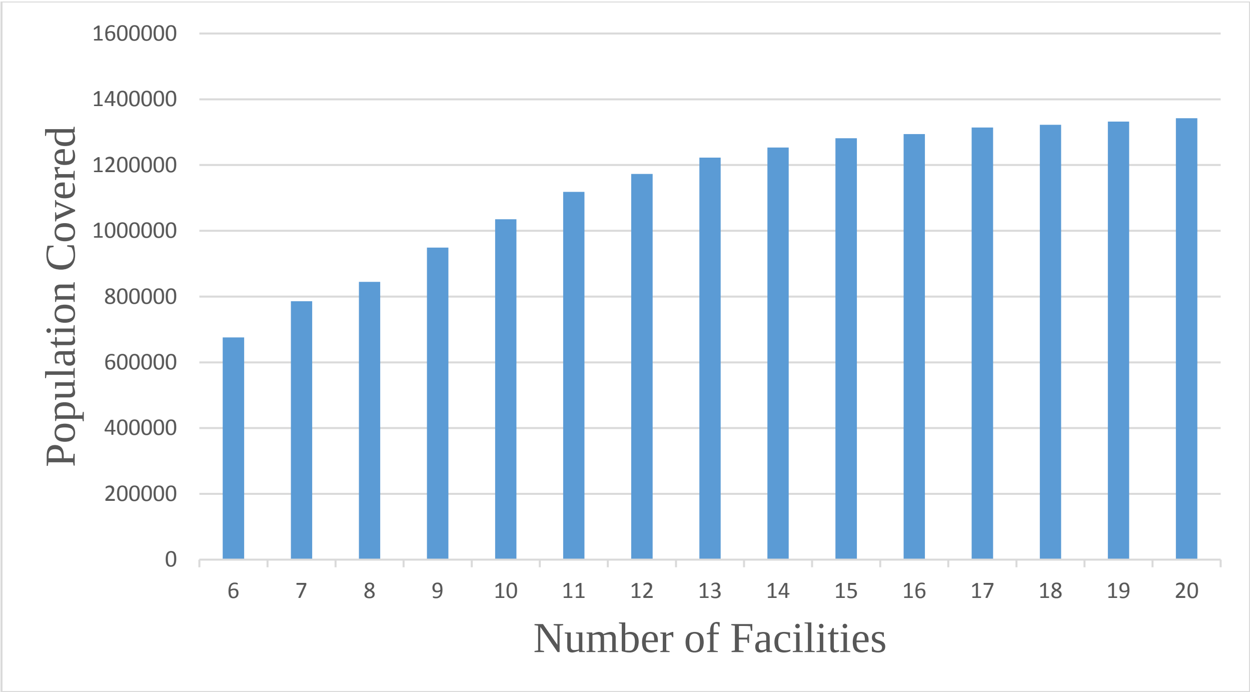

Figure 4.11. Trade off Curve for Additional Fire Stations within A 15minutes Response Time

CHAPTER 5

DISCUSSION AND CONCLUSION

5.1 Discussion

The spatial configuration of fire stations in KMA may be partly to blame for the huge loss of lives and the high cost of damage during recent fire outbreaks. Whereas approximately 40% of the total population is served by the existing fire stations for a 15 minutes response time, this could increase to approximately 48% with more efficient location of the same number of fire stations. Likewise, the total population served would increase from approximately 40% by the existing fire stations to 76% if 10 new fire stations were added for a 15 minutes response time. This research has identified the potential locations that should be considered priority for siting these additional fire stations.

Besides the limited geographic coverage of the existing fire stations, the GNFS faces many additional challenges. Some of the major ones include inadequate personnel, shortage of functional and dependable fire trucks, unreliable water supply, poorly located or non-existent fire hydrants, and an outdated emergency communication infrastructure. For example, the poor address system in the country makes it difficult for the GNFS to locate a fire scene. Consequently, responding to fire outbreaks takes much longer than necessary which results in huge losses of lives and property. Thus, improving the fire station locations alone is inadequate as long as these logistical problems persist. Addressing these challenges together with improving the efficiency of the spatial location of fire stations could minimize the loss of lives and property during fires.

Another major challenge facing the GNFS is the lack of functional water hydrants. According to Nyarkoh and Osei (2017), of the 58 fire hydrants in Kumasi, only 11 remain functional. New housing and other construction have rendered the rest inaccessible (Nyarkoh and

Osei, 2017). Even when water hydrants are located, frequently they carry little or no water. Some fire service personnel illegally tap the water from the water hydrants meant for firefighting and sell to individuals (Frimpong, 2003). Individuals also illegally siphon the water from the hydrants in the night for their personal use. Such acts hinder the performance of the GNFS.

Cities in developing countries are experiencing dramatic increases in population, stemming from rural urban migration. This unparalleled population growth leads to congestion and the over-use of infrastructure, increasing the risk of chronic emergencies and humanitarian crises (Zetter & Deikun, 2010). (Siame & Muvombo, 2016). This is the situation in Ghana. Despite the rapid urban population growth, urban infrastructure has not expanded proportionately to meet the increased demand. For example, the six existing fire stations in the KMA are concentrated in the south-central part of the study area, the historical core area of the city. Recently population growth has centered mostly in the north and west, and most importantly, away from the historical core area.

Consequently, when the maximum coverage model was used to evaluate the efficiency of the existing fire stations and determine more efficient locations for new facilities, the selected locations were mostly in the north and west of the KMA, the area of the most rapid population increase according to the 2010 population census. Because these results are based on the worst case scenario, they provide an opportunity for the GNFS to perform better under ideal or even slightly better conditions. Nonetheless, given the increase in population growth and the dynamics of population growth, the existing fire stations are not able to cover these new growth areas adequately.

Another objective of this study was to identify strategic locations for the siting of additional fire stations to maximize population coverage. City officials need to consider many factors before constructing additional fire stations. This includes the cost of relocating the existing fire stations or building new ones. Constructing a new fire station and furnishing it with firefighting equipment is costly. Relocating fire stations is also a very politically sensitive subject since sub-metropolitan areas that are likely to lose their fire stations may vehemently oppose it. Thus, a cost benefit analysis has to be done to determine the benefits of relocating the existing fire stations. Similarly, the cost involved in the demolition of existing structures to pave the way for siting new fire stations has to be assessed.

The redevelopment and regularization of informal settlements known for their illegal electrical wiring connections is also important in minimizing fire. In the case of Ghana, non-enforcement of building codes, regulations, repairs and maintenance in informal settlements is a risk factor for fire. In addition, building codes regarding portable fire extinguishers, fire and smoke detectors and fire alarms, and emergency fire exits should be enforced to prevent fire outbreaks.

Volunteer fire departments may be an important strategy for increasing the total number of trained personnel available in the event of a fire outbreak and reducing response time. Well trained and simply equipped fire volunteers can perform fire suppression in the event of a fire outbreak. Countries such as Australia, Austria, Canada and Germany with similar systems in place have significantly reduced the cost associated with fire outbreaks. An estimated 80% of France's total firefighters were volunteers in 2007 (Direction de la Sécurité Civile, DDSC, 2007). Communities, especially those with minimal or no coverage by the GNFS, should be encouraged to form volunteer fire fighters.

Responding to public health emergencies such as natural disasters, disease outbreaks, fire outbreaks and contaminated water requires a good transportation system. Yet, emergency transport, an essential component in any emergency response system, is a major challenge in most developing countries. This study found that a poor transportation system clearly hinders the effective performance of the GNFS. Other transportation services such as ambulances are also inadequate, serving as a barrier to care. In the rural areas and some urban areas, there are no ambulance services to transport the sick to the hospital. This takes a long time to get to the closest health care facility. The absence of good roads, and the inability to pay for transport services are drawbacks to emergency health care response (Razzak, & Kellermann 2002). Poor road networks and traffic congestion hamper emergency response to disease outbreaks, vaccination campaign programs and deprives the community of education (Mphande, 2016).

This study provides an example of how to use simple GIS analysis in developing countries where availability and access to data is a major challenge (Oppong and Ofori-Amoah, 2012). For example, locations were generated to serve as a proxy for fire incidents because the exact locations of fire incidents were unavailable. Another key contribution is the utilization of location-allocation modeling in this research. In addition, the findings from this thesis contributes to the scant literature on the applications of location-allocation models in developing countries. The results further demonstrate how emergency response systems, which are crucial to human health and development, can benefit from the application of simple spatial analysis approaches.

In the future, this study recommends additional factors such as wealth index of each sub-metropolitan area when assigning weights to the demand. For example, the Nhyiaeso sub-metropolitan area has a smaller population but has a lot of wealthy people. In the event of a fire, this produces excessive property damage compared to a more populous sub-metropolitan area with less property or structural development in it. Also, this research recommends other emergency response studies to be conducted in other sectors such as ambulance services.

5.2 Conclusion

The KMA situation examined in this study typifies the poor emergency response services experienced in most developing countries. Responding to and managing emergencies is a challenge for most developing countries. For example, the lack of timely treatment during health emergencies has led to a rise in the number of preventable casualties. Likewise, for any public health department to efficiently respond to any emergency, preparedness and a timely response are salient (Centers for Disease Control and Prevention, 2003). Generally, the emergency health care systems in most developing countries are either nonexistent or nonfunctional. For instance, a significant proportion of maternal deaths and neonatal complications in these countries could be reduced with the availability of emergency obstetric care (Bhandari & Dangal, 2014). However, due to the dearth of such emergency care systems, maternal and neonatal mortality arising from complications such as hemorrhage, obstructed labor, and infections remain a huge challenge (Keonig et al., 2007). Deploying simple spatial analysis tools such as implemented in this study in planning the location of emergency response facilities can improve the efficiency of response systems and reduce casualties and damage.

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