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# Determination of Optimal Routes to Markets for Efficient Fire Emergency Services in Gombe Metropolis, Gombe State, Nigeria

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**ABSTRACT**
Firefighting performance can be represented by the speed of handling the fire case, which is greatly influenced by the travel speed of the fire trucks to the fire location. This paper aims to determine the optimal routes to markets using remote sensing and GIS techniques for efficient fire emergency services to reduce time wasted in delivering services to fire victims in Gombe metropolis. It is observed that very often, the response of the fire service to distress calls for their intervention following fire outbreaks is well below the required standards. They arrive when significant damages have been done, thus, compromising their efficiency. In this paper, Google earth satellite imagery of the study area was downloaded, coordinates of fire emergency service and markets was obtained using handheld GPS (Garmin Oregon 550). Arc GIS network analysis extension tools was used for the generation of network geo-dataset and to measure the efficiency of services in terms of travel time. The study identified two (2) fire service stations (Tashan Dukku fire service and main market fire service) and twenty-four (24) markets. The study concludes that GIS-based network analysis is indispensable for identifying optimal emergency routes, and that the current spatial distribution of fire stations is inadequate for timely market coverage. The study recommends the use of real time imagery by creating an application, improvement in road networks in the study area, population distribution should also be a considerable factor in citing fire service stations in future as means for achieving better safety situations.

**Keywords:** GIS, Fire, Emergency Services, Markets, Optimal Routes, Gombe Metropolis

## INTRODUCTION

Fire is the rapid oxidation of a material in the exothermic chemical process of combustion, releasing heat, light, and various reaction products (Adekunle *et al.,* 2018). Providing immediate and effective response to fire is important because emergency is a situation that poses an immediate risk to health, life, property or environment (Isa *et al.,* 2016). Fire emergency services are involved in fire protection or prevention, rescue, emergency medical, or hazardous material response services (Forkuo & Quaye-Ballard, 2013). Isa *et al.* (2016) stated that, Fire-Fighting operations includes; rescue, fire suppression, and property conservation in buildings, enclosed structures, aircraft interiors, vehicles, vessels, aircraft, or like properties that are involved in an emergency situation.

In Nigeria, markets are very important to people in one way or the other and their importance cannot be over emphasized. They serve as an avenue for people to earn living (Sulaiman, 2021). Man being a social primate; to this end, it was noted that market places serve as an avenue for the interaction of people (Adekunle *et al.,* 2020). Market is commercial place where buying and selling take place (Arowolo, Adewale and Owolabi, 2021). Markets serve as avenues for interaction, income earning, companionship for entertainment, and other activities (Ngugi, 2015). Fire service in Gombe metropolis are not evenly distributed which leads to poor services delivery. Hence, the town constantly experiences fire disaster all around (Umar *et al.,* 2020). It is observed that very often, the response of fire service to distress calls for their intervention following fire outbreaks in Gombe metropolis is below the required standards. They arrive when significant damages have been done, thus, compromising their efficiency. Part of the reason for this is that the service is not guided on the choice of fastest routes to follow to get to the markets.

Optimal route is measured by time, it is the route that takes the least number of minutes and will get you to your destination in less time (Vaishali, 2019). Fastest route is the routes that used to reaches closest facility such as market, hospital, and emergency fire brigade facility from fire station to markets, industrial area or other fire locations in shortest time (Ritesh, 2013). Fastest route is the route that takes the least amount of time to accomplish all the stops for the day, that involves driving surface streets, back roads and frontage roads, and/or avoiding known areas of traffic congestion at certain times of day (Vaishali, 2019).

Applications of GIS to fire and other emergency mapping and management have been successful in many developed countries. GIS allows fire fighter personnel to make plans effectively for emergency response, determine mitigation priorities, analyze historical events, and predict future events; it helps fire officers to determine potential incident sites and facilitates to explore the relationship between incident and land use (Isa *et al.,* 2016).

The previous studies reviewed related to optimal routes, markets fire and fire emergency service response include that of: Dauda and Lawali (2014) that used an integrated approach for mapping road network in Gombe metropolis. They also revealed that Gombe has a network of mesh road pattern (i.e. net or interlocking structures). Agbonkhese *et al.* (2017) concerned with curbing fire outbreak in residential buildings in Gombe metropolis and identifies some challenges faced by Inhabitants as well as the authority with respect to fire management. Umar *et al.* (2019) attempted to assess socioeconomic effects and causes of fire outbreaks in Gombe

metropolis. The study employed descriptive statistics of the secondary data from fire service, Gombe.

Umar *et al.* (2020) studied the population and spatial analysis of fire service provision in Gombe Town, by identifying the availability of fire stations and their absolute locations in Gombe Town, to know the rate of fire incidences from Jan, 2019 to April, 2019 among various wards in Gombe Town. Isa *et al.,* (2016) analyzed the spatial distribution of fire incidences and people's perception on the fire service station in Kano metropolis, the result shows that only the old city of Kano is fully served while the other part of the metropolis is underserved, exceeding the minimum standard of 4-minute response time. Sulaiman (2021) determined the absolute locations for spatial and temporal analyses of fire outbreaks in markets of Kano Metropolis. The result indicates clustered pattern, extent of commercial activities, the use of electricity, and the flammability of the products, as the causes of fire outbreaks within the major markets. Meanwhile (Abousaeini *et al.,* 2015) conducted GIS modeling for determining the fastest route for fresh vegetables delivery. The results of the study indicate that land use variables such as residential areas and population size are the most effective parameters in determining the travel time for fresh vegetables delivery. Many markets in Nigeria have recorded significant losses from fire, such as Abubakar Rimi central market in Kano, the Kure central market in Mina, the mile one market fire in Port Harcourt, the Ariaria market fire in Aba, etc (Arowolo *et al.,* 2021).

In this study, GIS approaches was used to identify routes, fire emergency services and markets. Route planning systems using GIS have been carried out in several studies because GIS technology provides the ability of spatial data and network systems to represent real data in the production of various types of maps. Literatures reviewed in this study did not consider to determine the optimal routes to markets for fire emergency service responders in Gombe metropolis, thus the need for such research, the map produced at the end of the study will be of vital importance to both planners and managers to provide and enhance decision making associated with emergency planning, response, recovery, mitigation efforts and transportation planning in the study area.

Despite the documented importance of emergency response and the frequency of market fires in Nigeria, there remains a critical gap in the application of spatial technologies to optimize emergency routing within Gombe Metropolis. The current response of the fire service is often delayed, resulting in significant property damage and loss of livelihoods. The specific knowledge gap this study addresses is that previous studies in the study area (such as Umar *et al.,* 2020 and Dauda & Lawali, 2014) have focused on road network mapping, fire outbreak causes, and spatial distribution of fire service stations, but none have explicitly utilized GIS network analysis to determine and map the optimal routes to specific high-risk commercial zones (markets) for fire emergency responders.

Therefore, the primary objective of this study is to determine the optimal routes to markets for efficient fire emergency services in Gombe Metropolis. The specific objectives are to: (i) identify the locations of existing fire service stations and markets; (ii) analyze the spatial coverage of fire service stations based on varying response times; and (iii) generate optimal route maps connecting fire stations to markets.

The significance of this study lies in its potential to provide actionable spatial data to fire service managers, urban planners, and policymakers. By reducing travel time to incident sites, this research directly contributes to mitigating the devastating economic and social impacts of market fires in Gombe Metropolis.

**Study Area**

The location of the study is Gombe metropolis, which is located approximately at the center of Gombe State. It is bounded by Y/Deba LGA to the East, Akko LGA to the South, and Kwami LGA to the North respectively. Gombe Metropolis is approximately lying between latitudes 10° 13′ and 10° 20′ N and longitudes 11° 01′ and 11° 19′ E (Figure 1) and has an area of 175km² (Umar *et al,* 2019). Gombe metropolis had human population of 268,536 in 2006; with a projection of 363,061 people in 2017, Gombe State Government [GSG] (2015).

The vegetation of Gombe is within Sudan/Guinea savannah. This is characterized by shrubs and scattered trees with a different species of grasses. The predominant tree species include Locust bean tree, Baobab tree, Tamarin, Moringa, Date-palm, Neem trees and Azadirachtaindica. The soils are highly ferruginous, formed as a result of intensive weathering of the basement rocks (Mbaya *et al.,* 2019). Gombe is located within the sub-Sahara climatic zone, and has tropical continental type of climate, classified based on Koppen's (Aw) classification schemes. It is characterized by strong rainfall seasonality with distinct wet and dry season, that is, dry season November-April and wet season May-October (Amos *et al.,* 2015). The rainfall in Gombe metropolis is concentrated between the months of May and September with a single maximum in August. The average annual rainfall totals are about 863.2 mm (Amos *et al,* 2015). The mean maximum monthly temperature in Gombe metropolis is about 35℃ while the mean minimum monthly temperature is about 18℃ with relative humidity of about 95% in August (Abashiya *et al.,* 2019). Gombe metropolis is characterized by two distinctive seasons, that is, dry season (November-April) and wet season (May-October). The dry season comes with the north-east trade winds over the region originating from Sahara belt. The wind is dry and dust laden accompanied by low pressure system. The wet season comes with the southwesterly wind which is moisture laden, and originates from high pressure zone over the Atlantic Ocean to the low-pressure zone over the Sahara. (Mbaya, *et al,* 2019).

The major roads networks in Gombe metropolis are categorized to form 11.5% of the roads network that cover only the central district of the metropolis. Minor roads form about 22.9% of the road network. Access roads forms about 65.6% of the motorways in the study area connecting both the major and minor roads with dwelling, public places and utilities. Gombe is well linked to other regional centers by trunk "A" roads. A single gauge railway line on the Bauchi – Maiduguri route also links the town, in addition to an international airport (Dauda & Lawali, 2014).

According to Gombe State Economic Empowerment and Development Strategy [GOSEEDS] (2007) markets in Gombe metropolis are compared to market places in Nigerian states such as Lagos, many people believe that the prices of goods in Gombe markets are modest and affordable. Buyers from surrounding states are known to be drawn to the price range of products as a result. The following are the most well-known marketplaces in Gombe metropolis: Gombe main market, Gombe Old market (Tsohuwar Kasuwa), Gombe Grains Market (Tudun Hatsi), Pantami Market, Timber Market, Tiken Dabbobi, Oil seeds milling industries, Rice milling industries, Tumfure Market, etc. The inhabitants of Gombe metropolis are mostly traders, civil servants, small-scale farmers and other non-agricultural service providers. Industrial and other agro-business activities in the study area

are in the form of large, medium, small and cottage scales include; ginnery, oil seeds milling, rice milling, table water production, leather works, fish and meat processing etc, Gombe State Economic Empowerment and Development Strategy, [GOSEEDS] (2007).

In Gombe Metropolis, the Fire Service Station is located at Shamaki ward (Tashan Dukku) while Main Market Fire Service Station is located at Herwagana ward **(**Umar *et al.*, 2020).

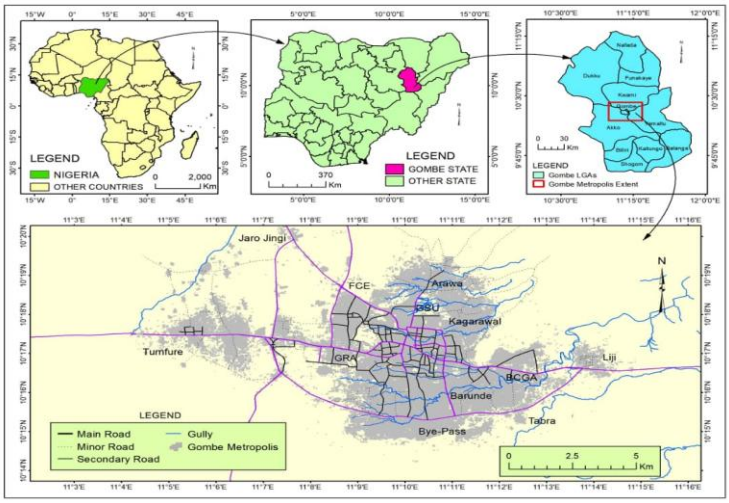



Figure 1: Map of the Study Area

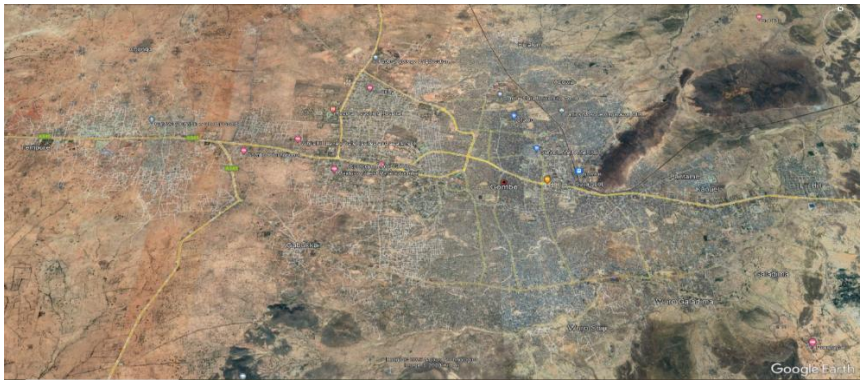



Figure 2: Satellite Imagery of the Study Area

## MATERIALS AND METHODS

### Study Design

The study adopted a quantitative spatial analysis design, utilizing both primary and secondary data gathered from specific sources, including field visits and online sources.

### Data Acquisition

Hand-Held Global Positioning System, GPS (Garmin Oregon 550), was used to obtain the coordinates of fire service stations and markets in the study area. The coordinates of fire service stations and markets were accessed through field work. A recent digital globe imagery covering the area was also acquired online (Google Earth Pro, 2026) to have an overview of the area. A database was created in Microsoft Excel (2016) and used to record coordinates, names, and remarks before being imported and plotted into ARCGIS as a layer.

### Data Processing and Analysis

Geospatial techniques were used. The excel data were saved as dbf and then imported to the Arcmap environment of ArcGIS 10.3.1 for the analysis. The data was georeferenced and digitized; shapefiles and layers for the features (roads, fire emergency services station and markets) were generated. A Network Geodataset was also generated and the optimal route was created using the ArcGIS 10.3.1 network analysis tool extension. The final map elements, which include the date on the map, the North arrow, Grid, Scale, and Title, were exported in TIFF format.

Road layer was developed into a network layer using the create network and 'build' tools in the network analyst toolbox of Arc tool box to ensure that the vertices (nodes) and links (edges) are defined and are attributed as road type, distance, and travel speeds (miles or kilometers per hour). This allowed for the identification of station locations, specifying a travel time, and running a network analysis. The study specified time as the attribute on which the service area and optimal routes calculations were based. The road network data required attributes like name, length, speed limits, and travel time to perform the network analysis. Hence, the fields 'name' 'length', 'speed limit' and 'travel time' were added to the road attribute table. An average speed of 40 km/hr for a truck on a 60 km trip was adopted for all roads, and the travel time for each road was calculated in minutes using the field calculator in the attribute table. The formula entered was ([length]*(60/[speed limit])), which implies that the travel time on the road is a function of the length of the road.

## RESULTS AND DISCUSSIONS

### Spatial Coverage and Service Area

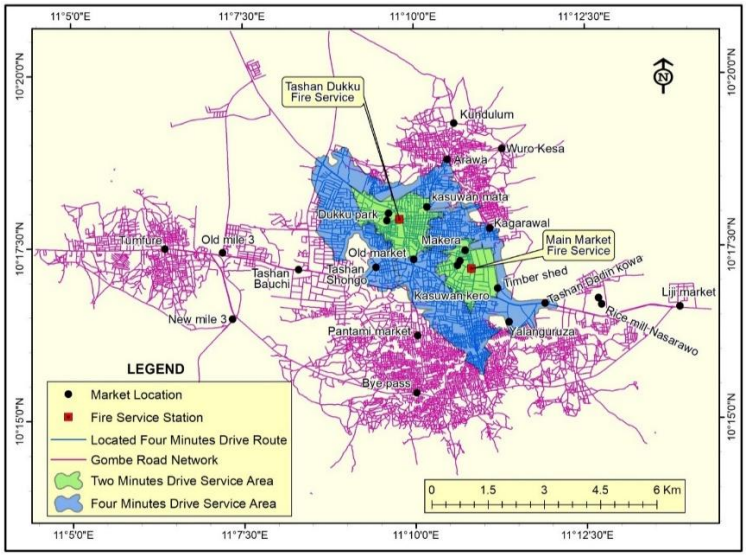



Figure 3: Fire Service Stations Area Coverage

Figure 3 reveals the 2 and 4-minute driving time polygon from the two fire stations. The small size of the green and blue spheres (service area) shows that fire incidents within those polygons can easily be handled, while any fire incidence occurrence outside the two- and four-minute polygon (service area) will suffer delay in response. It can clearly be seen from the separation of the green and blue spheres around the fire stations that there is a wide gap between the coverage areas of the two fire stations, indicating that the fire stations are not located in close proximity to one another for quicker response time. The result shows that only a few market areas can easily be covered while others cannot be reached within the stipulated time. The resultant effects are that more markets are at risk due to delay in fire service response under the four (4) minute response time analysis. The locational separation of the two available fire service stations is detrimental to the study area with an increasing level of urbanization.

### Optimal Route Analysis

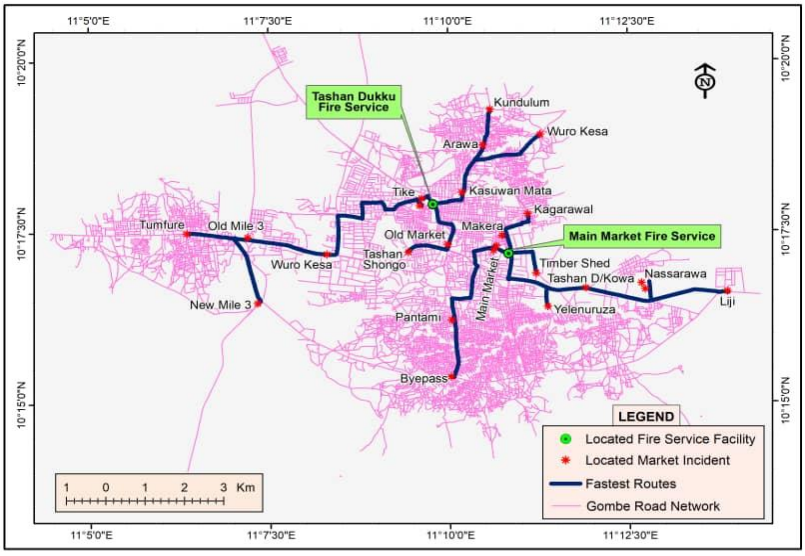



Figure 4: Optimal Routes from Fire Service Stations to Markets

The system (ArcGIS network analysis tools) generates the optimal routes between two locations by calculating its total travel time on the road, as indicated in Figure 4 above. This will help the fire emergency service providers choose the quickest routes to follow to get to the incident sites to reduce the traveling time wasted to reach a particular market. The travel time is determined using the Network analyst of ArcGIS. The calculation of the optimal route is a built-in feature in the software of the Network Analyst. The travel time from the fire service stations to the markets has to be computed in the formulation of the total cost in order to optimize the incident locations.

### Discussion

The findings of this study corroborate the assertions of Umar *et al.* (2020), who noted that fire service stations in Gombe are not evenly distributed, leading to poor service delivery. The service area analysis (Figure 3) quantitatively confirms

this, showing a vast spatial gap and demonstrating that the current infrastructure cannot meet a standard 4-minute response time for the majority of the markets. Furthermore, the optimal route maps (Figure 4) provide a practical solution to the theoretical problem raised by Isa *et al.* (2016), who highlighted that underserved areas exceed minimum response standards. By providing these specific optimal routes, this study bridges the gap between spatial analysis and practical emergency response, offering fire officers the exact paths needed to navigate Gombe's mesh road network, as described by Dauda and Lawali (2014), minimizing travel time.

## CONCLUSION

This study assessed the geographic distribution of existing fire emergency service stations and markets in Gombe Metropolitan Area. It further sought to evaluate the spatial coverage for each fire emergency service station under predefined response times. The rationale behind this study was how optimal routes can be used to effectively manage fire outbreaks. GIS is a useful tool in identifying spatial problems and giving spatial solutions to issues inherent in human society. It combines and analyses relevant geographic data to support decision making by stakeholders and users. This study has shown one of the numerous strengths of GIS and its ability to provide specific, measurable, attainable, and realistic as well as time-bound responses of fire emergency services to markets in Gombe Metropolis.

It is clear that the fire service stations were not enough and the services rendered are poor. The study was able to identify two (2) fire service stations, twenty-four (24) market areas, and the road network in the study area. It was found that the fire services stations are not evenly distributed in the town as the fire service stations are not capable of supplying adequate services to the inhabitants of the town. It is on this basis that the study makes the following recommendations: The Gombe State Government should site a new fire service station in areas such as Liji, Tumfure, Old Mile Three, New Mile Three, ByePass, etc. Population distribution should be a considerable factor in providing and evenly distributing fire service stations in all the strategic locations. Emergency service providers such as the fire departments, hospitals, and police stations should improve their services.

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## CONFLICT OF INTEREST STATEMENT

The authors declare that there is no conflict of interest regarding the publication of this paper.

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