Geospatial Mapping and Evaluation of Fire Service Station for Optimum Operation and Response in Damaturu Metropolis Damaturu Yobe State, Nigeria

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Abstract

This study focuses on the optimization of fire station locations in Damaturu Metropolis to enhance emergency response capabilities. The research employed geospatial analysis techniques using ArcGIS 10.5 and ERDAS Imaging 2015 software packages. Satellite imagery was processed and analyzed to map the existing fire stations and evaluate their placement. Additionally, the study utilized the Network Analysis tool in ArcGIS 10.5 to propose new fire station locations based on global standards and best practices. The findings revealed that the existing fire stations in Damaturu Metropolis were situated haphazardly without adhering to global standards. Issues such as inadequate spacing between stations and congested road networks were identified, posing challenges to timely emergency response. Furthermore, the study identified lack of connectivity and dead-end streets as additional obstacles for fire services in navigating the city efficiently. To address these shortcomings, the study proposed strategic fire station locations at key intersections, specifically at the corners of four roundabouts within the city. These locations were selected based on their proximity to major road networks, hospitals, and adherence to global standards. The Network Analysis tool was utilized to determine service area coverage for each proposed fire station, considering factors such as response time and travel distance. The results demonstrated that the recommended fire station locations aligned with global standards and offered improved coverage for the city. By following best practices, the proposed fire stations would optimize response times, reduce fuel consumption, and enhance proximity to incident points. Furthermore, the study emphasized the importance of collaboration and resource sharing among neighboring fire stations to further enhance efficiency and cost-effectiveness. The findings highlight the need for urban planning considerations, infrastructure improvements, and better road connectivity to facilitate swift emergency response. By integrating these recommendations into fire station siting, Damaturu Metropolis can significantly enhance its emergency preparedness, protect lives and properties, and allocate resources effectively.

Key Words: *Geospatial, Mapping, Fire service and Optimum Operations*

Introduction

The geospatial mapping being a spatial analysis technique that typically employs software capable of interpreting maps, processing spatial data, and applying analytical methods and terrestrial datasets including the use of geographic information system (Granell-Canut, & Aguilar-Moreno, 2018).

According to Burrough, McDonnell, & Lloyd, (2015). The Geographic Information System (GIS) is a computer system that analyzes and displays geographically referenced information. It uses data that is attached to a unique location. Most of the information obtained about the world contains a location reference (Burrough et al., 2015). The GIS originated in the 1960's created to assist in land management, these systems evolved to manage data from two related but distinct perspectives. It provides graphical depiction of the location of features on plotted map and they were also capable of linking sophisticated conventional data base and statistical functionality to mapped information in order to allow more sophisticated interpretation of the characteristics of location (Gregory, Kemp & Mostern, 2001). The population, industrialisation, and urbanization of cities are all growing quickly on a global scale (Tobin, 2020). All levels of governments -Local, State and Federal are involve in emergency management; while some emergency responses and functions are common to all. Each of the level has its own unique responsibilities and resources. The roles are similar in many ways as each has an effective organization and develop and maintain necessary plans, facilities and equipment. On a day to day basis, it must manage an activity, ongoing emergency management programme of both, example most states have a single agency that takes "Lead" responsibility for emergency preparedness and response activities.

Fire service departments face a significant issue in responding to emergencies on time when contacted by the public due to the growth of industry and population in emergency circumstances. Shahparvari, Fadaki, & Chhetri, (2020), Explains that "Fire, an ever-present hazard in Australia, causes roughly 100 fatalities and over 3,000 injuries per year" according to them, Response to calls for emergency service and the amount of structural damage are found to be highly correlated. The estimated cost of damage to the structure increases at the rate of approximately AUD$3,830 per fire per minute of response time. In 2017, Victoria experienced 1,588 house fires with the top three causes of residential fire are cooking (28%), electrical fault (25%), and heating (17%). These fires have resulted in approximately $42 m of total property loss they added.

If a fire is not put out in a timely manner, it can cause significant property damage and casualties. Fire control and suppression are vital tasks for fire services. Around 300,000 people die from fires each year globally, most of them at home, (Aleisa, 2018), Planning for disaster preparedness is a crucial topic that can have an impact on people's lives when creating a fire emergency response database, if properly designed and promptly executed, it can save hundreds of thousands of lives and reduce some of the negative effects, (Yagoub & Jalil, 2014). Regarding the monetary losses in the impacted regions. Disasters can occur with little or no notice. However, jurisdictions with effective emergency response plans are better equipped to deal with such catastrophes and emergencies than those without such plans. (Parentela & Nambisan, 2000). The Zhou & Wang, (2013) work proposes a multi-objective goal programming approach that takes service quality, setup costs, and running costs into account in an uncertain context. Both the academic and the practitioner have long been interested in figuring out where to fixed fire stations in a particular area (city). The decision of

how many fire stations to have and where to build them may be the most crucial one for any Chief Fire Officer, (Badri, Mortagy & Alsayed, 1998). Prior to the development of Geographic Information System (GIS), judgments on emergency response were frequently made based on a manager's perception and professional experience rather than the most recent facts regarding the occurrence that called for emergency response, (Conweh, 2012). Zhang & Jiang, (2012), Revealed that module uses object-oriented coding to create spatial data for GIS. It appears that the entire module is capable of appropriately resolving the urban fire station's site selection problem, which satisfies the quick response's requirements. The goal of this study is to simulate areas susceptible to fire dangers within the study area using a GIS and a Global Positioning System (GPS).

Materials and Methods

In order to mapped and evaluate the fire service stations for optimum operation and response in the study area, the spatial and attribute data of all the fire service stations within the study area were acquired as well as verbal interview with some fire service experts on some salient information were conducted. The satellite imagery of the study area was acquired, corrected, digitized and analyzed using Arc GIS 10.5, ERDAS Imagine and SPSS Software Packages.

The spatial and the attribute data acquired were integrated in an ArcGIS 10.5 Software and overlaid on a digitized map to produce map of different layers as existing fire stations functional, Service area coverage of fire service stations, recommend fire stations, composite map showing service area coverage of recommended fire service stations and the composite map showing service area coverage of recommended fire service stations.

Results and Discussion

The results produced in form of map in figures below shows the map of the existing fire service stations, service area coverage of the existing fire service station, recommended fire service stations, the composite map that shows a service area and the composite map that shows the service area coverage of the recommended fire service stations all within the study area.

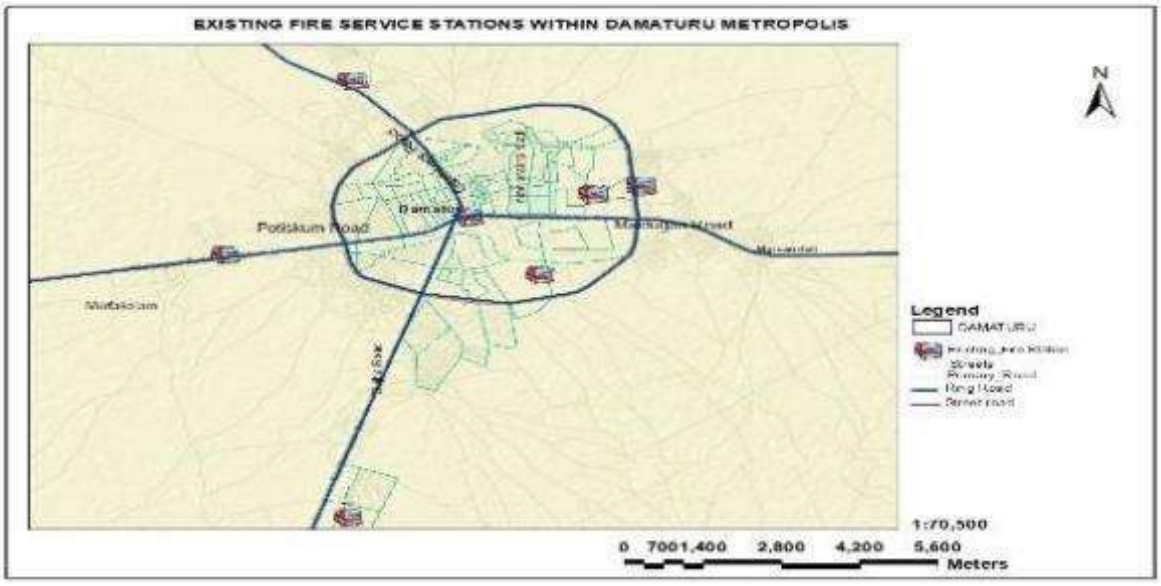

Figure 1: Existing fire service stations within Damaturu Metropolis

The map above shows the existing fire station locations in Damaturu Metropolis, revealing some significant observations. There is a total of seven fire stations, two of which are associated with academic institutions, namely Federal polytechnic Damaturu (FEDPODAM) and Yobe state University (YSU). However, the placement of these fire stations appears to be haphazard and lacking a systematic criterion. One key issue is the spacing between the fire stations. Some stations may be located too far apart, resulting in longer response times and potentially delayed fire incident management in the areas situated farther away from these stations. On the other hand, there are instances where fire stations are placed too close to each other, which can lead to redundant coverage and inefficient utilization of resources. This clustering of fire stations in certain areas can leave other regions at a disadvantage in terms of fire incident response.

The analysis of road networks around the existing fire stations also reveals challenges. The roads seem congested and overcrowded, which can hinder quick response times and emergency drives to and from the fire stations. This congestion could pose obstacles to accessing fire incidents swiftly and potentially impact the effectiveness of fire response efforts. Furthermore, the distance between some fire stations and hospitals is noteworthy. In cases where hospitals are located far away from the fire stations or the road networks are congested, it may impede the timely transfer of injured individuals or limit the availability of immediate medical assistance during fire incidents.

An analysis of the road network in Damaturu Metropolis reveals several challenges for emergency response. Many of the roads in the streets are narrow, congested, and inadequately designed for quick emergency access. These tiny roads and congested areas can impede the movement of fire trucks and other emergency vehicles, delaying their arrival at the incident site. Additionally, the presence of curved roads can further hinder emergency response efforts. Sharp curves make it difficult for large fire trucks to maneuverer swiftly, potentially slowing down their response time. These road characteristics pose significant challenges for firefighters and other emergency personnel, potentially compromising the effectiveness of their operations.

Moreover, the issue of dead-end streets adds another layer of complexity. Dead-end streets, which do not connect to other streets, limit accessibility and create obstacles for emergency vehicles. Firefighters may face difficulties in navigating these streets and reaching the affected areas in a timely manner. The lack of connectivity between streets can significantly impact response time, potentially exacerbating the consequences of fire incidents. These road-related challenges highlight the need for infrastructure improvements and urban planning considerations. Widening the roads, addressing traffic congestion, and redesigning curved sections can enhance the efficiency of emergency response. Ensuring a well-connected street network with multiple access points is vital to facilitate swift and effective emergency operations. Addressing these road infrastructure issues would require collaboration among relevant stakeholders, including Yobe Geographic information services (YOGIS), city planners, transportation authorities, and emergency services. By prioritizing the improvement of road networks and addressing congestion and dead-end streets, the overall emergency response capabilities can be significantly enhanced. Quick and unimpeded access to incident sites is crucial in mitigating the impact of fire outbreaks and ensuring the safety of lives and properties.

Therefore, integrating urban planning and emergency management strategies becomes imperative to optimize road networks, reduce

response time, and improve overall emergency preparedness.

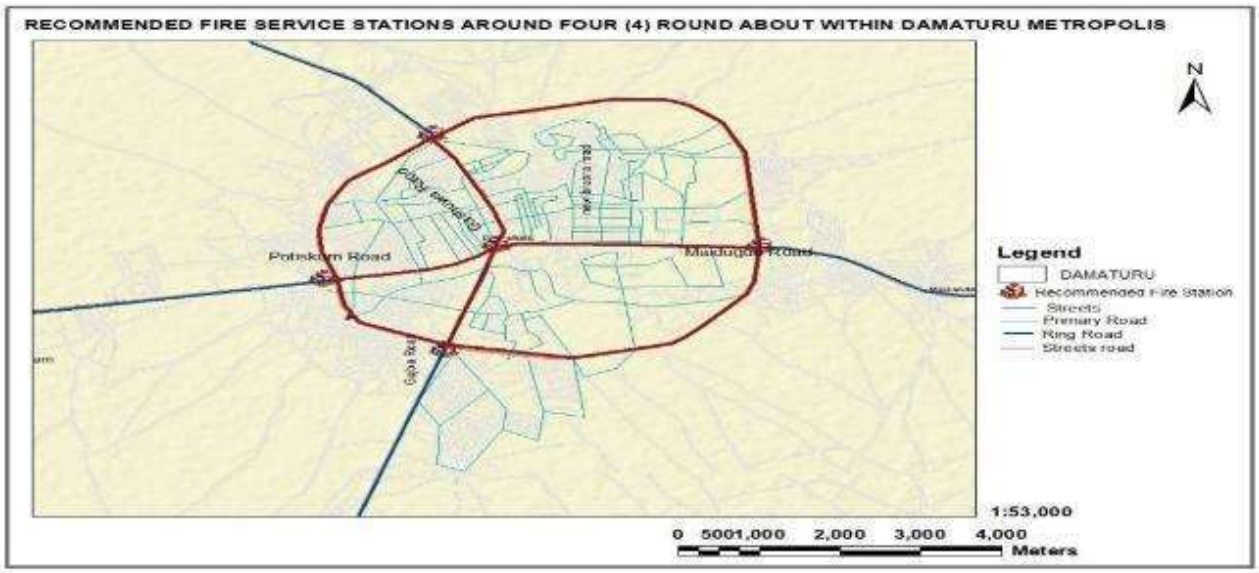

Figure 2: Recommended Fire Station

Based on the Network Analysis performed on ArcGIS 10.5, and best practices around the globe the proposed fire station locations in Damaturu Metropolis were strategically determined based on global standards and service area coverage component of network analysis tool in ArcGIS 10.5. The map shows that the proposed fire stations are situated at the corners of four (4) roundabouts within the city. This placement follows global standards that recommend fire stations to be strategically positioned at key intersections for easy accessibility and efficient coverage.

These roundabouts provide multiple access points and are connected to double highway express roads, ensuring quick response times for emergency vehicles. The proximity of the proposed fire stations to hospitals is also considered, enabling swift coordination between fire services and medical facilities during emergencies. Roundabouts serve as ideal locations for fire stations due to their central positioning and ability to provide access from multiple directions. This strategic placement allows fire services to respond quickly to incidents, regardless of the source or direction of the emergency. It also facilitates a more efficient allocation of resources, as fire trucks can easily navigate the city's road network to reach the incident scene in a timely manner.

Moreover, the use of double highway express roads connected to the roundabouts further enhances the efficiency of emergency response. These roads offer smooth, unobstructed travel, allowing fire vehicles to navigate through the city with ease. The presence of such well-designed road infrastructure, combined with the recommended distance of approximately 2,000 meters from the existing fire stations, ensures a comprehensive and coordinated response system that optimizes the use of available resources. Global Standards for Siting Fire Stations: Internationally recognized standards and best practices for fire station siting emphasize factors

such as response time, coverage area, population density, and risk assessment. These standards aim to ensure that fire stations are strategically located to provide optimal coverage and response capabilities. However, it appears that these global standards were not adhered to during the siting of the existing fire stations in Damaturu Metropolis.

1. **Response Time Optimization**: Response time is a critical factor in fire incident management. By following global standards, fire stations can be strategically placed to minimize response times and ensure prompt emergency response. This involves considering the geographic distribution of the population, traffic patterns, and road connectivity. Optimizing response times can help mitigate the spread of fires, reduce property damage, and potentially save lives.

2. **Impact on Cost of Fuel:** The placement of fire stations in a manner that adheres to global standards can also have an impact on the cost of fuel. When fire stations are located optimally, it reduces the distance traveled by fire trucks to reach the incident site. Consequently, the fuel consumption of fire vehicles can be minimized, leading to cost savings for the fire service department.

3. **Distance from Incident Point:** The distance between fire stations and incident points is crucial for effective fire response. When fire stations are situated closer to high-risk areas or areas prone to fire incidents, it enables quicker arrival and intervention. By reducing the distance, fire departments can significantly enhance their ability to control and extinguish fires in a timely manner, minimizing property damage and potential casualties.

4. **Cost-Benefit Analysis:** Evaluating the cost implications of fire station siting is essential. While adhering to global standards may require initial investment in infrastructure and equipment, the long-term benefits in terms of reduced property damage, enhanced public safety, and potential lives saved outweigh the initial costs. Conducting a cost-benefit analysis can help justify the investments required for optimizing fire station locations.

5. **Collaboration and Resource Sharing:** Optimized fire station siting also facilitates collaboration and resource sharing among neighboring fire stations. By strategically locating fire stations in proximity to one another, resources such as personnel, equipment, and specialized units can be shared, leading to cost efficiencies and improved emergency response capabilities.
   It is upon the above global standards that this paper recommends from a spatial perspective, new location for fire stations in Damaturu Metropolis in line with global standards. This will optimize response times, reduces the cost of fuel consumption, ensures closer proximity to incident points, and improves overall emergency response capabilities. Considering these factors in the planning and siting of fire stations can lead to more effective fire incident management, enhanced public safety, and efficient allocation of resources.

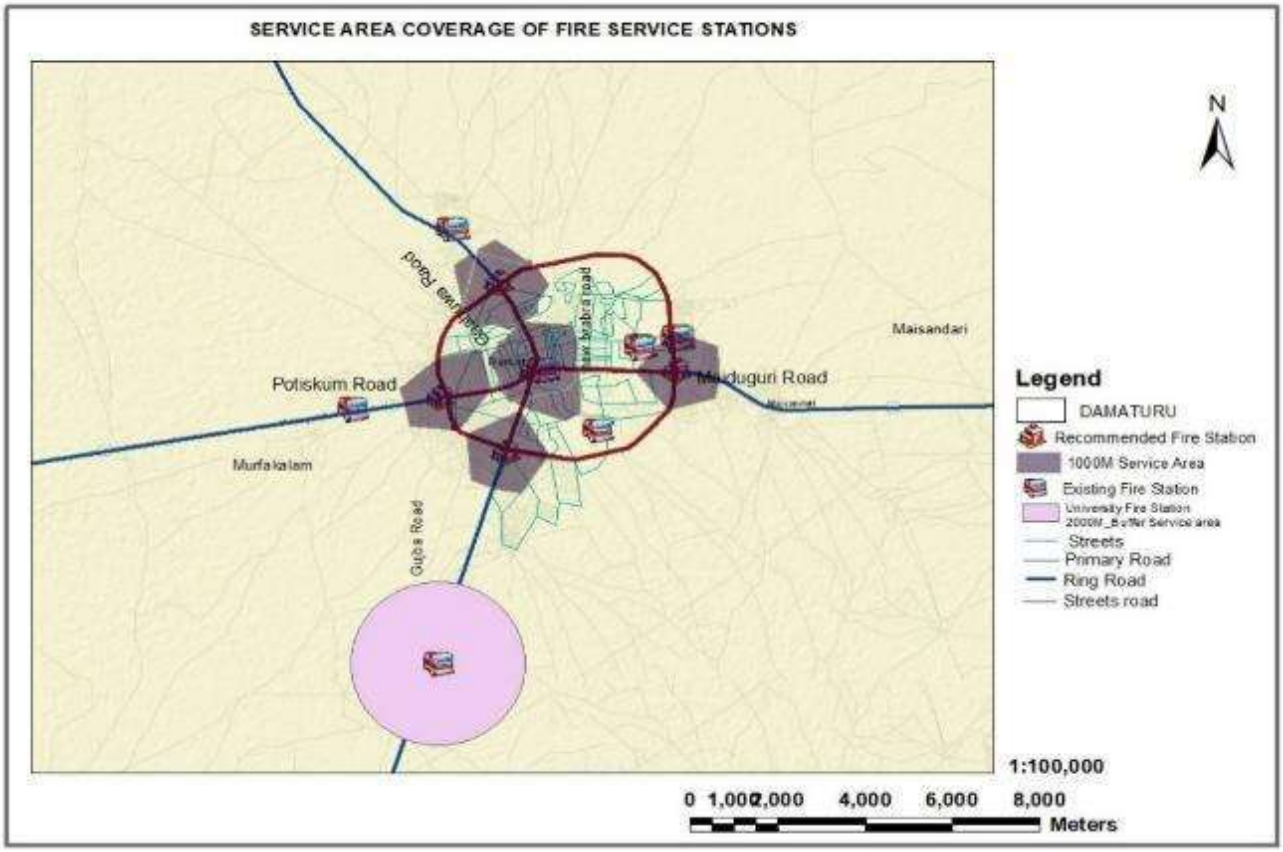

Figure 3: Service Area coverage of fire stations in Damaturu metropolis

The recommended fire station siting in Damaturu Metropolis exemplifies a comprehensive approach that aligns with global standards and best practices for efficient emergency response. By strategically placing the fire stations at the corners of roundabouts, approximately 2000 meters away from the existing fire stations, the city ensures optimal coverage and avoids duplication of resources. Furthermore, the consideration of proximity to hospitals in the fire station siting process underscores the importance of coordination between fire services and medical facilities during emergencies and facilitates seamless collaboration between firefighting teams and medical professionals, enabling faster and more coordinated responses to emergencies. This integration contributes to a more comprehensive emergency response system, enhancing the city's capacity to handle fire incidents and medical emergencies effectively. By implementing these recommendations, Damaturu Metropolis can significantly enhance its capacity to protect lives, properties, and socio-economic.

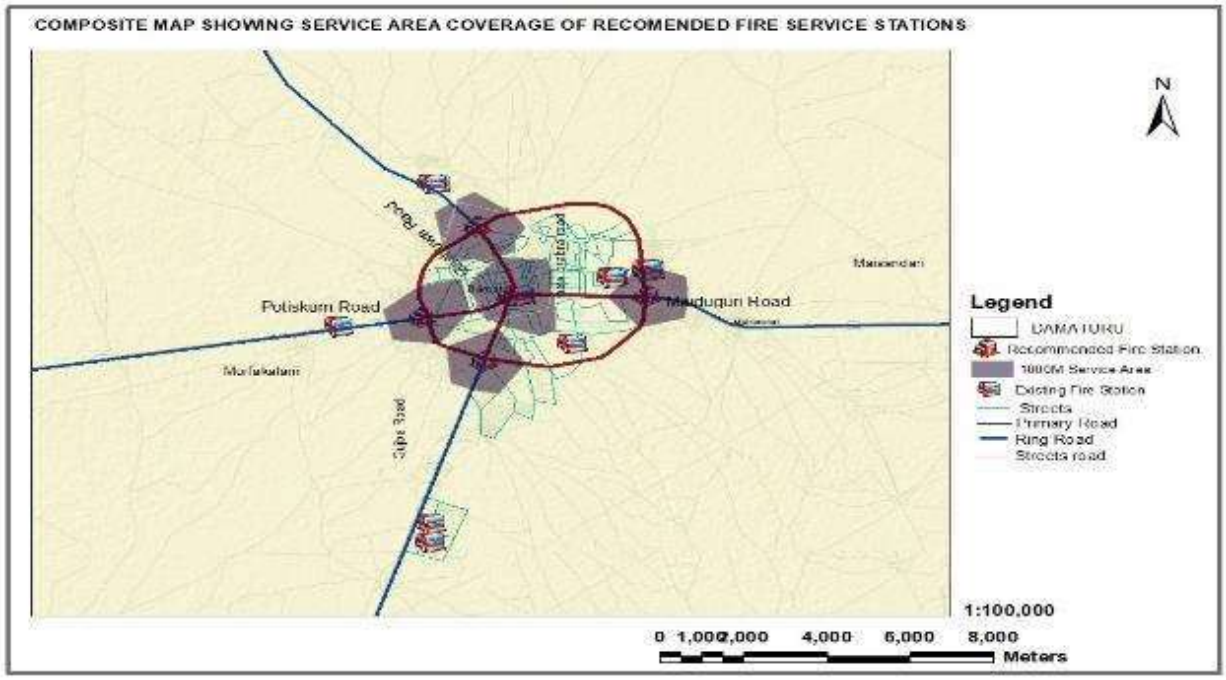

Figure 4: Composite map showing service area coverage of recommended fire service stations

To ensure comprehensive coverage, a buffer zone with a radius of 1,000 meters was established around each proposed fire station. This buffer zone ensures that all areas within the coverage zone are within a travel distance of less than 20 minutes from the fire station, aligning with global standards for response time. Additionally, the existing fire station at Yobe State University was analyzed, and when buffered at 2,000 meters, it covers areas such as Mallam Matari, Obasanjo housing estate, Malari, and parts of Abba Ibrahim housing neighborhood. This helps extend the coverage to these areas and provides a strategic distribution of fire stations throughout the metropolis. However, it is important to note that there is a need for further improvement in the connectivity of routes within wards to facilitate future emergency responses. Enhancing road networks and ensuring better connectivity between neighborhoods will optimize emergency response capabilities and further enhance the effectiveness of the proposed fire station locations.

Furthermore, the consideration of proximity to hospitals in the fire station siting process underscores the importance of coordination between fire services and medical facilities during emergencies. By locating fire stations near hospitals, the city facilitates seamless collaboration between firefighting teams and medical professionals, enabling faster and more coordinated responses to emergencies. This integration contributes to a more comprehensive emergency response system, enhancing the city's capacity to handle fire incidents and medical emergencies effectively.

Conclusion

The use of satellite imagery, attribute and spatial data were integrated in GIS through the use of ArcGIS 10.5, ERDAS imagine 2015 and SPSS software packages to mapped, evaluate and analyse the fire service stations for optimum operation and response in Damaturu Metropolis. A recommendation was made based on the results

achieved in order to ease the operation. The factors ought to have been considered in siting the fire service stations were highlighted so as to avoid repeating the same mistakes.

Recommendations

The factors such as response time, coverage area, population density, and risk assessment ought to have been considered in siting the fire service stations were highlighted based on the network analysis performed on ArcGIS 10.5 software.

If the above highlighted recommendations were strictly adhered to, it will no doubt provide access from multiple directions and will allow fire fighters to response quickly to incident regardless of the source of direction of the emergency.

References

Aleisa, E.E. (2018). The fire station location problem: a literature survey. *International Journal of Emergency Management*, *14*, 291.

Badri, M.A., Mortagy, A. K., & Alsayed, C. A. (1998). A Multi-objective model for locating Fire stations. European Journal of operational Research, 110(2), 243-260

Burrough, P. A., McDonnell, R. A., & Lloyd, C. D. (2015). *Principles of geographical information systems*. Oxford University Press, USA.

Conweh, C. (2012). The Use of GIS for Effective and Efficient Emergency Management: A case study of the Cardiff Fire Services in South Wales. Conweh Chiedu.

Granell-Canut, C., & Aguilar-Moreno, E. (2018). Geospatial influence in science mapping. In *Encyclopedia of Information Science and Technology, Fourth Edition*. IGI Global.

Gregory, I. N., Kemp, K. K., & Mostern, R. (2001). Geographical Information and historical research: Current progress and future directions. *History and Computing*, *13*(1), 7-23.

McLoughlin, D. (1985). A framework for integrated emergency management. *Public administration review*, *45*, 165-172.

Parentela, E. M., & Nambisan, S. S. (2000). Emergency response (disaster management).

Shahparvari, S., Fadaki, M., & Chhetri, P. (2020). Spatial accessibility of fire stations for enhancing operational response in Melbourne. *Fire safety journal*, *117*, 103149.

Tobin, T. Weynand (2020, May 26). *cultural imperialism*. *Encyclopedia Britannica*. https://www.britannica.com/topic/cultural-imperialism

Yagoub, M. M., & Jalil, A. M. (2014). Urban fire risk assessment using GIS: Case study on Sharjah, UAE. *International Geoinformatics Research and Development Journal*, *5*(3), 1-8.

Zhang, W., & Jiang, J. C. (2012). Research on the location of fire station based on GIS and GA. In *Applied Mechanics and Materials*, 130, 377-380). Trans Tech Publications Ltd.

Zhou, J., Li, Z., & Wang, K. (2013). A Multi-Objective Model for Fire Station Location under Uncertainty. *International Journal on Advances in Information Sciences and Service Sciences*, *5*, 1184-1191.