Application of Geographic Information System in Emergency Service Delivery – A Case of Ghana National Fire Service*

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Abstract

The Ghana National Fire Service (GNFS) since its inception has been faced with several challenges in executing its firefighting duties. Some of the challenges include: lack of appropriate logistics to fight fires, inaccessibility to fire sites, inadequate training facilities and inability of GNFS to carry out fire risk assessment prior to operations. This has contributed to the GNFS having low emergency response time of 12½ minutes as against the international standard time of 4 minutes. This project therefore adopted GIS techniques that enable significant reduction in time for emergency service response and delivery by the GNFS. Data used for the project include georeferenced high-resolution satellite image, topographic map of the study area and fire outbreak statistics of Tarkwa. A suitability analysis was performed to select appropriate sites in the unplanned communities for mounting fire hydrants in open spaces. These selected open spaces together with the community centre feature were fed into a model builder in Arc GIS. Through the processes of buffering, reclassification of the input features and weighted overlay operations, the final outcome was obtained. The results show the fastest route to be used for emergency service delivery from the Tarkwa fire station. The study created scenarios to show the extent of service areas for different travel times of one, two, three and four minutes using travel speed of 50 km/h, 80 km/h and 100 km/h respectively. The results revealed that with a travel speed of 80 km/h, the entire study area could be reached to meet the international standard of 4 minutes response time. The project proposed an emergency service delivery plan for the GNFS. It recommends that this project be adopted by GNFS to minimize delays in the delivery of emergency services in the country. GIS techniques would also aid decision making, improve efficiency and response time of emergency delivery agencies.

Keywords: Fire Outbreak, Emergency Service Delivery, Unplanned Communities, GIS, Network Analysis

1 Introduction

Rampant fire outbreak is an age-old challenge that has caused the ruins of many homes, properties and industries. This is a global hazard that has transcended the boundaries of several generations threatening the very survival of humanity. Fire outbreak is a major concern confronting many developed and developing countries (Nisanci, 2012).

In Ghana for instance, fire outbreaks have become a yearly plaque that char homes, markets, factories, offices and cause the death of a substantial number of lives. Between 2006 and 2012, 255 lives and properties worth millions of Cedis were lost through rampant fire outbreaks. The Ghana National Fire Service (GNFS), the agency mandated to fight fires in Ghana, however, has a challenge executing its duties with a poor response time of 12½ minutes as against 4 minutes required by international standards (Oppong *et al*., 2017).

The cause of delays on the part of the GNFS is largely attributed to the following factors: lack of appropriate logistics to fight fires, poor collaboration with its major stakeholders, inaccessibility to fire sites, inadequate training facilities and inability of GNFS to carry out fire risk assessment prior to operations (Oppong *et al*., 2017).

To reduce the response time of the GNFS, this study proposes an effective service delivery system to facilitate rapid service delivery in the study area. This study is significant as response time is key to firefighting and rescue missions. The swiftness in response time is a determining factor between saving or losing of lives and properties. It is therefore necessary to replace the conventional approach adopted by GNFS with a technological and innovative driven technique. Geographic Information Systems (GIS) is an efficient technological tool that supports planning, preparedness, mitigation, response, and incident management. GIS helps to improve various aspects of fire emergency services such as pinpointing and determining routes to fire outbreak sites, and resources to be deployed to such sites (Greene, 2002). GIS technology has been found helpful in all phases of fire emergency planning, management and decision making (Akay and Aziz, 2015).

GIS has been applied in solving and mitigating challenges facing fire services across the world. For instance, designed a spatial database for queries and network analyses to map accident risk zones required for emergency response. The system also provided information about the locality of the emergency as well as direction to the place. Nisanci (2012), also designed a GIS based system capable of locating fire hydrants and fire sites. Dynamic

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fire maps were produced from that study for use by the fire service in Turkey. Akay and Aziz (2015), employed GIS decision support system to determine the fastest routes to fire outbreak sites in the forests of Erbil city. Similarly, Mali and Mane (2013), used GIS to find the optimal routes and service areas for better emergency service delivery service. Furthermore, Forkuo and Quaye-Ballard (2013) used GIS to determine the optimal routes for use by the GNFS in a pilot project at Kumasi, Ghana. These studies demonstrate the expediency of GIS technology in firefighting and emergency service delivery. However, little effort was made to develop a system to help reduce time of emergency response delivery. This study therefore proposes an emergency service delivery system for the GNFS that would enable them comply with the international service delivery response time of four minutes.

2 Resources and Method Used

2.1 Resources Used

Tarkwa is a mining town in the western region of Ghana and the capital of Tarkwa Nsuaem Municipality. The Municipality has an estimated total land area of 3 783.64 km^2 (Kumi-Boateng *et al*., 2012). It shares boundary with Prestea Huni-Valley District to the north, Nzema East District to the west, Ahanta West District to the south and Mpohor Wassa East District to the east. Tarkwa is located on latitude 5º 18′ 00″ N and longitude 1º 59′ 00″ W with topographic elevation of about 78 m above mean sea level (Peprah *et al*., 2018) (See Fig. 1). The land use may be classified as largely industrial, with a projected population of about 116 406 (Anon., 2010a). It has one fire station and eleven fire hydrants that are widely distributed at vantage sites in the municipality. Between 2012 and 2016, an average of 34 fire outbreaks were reported annually in the study area with over 65% of these fires attributed to domestic sources. Other causes of fire outbreak in the area are from industries, commercial vehicles, bush fires, accidents and electrical sources. Fig. 2 shows statistics of fire outbreaks in the Tarkwa Nsuaem Municipality.

Like other municipalities in Ghana, there are approved planning scheme for some parts of the Tarkwa Nsuaem municipality whereas other parts are unplanned. The unplanned communities are characterized by haphazard development of buildings and inaccessible by road (Chitrakar *et al*., 2016).

Materials used for this project include georeferenced high-resolution satellite image, topographic map of the study area obtained from the Surveying and Mapping Division of the Ghana Lands Commission and ArcGIS software

2.2 Methods Used

2.2.1 Network data Creation and Classification

The roads in the study area were digitised, classified and assigned travel speed. The travel speed for urban roads on which fire tenders mostly commute in Ghana was initially adopted (*i.e.* 30 km/h to 50 km/h) (Anon., 2010b). To build network dataset for this study, road lengths and drive time were computed. Vehicle speed of 50 km/h, 80 km/h and 100 km/h respectively were used in the computation of the drive time which then served as the impedances for the analysis of the fastest routes and service areas. This process was carried out as travel speed is crucial to emergency service delivery (Xia *et al*., 2017). The travel speed of an emergency vehicle depends on several factors. For example travel distance, road condition, traffic condition, weather condition, experience of the driver and the type of the vehicle used (Claridge and Spearpoint, 2013).

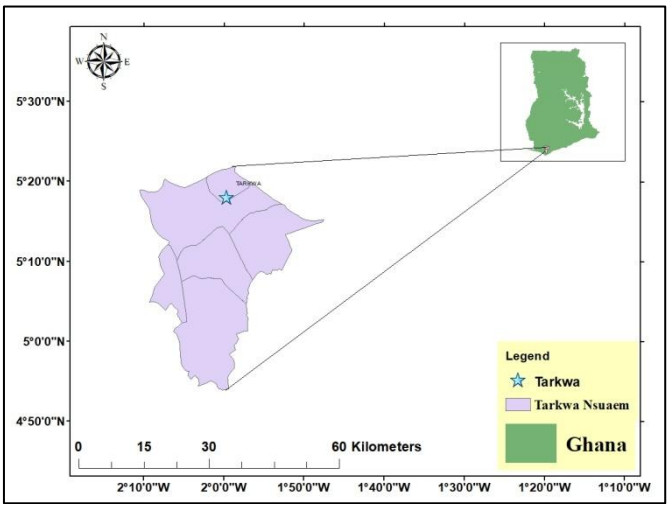

Fig. 1 Study Area Map

In this study, the different travel speeds were used to assess the impact of travel speed on the efficiency of service delivery by the GNFS in particular. This also demonstrated generally, how crucial travel speed is in emergency service delivery (Xia *et al.*, 2017).

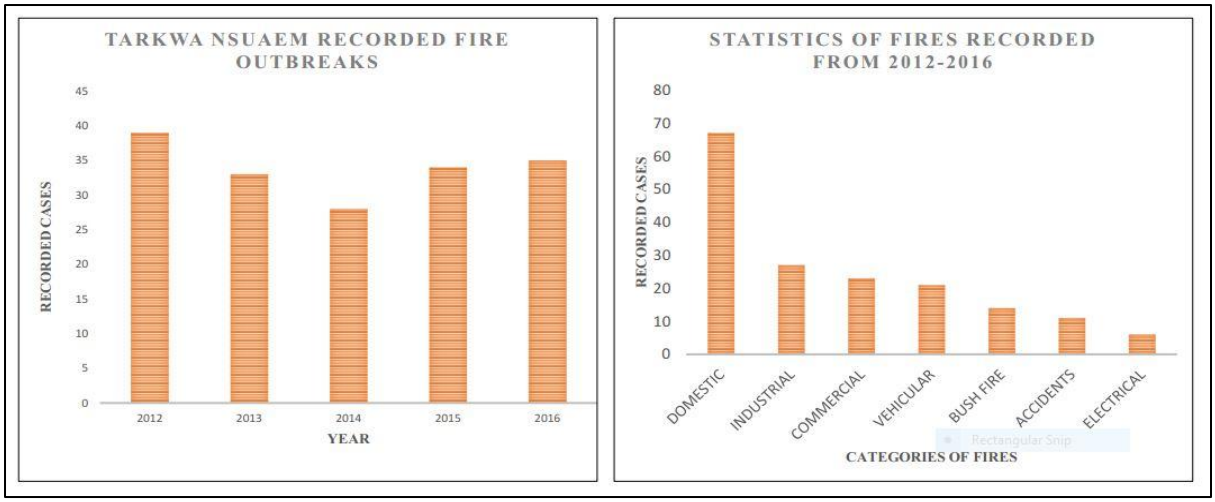

Fig. 2 Statistics of fire outbreaks in the Tarkwa Nsuaem Municipality (source: Tarkwa Fire Service Station)

2.2.2 Site Selection for Fire Hydrants

To effectively combat fire in crowded areas of the study area where accessibility is poor, suitable sites for construction of fire hydrants were proposed in open spaces. Factors considered were closeness of the suitable site to community centre (s) as well as the size of available open spaces. The nearer the open space is to the center of the community the greater the number of buildings that could be served by the hydrant. As such, open spaces within crowded communities in the study area were identified and digitised from geo-referenced high-resolution image of the study in an ArcGIS environment. Also, the centers of the communities were identified and digitised with the help of central feature tool in ArcGIS.

2.2.3 Neighbourhood Suitability Analysis

To ensure availability of required resources to combat fire in each community of the study area, suitability model was developed. Weights were assigned to the open spaces based on their proximity to the crowded community centre. This method was adopted to ensure that selected sites have ample space to serve as stations for fire hydrants and also located close to the community centre. The selected open spaces for the fire hydrants together with the community centre feature were fed into the model builder in Arc GIS. Through the process of buffering, reclassification of the input features and weighted overlay operation the final outcome was obtained (see Fig. 3).

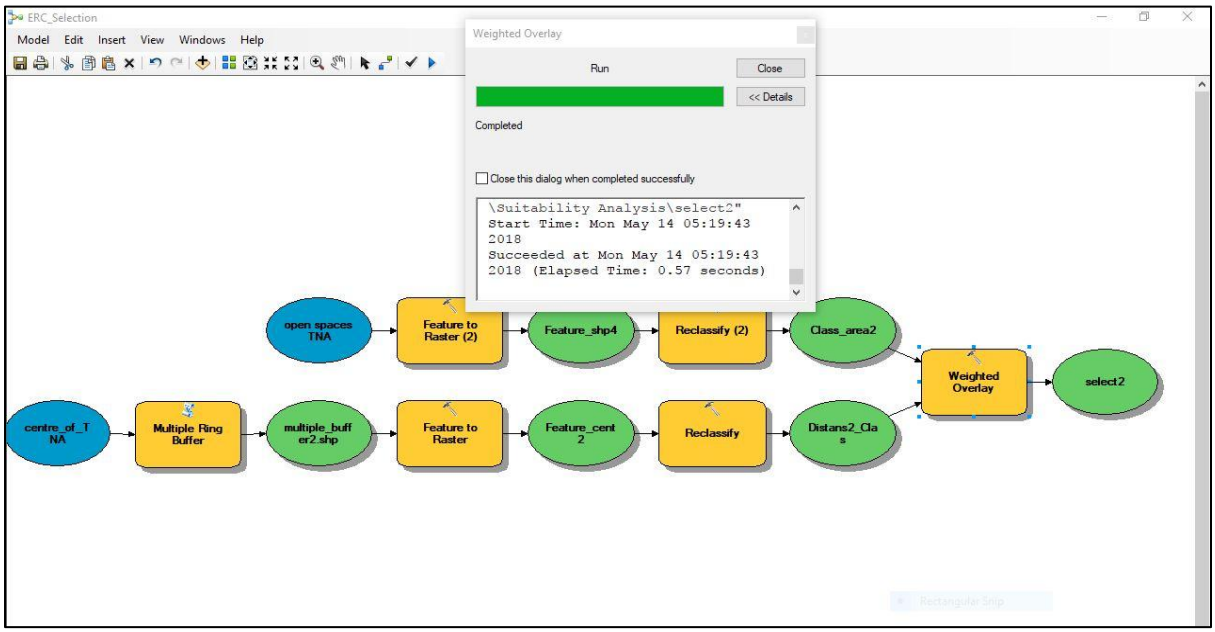

Fig. 3 Suitability Model Built in ArcGIS for the Analysis

2.3.3 Building of a Network Analyst Dataset

A network analysis dataset was built from the road data captured and their attributes. The vehicle speed of 50 km/h, 80 km/h and 100 km/h respectively used in the computation of the drive time also served as the impedance to determine the fastest routes. Based on the network dataset built, a service area layer was created to analyse a four-minute service area for the fire station in the study area.

3. Results and Discussion

3.1 Suitable Sites for Fire Hydrant

Fig. 4 shows the outcome of the developed model for selecting sites suitable for fire hydrants in the unplanned communities. The areas shaded green in Fig. 4 shows open spaces that could be used for construction of fire hydrants in the unplanned communities in the study area. Since such communities lack access roads for fire tenders this intervention would give firemen opportunity to access the communities on foot so far as they would have access to water and facility to fix their fire hose. More lives and properties could be salvaged in case of fire outbreak with this intervention.

3.2 GIS Network Dataset and Scenarios

Fig. 5 is a map showing the fastest route generated from the Tarkwa fire station to a selected fire site *i.e.* UMaT Library as a test case of fire spot. The selected route in blue (Fig. 5) indicates the fastest route in terms of travel time to reach the fire spot.
Figs. 6-8 show different scenarios of extent of service area to be covered by fire tenders within specified time intervals (1 to 4 minutes) at travelling speed of 50 km/h, 80 km/h and 100 km/h. From Fig. 7, it is observed that travelling at 80 km/h the entire communities could be reached within four minutes service time. At a travel speed of 100 km/h, almost the entire communities could be reached in three minutes travel time (Fig. 8). It is also evident from Fig. 6 that the entire central business area of Tarkwa falls within the service area that could be reached under three minutes at 50 km/h. However, large communities remained outside the service area within 4 minutes travel time at a speed of 50 km/h. For safety purposes, travelling at 80 km/h for emergency service delivery vehicle in the study area is laudable as the desired service area would be covered on condition that roads are motorable.

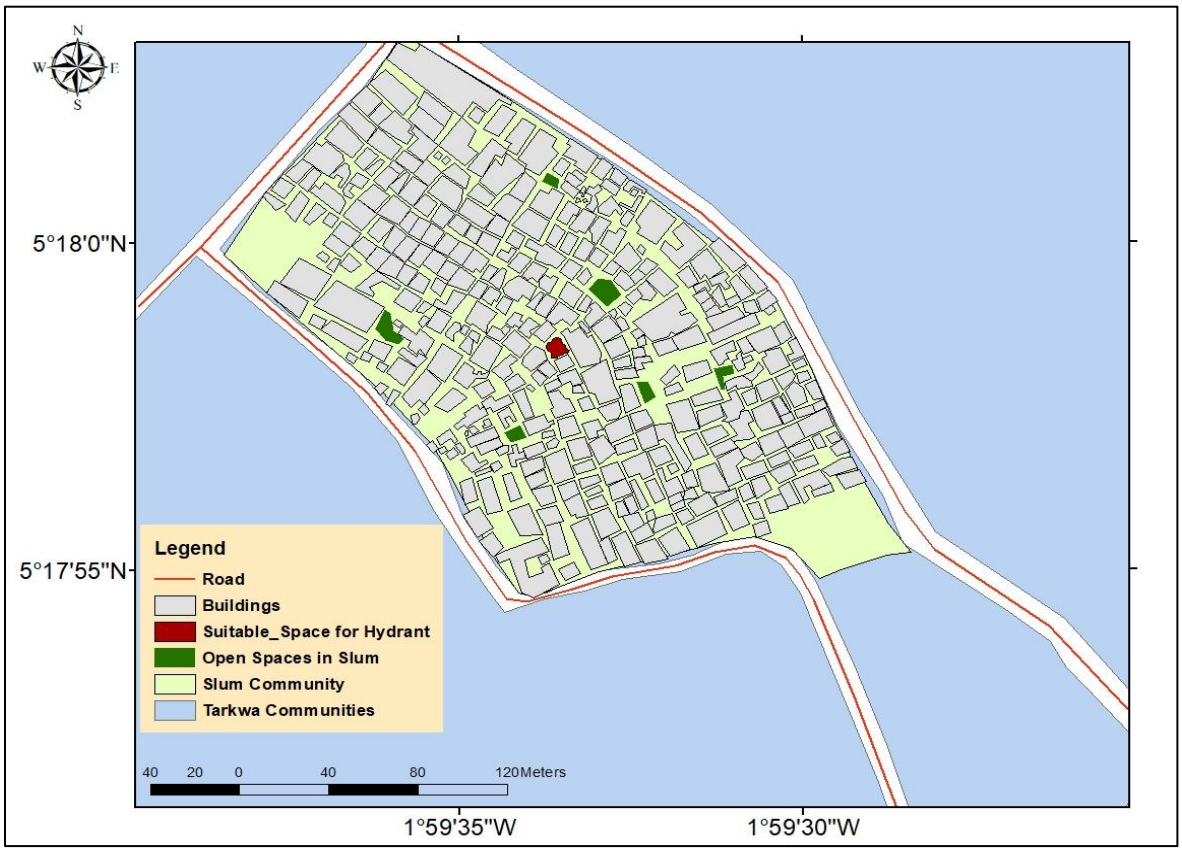

Fig. 4 Selected Location for Fire Hydrant in a Crowded/Inaccessible Community

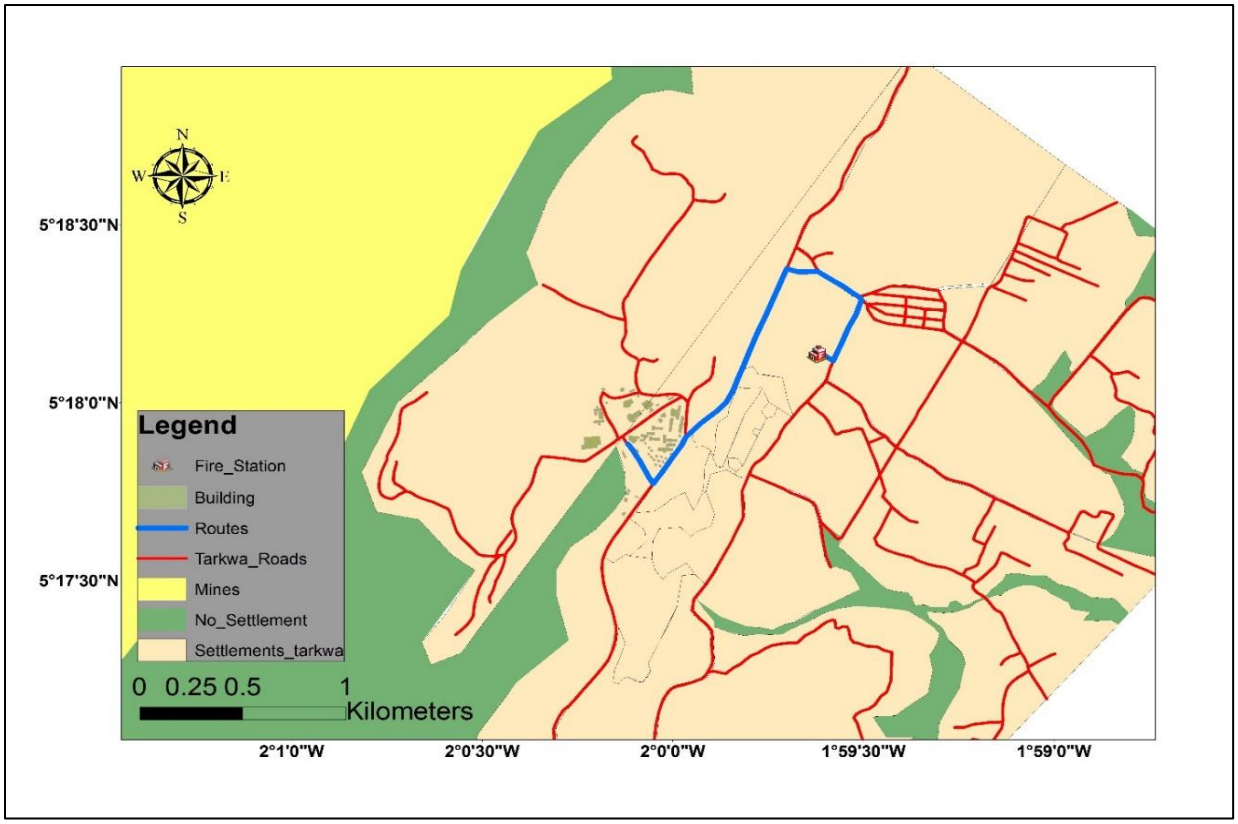

Fig. 5 Fastest Route from Tarkwa Fire Station to UMaT Library

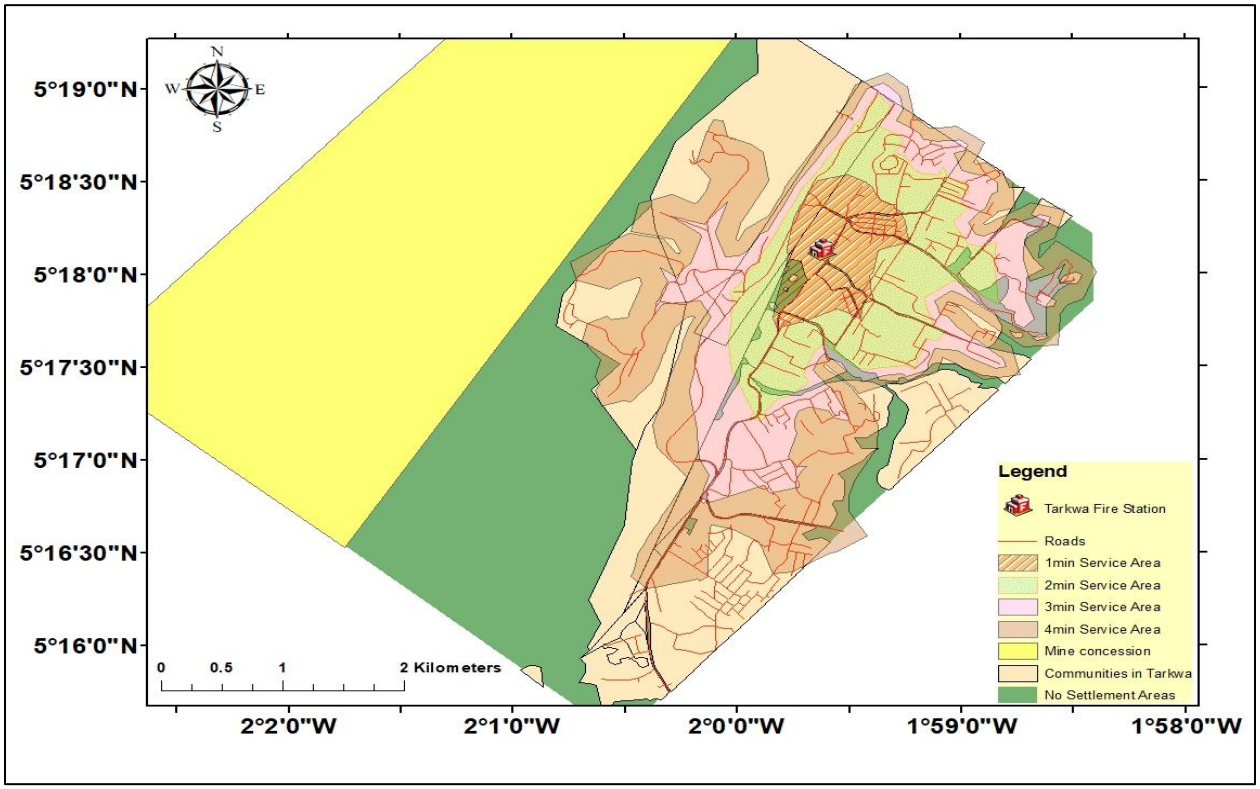

Fig. 6 One, Two, Three and Four Minutes Service Areas at 50 km/h from the Tarkwa Fire Station

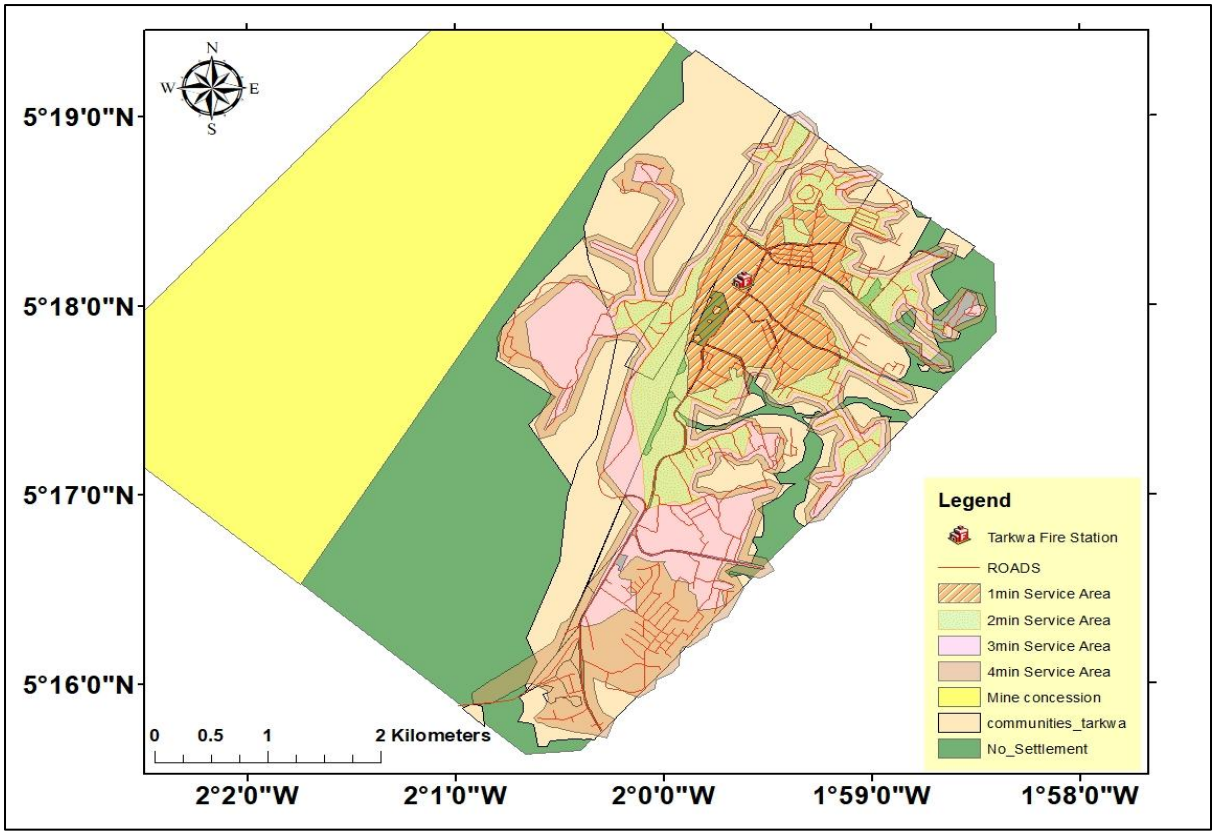

Fig. 7 One, Two, Three and Four Minutes Service Areas at 80 km/h from the Tarkwa Fire Station

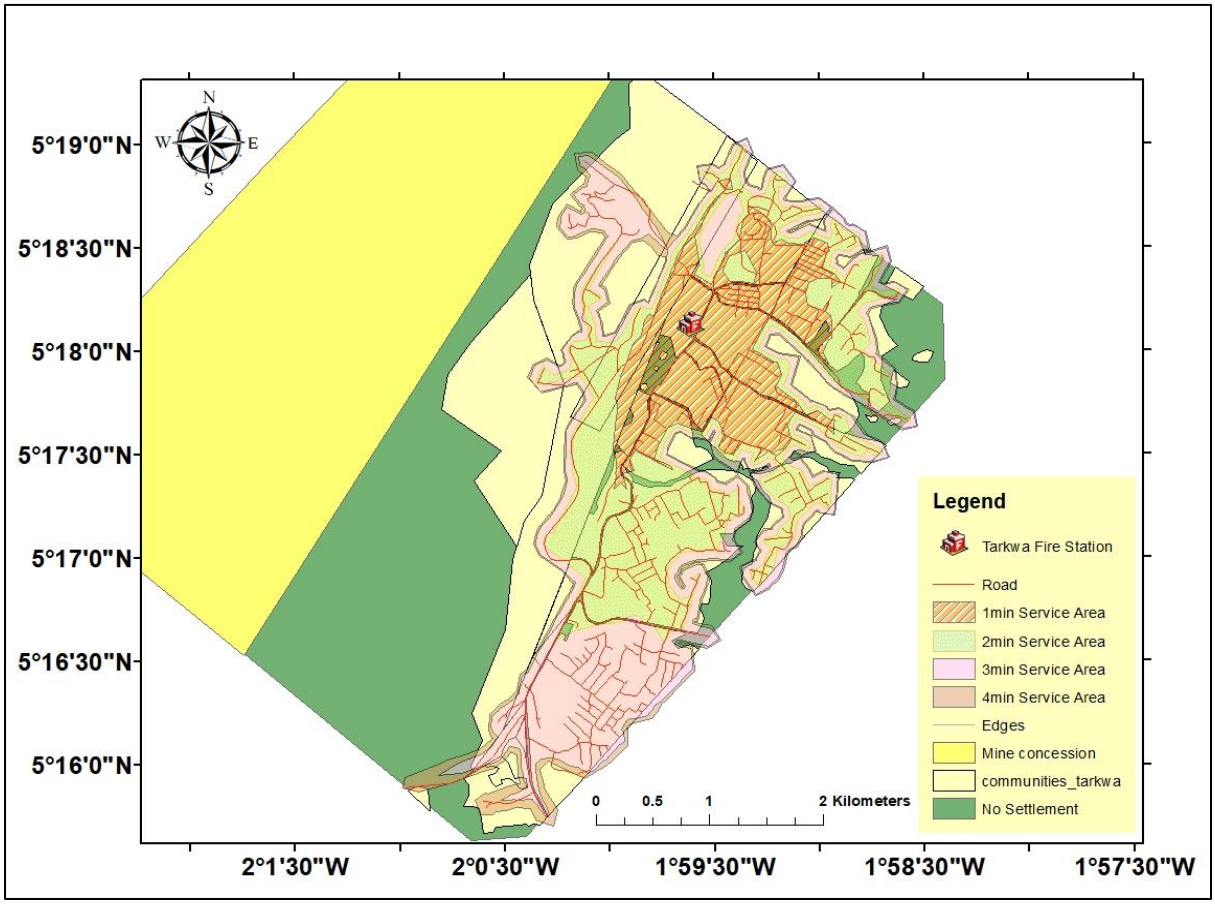

Fig. 8 One, Two, Three and Four Minutes Service Areas at 100 Km/h from the Tarkwa Fire Station

3.3 Propose Strategy for Firefighters

As information on fire outbreak sites are indispensable in planning an emergency service delivery, a GIS application with updated database on buildings characteristics (*e.g.* number of storeys, uses *etc.*) and hyperlinked to the respective digitised building features is proposed. This is to aid quick retrieval of information during emergency situations. Such database would help firemen infer the possible cause of fire, class of fires, and consequently aid in deciding the apt logistics and fire quenching materials to help fight the fires. This would help avert situations where GNFS get to fire scenes to find themselves incapacitated. Fig. 9 is a result showing a retrieved hyperlinked building data. An emergency service delivery plan/strategy which indicates the steps to be taken from the time emergency call is received to the time the firemen are dispatched to of fire spots. The steps include a query in ArcMap to locate the exact building or property on fire, retrieval of buildings data, query to determine the nearest fire hydrant to the fire outbreak site and the generation of the fastest route map to the fire spot for the firefighters. Fig. 10 shows the emergency service delivery plan developed.

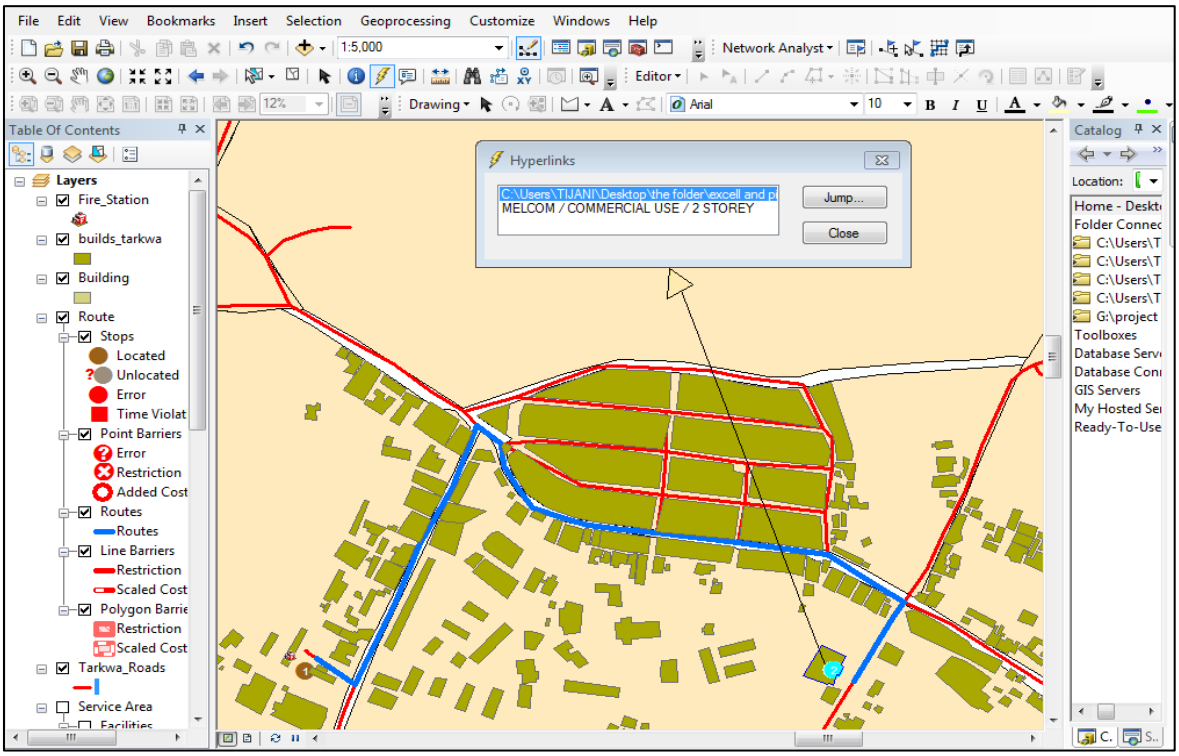

Fig. 9 Retrieved Building Data (Melcom)

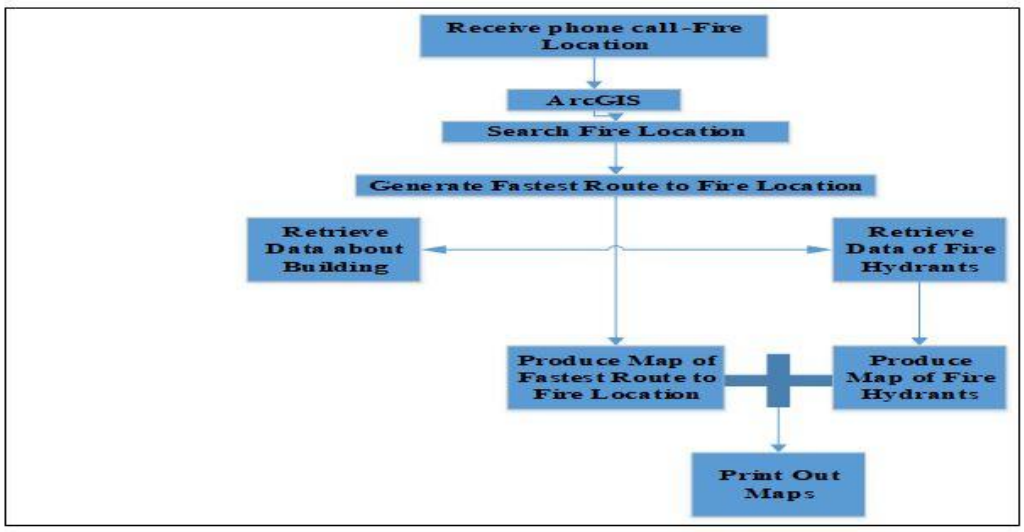

Fig. 10 Emergency Service Delivery Plan

4. Conclusion and Recommendations

This study has proposed suitable open space for the construction of fire hydrant to facilitate firefighting operations in inaccessible parts of the study area. This mitigation measure is to make inner communities accessible to firemen in order to save more lives and property in the event of fire outbreaks. A network dataset has been designed for determining the fastest routes to fire spots and also for determining service area at given time intervals and travel speed. It can be concluded that the international responds time of 4.5 minutes is feasible in the study area if the proposed strategy is adopted. Nonetheless, addition time of preparation time (2 minutes) may be required for effective service delivery. It has been found that a travel speed of 80 km/h is appropriate to provide service over the entire area of the study area. In addition, an emergency fire service delivery plan/strategy has been developed. Albeit Tarkwa is the study area for the study, on analyzing the results, it is suffice to say the project could be implemented by all the fire stations across the country, Ghana.
It is recommended that the road network in most parts of the country be improved to help realise the full potential of the mitigation measures proposed in this project.

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