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Network Analysis of Road Traffic Crash and Rescue Operations in Federal Capital City

Mamman Saba Jibril, David Sesugh Aule*, Badiatu Danladi Garba, Taye Oluwafemi Adewuyi

Department of Geography, Nigerian Defence Academy, Kaduna, Nigeria
Email: *auleds@yahoo.com

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Abstract

Abuja is witnessing an upsurge of victims from Road Traffic Crash (RTC) which is mostly due to the attendant rapid increase in the volume of vehicles, traffic jams, bad driving, over speeding, insufficient road signs and bad conditions of vehicles that ply the roads. The problem is compounded by a lack of early emergency response. Geographic Information System (GIS) based travel time model was applied in the street network analysis to identify RTC black spots that are outside the close reach of Federal Road Safety Commission (FRSC) rescue points/health facilities in Federal Capital City (FCC). Five minutes, Ten minutes and Fifteen minutes travel times were used as the impedance factor. Remote Sensing and GIS techniques were used to carry out network analysis. This was achieved by conducting the closest facility operation in the ArcGIS network analyst extension using the time of travel from each FRSC zebra point location to the RTC black spot zones/health facility. The results were presented on road network maps and bar graphs. The areas where quick response and medical facilities are insufficient were identified. It was concluded that the available health centres can sufficiently service RTC black spots in FCC, but the FRSC zebra points are insufficient which renders rescue operations inefficient and thereby exposes RTC victims to more danger. In order to ensure that there is sufficient coverage for response times, it was suggested that additional zebra points be created.

Keywords

Network Analysis, Health Facilities, Zebra Points, RTC, GIS, FCC, Remote Sensing

1. Introduction

1.1. Background of the Study

Motorization has enhanced the lives of many individuals and societies, but the

benefits have come with a price [1]. In the developing world, the burden of road traffic injury is rising substantially. Injury and deaths due to Road Traffic Accidents (RTA) are a major public health problem in developing countries where more than 85% of all deaths and 90% of disability-adjusted life years were lost from road traffic injuries [2]. The 2018 global status report on road safety also projects road traffic injuries to rank seventh in the global causes of death by 2030. In 2018, World Health Organization (WHO) reported that Africa accounts for about 16% of global road fatalities [2]. According to [3], every year the lives of approximately 1.3 million people are cut short as a result of road traffic crashes [3]. More than 90% of road traffic deaths occur in low and middle-income countries. This challenge is endemic among the developing nations of Africa. Similarly, the WHO reported that road traffic death rates are the highest in the African region.

In Nigeria, Federal Roads Safety Corps (FRSC) reports that about 69,941 crashes were recorded on Nigerian roads from 2011-2016, resulting in 35,179 fatalities [4]. The trend is alarming and is constantly leading to a frightening situation from one geopolitical region to another. The risk factors include speeding, driving under the influence of alcohol and other psychoactive substances, nonuse of motorcycle helmets, seat belts, child restraints, distracted driving, unsafe road infrastructure, unsafe vehicles, use of phone while driving, inadequate post-crash care and inadequate law enforcement of traffic laws among others.

In an era of continuous growth in mobility and demand for transportation, safety is an issue of major social concern necessitating the search for methods or alternatives that ensure safe, efficient, and faster means of transport [5]. This is also true in a country like Nigeria, where cities like Abuja, Lagos, Kano and all the other major cities are experiencing continuous growth in terms of population and built-up areas. Among the three morphological entities that form the city (road network, parcels and buildings, road layout is the most permanent over time [6]. The cities being the hub of business activities are facing ever-increasing vehicular movement, which results in multifaceted traffic problems such as RTC and peak hours' congestion among others. These situations, particularly emergency situations arising from RTC demand a method that can ensure speedy attention to victims. Immediate medical attention in such circumstances saves valuable human lives. Analysis and modeling research works can be conducted on road networks to analyze their growth mechanisms [7] [8].

In the search for a lasting solution to this challenge, the United Nations General Assembly in 2010 launched "The Decade of Action for Road Safety (2011-2020)" with the stated goal to "reduce road traffic deaths and injuries by 50% by 2020." Similarly, this study is embarked upon with a view to identifying RTC black spots that are outside the close reach of FRSC rescue points/health facilities, in order to suggest points for the creation of new black sports and ensure wider coverage for rescue operations in the area. Remote Sensing and Geographic Information System (GIS) play a vital role in proximity analysis, transportation and urban planning applications [9] [10] [11]. GIS can be applied to infrastructure

management, fleet/logistics management, and Transit management as well as provide solutions to traffic congestion [12].

This research focuses on network analysis of RTC black spots, FRSC zebra points and emergency health care facilities in Nigeria's Federal Capital City (FCC). The findings of the study will be useful for both policymakers and the FRSC rescue team in their continued efforts to ensure safe road transportation in the FCC. The study is limited to Federal Capital City. It involved the collection of RTC black spots from FRSC for 2011-2012 and subsequent identification of coordinates of the RTC black spots, FRSC zebra points and medical facilities in the study area. Steps were also taken to examine coverage time for emergency response through the use of network analysis, with a view to determining measures that can be used for effective emergency response in FCC. However, this analysis where limited because traffic delay data from the Police was not available.

1.2. Statement of Research Problem

Abuja is witnessing an upsurge of victims from RTC which is mostly due to the attendant rapid increase in the number of vehicles, traffic jams, bad driving, over speeding, insufficient road signs and bad conditions of vehicles that ply the roads. Many studies posit that this problem is common in most cities [13] [14] [15] [16]. The problem is been compounded by a lack of early emergency response, which can be attributed to the inadequate number of emergency health care facilities, inadequate emergency response facilities, and routing problems among others [12] [17].

According to Federal Road Safety Commission (FRSC), road accident figure has increased by 22 percent in the first half of 2013 with April going down as the bloodless month, and the increase is largely due to poor response to accident victims by the public, the proximity of medical facilities and organizational problems [18]. Similarly, the contribution of RTC to the National death burden rose from 38.9% in 1967 to 60.2% in 1974 and 25% in 2012 [19]. The deadliest accidents in the country occur on Federal Capital Territory (FCT) roads, due to bad driving rather than bad roads [20] [21] [22]. An early emergency response approach can reduce this toll. The early response includes rescue operations and medical services. Unfortunately, the distances and travel times from some accident sites to the emergency health care facilities can be significant; similar is the quality of services from the FRCS zebra points (emergency ambulance post)/police post to accident sites.

This is indicative of the need for measures that can be used for effective emergency response in FCC. However, this problem can be reduced if RTC black spots are identified mapped and analysis of the spatial relationship between these black spots, health facilities and zebra points is carried out with a view to identifying areas where quick response and medical facilities are insufficient. This study purposes to achieve this using rescue operations and medical services. It is against this backdrop that this research work studied the spatial network of RTC black spots and emergency health care facilities in FCC through the ap-

plication of geospatial techniques so as to enhance rescue operations and save lives.

2. Materials and Methods

2.1. Study Area

The entire Federal Capital Territory is located between latitude 8˚25' and 9˚25' north of the equator and longitude 6˚45' and 7˚24' east of the Greenwich Meridian (Figure 1). The Federal Capital City (FCC) is planned to cover an area of about 250 square kms, while the rest of the territory of the city region covers about 7750 square kms [23]. The FCC is currently the administrative Headquarters of the Federal Republic of Nigeria. It is made up of five districts namely: Wuse, Garki, Asokoro, Maitama, and Jabi districts [24]. The FCC is a subset of Abuja Municipal Area Council (AMAC) which constitutes the core area of this study, AMAC is made up of both built-up (planned) and rural (unplanned) areas, AMAC doubles as the headquarters of the Federal Republic of Nigeria (FRN) as well as that of the FCT, as it constitutes the economic, financial, trade and administrative center of the territory [25]. The bulk of federal institutions, ministries, and embassies are located within the confines of the FCC. Due to the slow pace of road reconstruction, many inhabitants of Abuja spend hours in traffic trying to get to work each day. About 75 percent of residents reside in the outskirts of the main city where all economic activities are located [26].

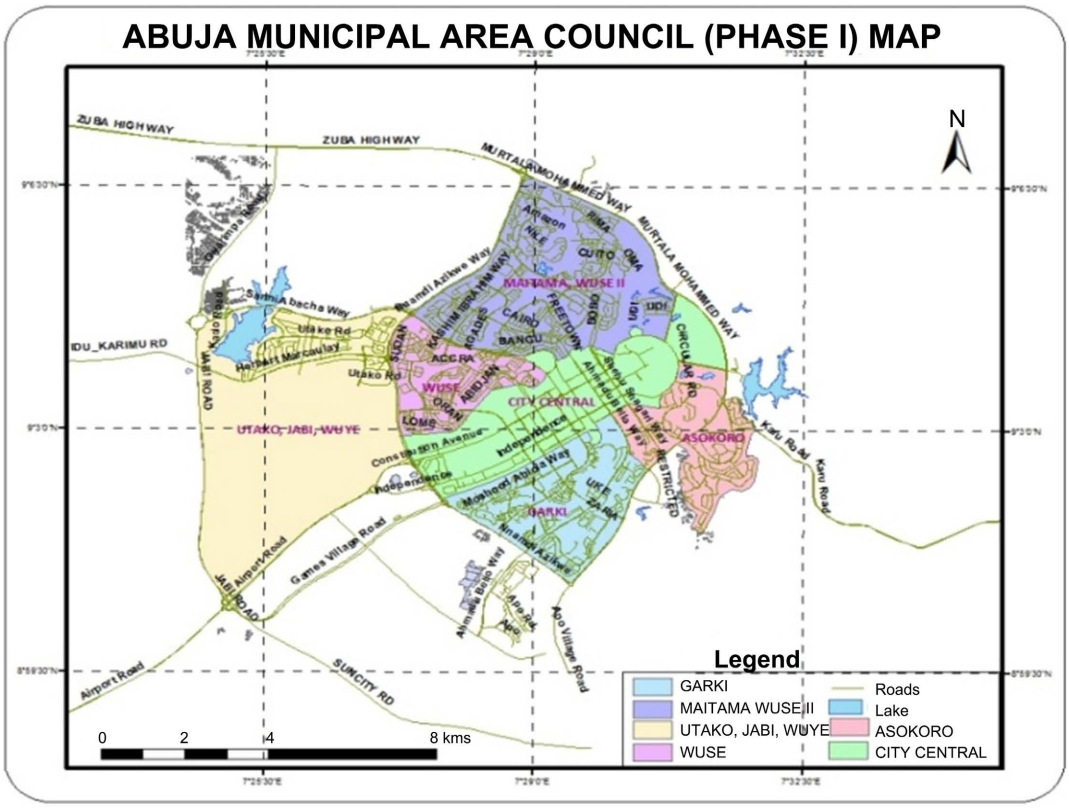

Figure 1. Federal capital city. Source: NARSDA (2012).

2.2. Data Source and Data Acquisition

The data used for this study were obtained from both primary and secondary sources. Primary data is the site survey. A site survey of the study area was carried out to obtain the coordinates of RTC black spots and zebra points collected from FRSC as well as hospital locations with the use of a GPS Map 76S Mark (GARMIN) for validation. This instrument was used to locate and pick coordinates in (Universal Transverse Mercator (UTM) usually in meters) of data in the study area. The secondary data includes data obtained via satellites and other cartographic devices and agencies. Hence, the data comprises of the source, description and types as summarized in Table 1.

List of 16 possible emergency health care facilities were obtained from FRSC which are: National Hospital, Garki General Hospital, Asokoro General Hospital, Wuse General Hospital, Gwarimpa General Hospital, Zankli Medical Centre, Lifeway Medical Centre, Fereprod Medical Centre, Winners Medical Centre, Ruz Medical Centre, State House Clinic, Amana Medical Centre, Abuja Clinic, Arewa Specialist Hospital, Sauki Private Hospital and Maitama General Hospital. A total of seventy RTC black spots obtained from FRSC and five zebra points locations obtained from FRSC in the study area are: Area 10 Old Parade Ground, Federal Secretariat by National Assembly, City Gate, Gwarinpa by Kubwa Express and Kugbo under bridge.

2.3. Image Interpretation Technique

The ArcGIS 10.0 software developed by Environmental Scientific Research Institute (ESRI) was used to display Nigeria Sat II imagery in three bands (Red, Green and Blue). The software was employed to combine the three bands to produce a true colour image of the study area (multispectral band) which enhanced the ability to visualize, identify and extract features from the imagery.

2.4. Data Projection and Geo-Referencing

The Nigerian Sat II, 2013 multispectral imagery covering the study area was projected to WGS 1984, Universal Transverse Mercator, Datum 100 Minna-Nigeria, Zone 32P via the data frame property of the software. The imagery was georeferenced by the collection of the X and Y coordinates of T-junctions (roads) and identifiable buildings via the use of Garmin global positioning System device

Table 1. Summary of data sources.

Data Type	Description	Source	Year
NIGERIAN SAT II IMAGERY	5 metres multi spectral	NASRDA	2013
Blackspots and coordinates	Area of high accident occurrence	FRSC/Field work	2011/2012
Zebra points and coordinates	Road safety emergency rescue centers	FRSC/Field work	2012
Emergency health care facilities and coordinates	Emergency health care facilities within FCC	FRSC/Field work	2013
Road network	Digitized from the satellite imagery	Field work	2013

during the field work (ground thruthing exercise). The points collected where then used to geo-reference the image. At the end of the geo-referencing exercise, an image clipping operation was performed using the ArcGIS 10.0 software in the arc toolbox to extract the area of interest. This was done to obtain a rectified map and to aid the visibility of the features to be digitized which include road network of the study area.

2.5. On-Screen Digitizing

This involves the digitizing process of converted geographical features from raster map into vector format; hence, a personal geo-database for each feature of interest was created in the Arc Catalogue of the ArcGIS software. The features created were projected to WGS 1984, Universal Transverse Mercator, Datum 100 Minna-Nigeria Zone and later imported into the ArcMap environment as shape files.

2.6. Data Base Creation, Feature Integration and Overlay

The creation of database was carried out after geo-referencing in Arc-Catalog, after which feature dataset and feature classes were fashioned out, they include: FCT Roads, Rivers, Built-up Area, Water Body, River Channels, FCT Boundary, and various Districts. Four layers were extracted from the satellite imagery via a digitization operation, hence the layers digitized include: FCT Roads, River Channels, FCT Boundary, and various Districts (Maitama, Wuse, Central Area, Asokoro, Garki, and Jabi) respectively. The roads include: B/4 City Gate, 3 Arm Zone, Sagari/Fikko/Area II, A Bello/Benue Plaza, Obasanjo, Karmo, Lifecamp, Durumi/Kado, etc. The diagram below (**Figure 2**) is the methodology chart of the study.

2.7. Network Analysis

The network analysis data for the operation include the RTC black spot, zebra points, emergency health care facilities and the road network. The digitized road network was verified and cleaned up for correction on digitization error via snapping of vertexes and planarization using the Arc tool box. The Integrate function tool was used to snap all lines together. Also, types of roads, driving distances of the road were determined when preparing the network dataset. Also, with the aid of the field calculator, the distance of each lane was calculated in respect to time (seconds). Fields created for the analysis include cost (road distance), speed limit of lane, delay and time in seconds.

The networking analysis operation was executed to determine the shortest distance from each RTC black spot to the nearest hospital location within the area as well as within time ranges of 5 minutes, 10 minutes and 15 minutes. This was achieved by conducting the closest facility operation in the ArcGIS network analyst extension whilst the distance and time of travel from each FRSC zebra point location to the RTC black spot zones within the same time frame.

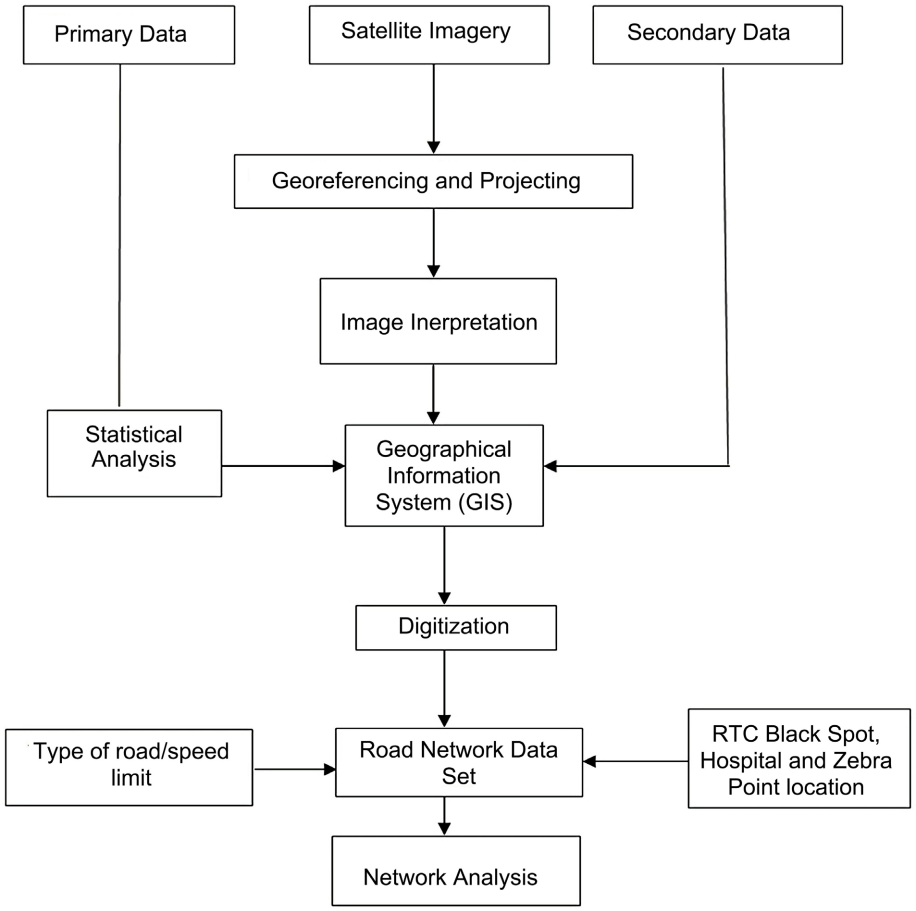

Figure 2. Methodology chart.

3. Results

This analysis was conducted to determine the time of travel from RTC black spot zones to emergency health facilities. The network analysis comprises of both connectivity reconstruction and network data set maintenance. Four features were relevant for the network analysis and they include the RTC black spots, emergency health care facilities locations, zebra points and road network route. The road network became the principal tool hence the road network data was first cleaned up to remove digitization error from each connecting node, making sure all points are snapped together to avoid ambiguity of error. The road network data set was converted from multi part to a single part poly line feature. The integrate tool was used to auto join nodes that are very close to each other. The network data set design for this research purpose was constructed with fewer restrictions, hence, U-turns and elevations were restricted for easy analysis. Therefore, the attribute fields created include: Name, Lane type, Speed limit and Cost (distance of Path in kms) with delay and seconds (time). While the Name, Lane type and speed limit were manually inserted into the attribute data. The delay can be calculated via CMS field ArcGIS, cost was calculated via the calculate geometry field while seconds were calculated using the field calcu-

lator.

3.1. Feature Integration

The zebra points, black spots and hospital coordinates obtained during the field work and from the Federal Road Safety Commission (FRSC) were first recorded into Microsoft excel document. It was then converted to the.csv file delimited format and subsequently imported into the ArcGIS software as longitude and latitude coordinates. Then it was converted to an event file and tied to the coordinate system of the data frame property and finally exported into the map layer as a shape file.

3.2. Feature Overlay

Spatial analysis of the remotely sensed data was done using the feature overly component of ArcGIS. This is the display of all data which comprise of the satellite imagery, road networks, districts, rivers, water bodies, zebra points, black spots and emergency health care facilities on a single map (**Figure 3**). The features displayed were subsequently used for network analysis via geospatial techniques.

3.3. Travel Time Distances from RTC Black Spots to Health Facilities

The closest facility analysis was performed to determine the distances and times

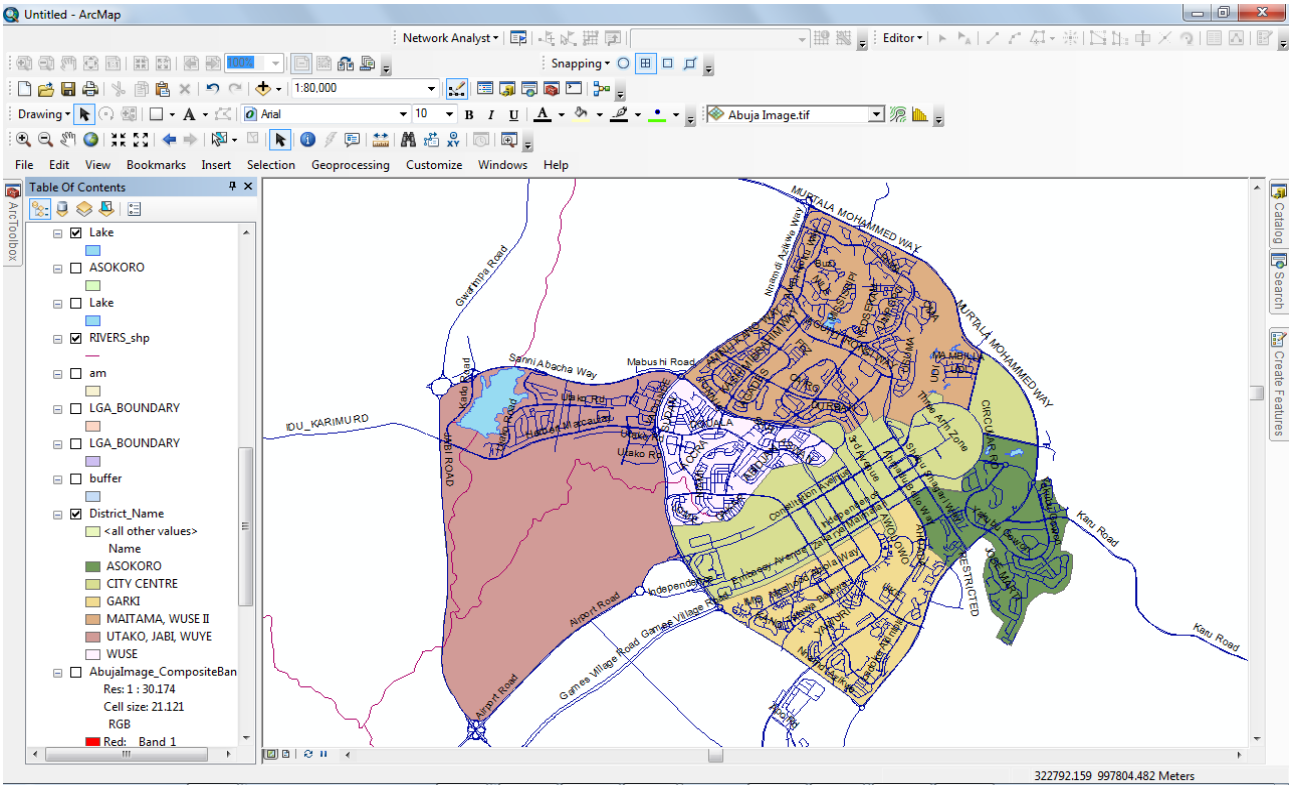

Figure 3. Overlay of digitized features on the study area. Source: Field work (2013).

of travel from the RTC black spots to the nearest emergency health facility centers. The NTHSA time frame of less than 30 munities of emergency response for victims that are not to be coded as dead at scene was adopted considering assumed average traffic delay of 10 mins. Therefore, nearest facilities within the time frame of 5 mins, 10 mins and 15 mins were routed as shown in Figures 4-6. Figure 4 shows medical facilities within 5 minutes to the accident spots using GIS visualization technique. The spatial network of health facilities visualized include Amana Medical Centre, Zankli medical centre, Fereprod medical centre, Sauki private hospital and Garki General Hospital.

Furthermore, Figure 5 uses geospatial technique to present the network of health facilities and RTC black spots that are within 10 minutes travel distance. The network comprises of Arewa Specialist Hospital, Zankli Medical Centre, Sauki Private Hospital, Amana Medical Centre, Fereprod Medical Centre and Garki General Hospital.

For the 15 minutes travel time, Figure 6 displays additional facilities which include Maitama General Hospital, Asokoro General Hospital, National Hospital, Wuse General Hospital, Arewa Specialist Hospital, Zankli Medical Centre, Sauki Private Hospital, Amana Medical Centre, Fereprod Medical Centre, Cruz Medical Centre and Garki General Hospital. The road network that interconnects the health facilities with RTC black spots include Mohammed Buhari Way, Shehu Yaradua Way, Tafawa balewa Way, Sani Abacha Way, Murtala Mohammed Express Way, Alex Ekueme Way, Gwarinpa Junction, Namdi Azikiwe Express Way,

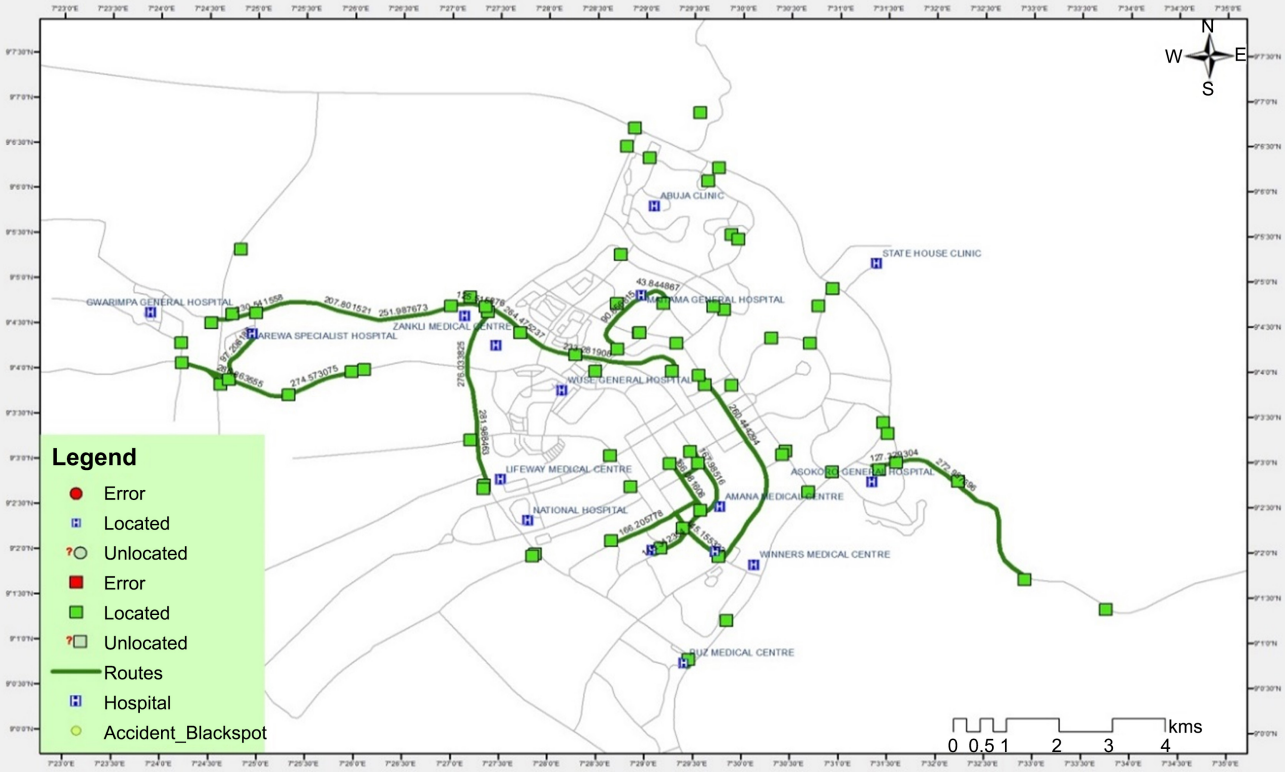

Figure 4. Network analysis: closest facilities within 5 mins from RTC black spots. Source: Field work (2013).

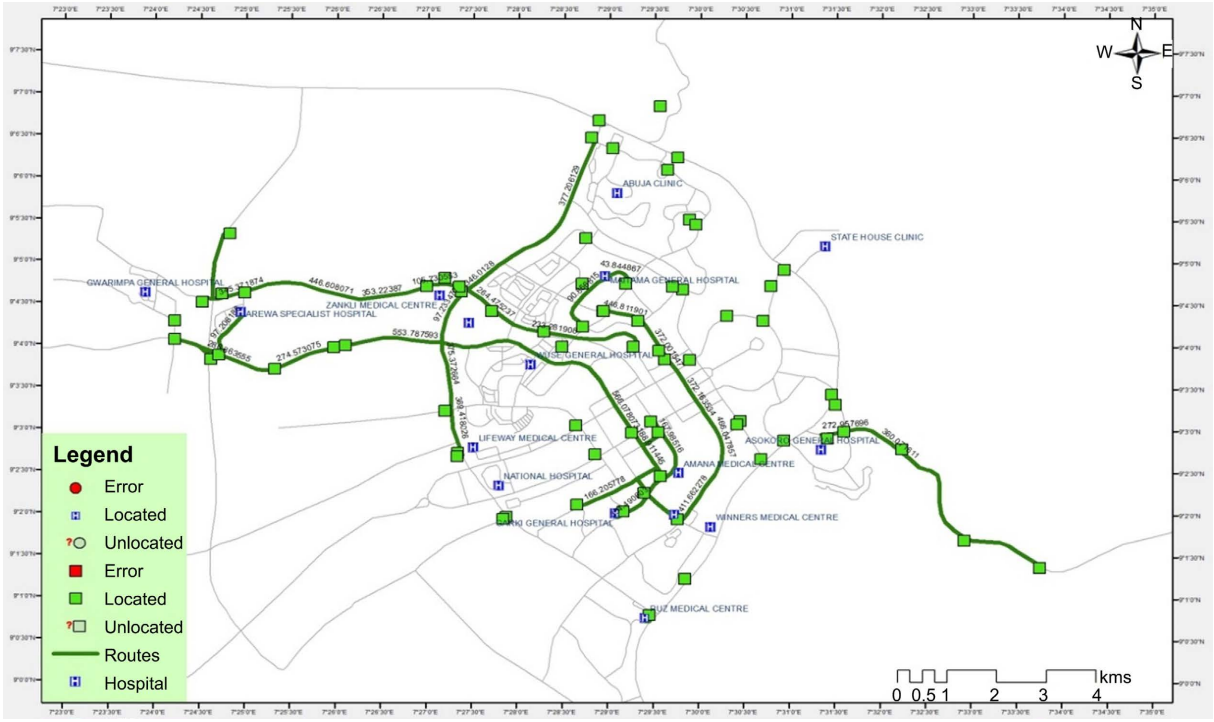

Figure 5. Network analysis: closet facilities within 10 mins from RTC black spot. Source: Field work (2013).

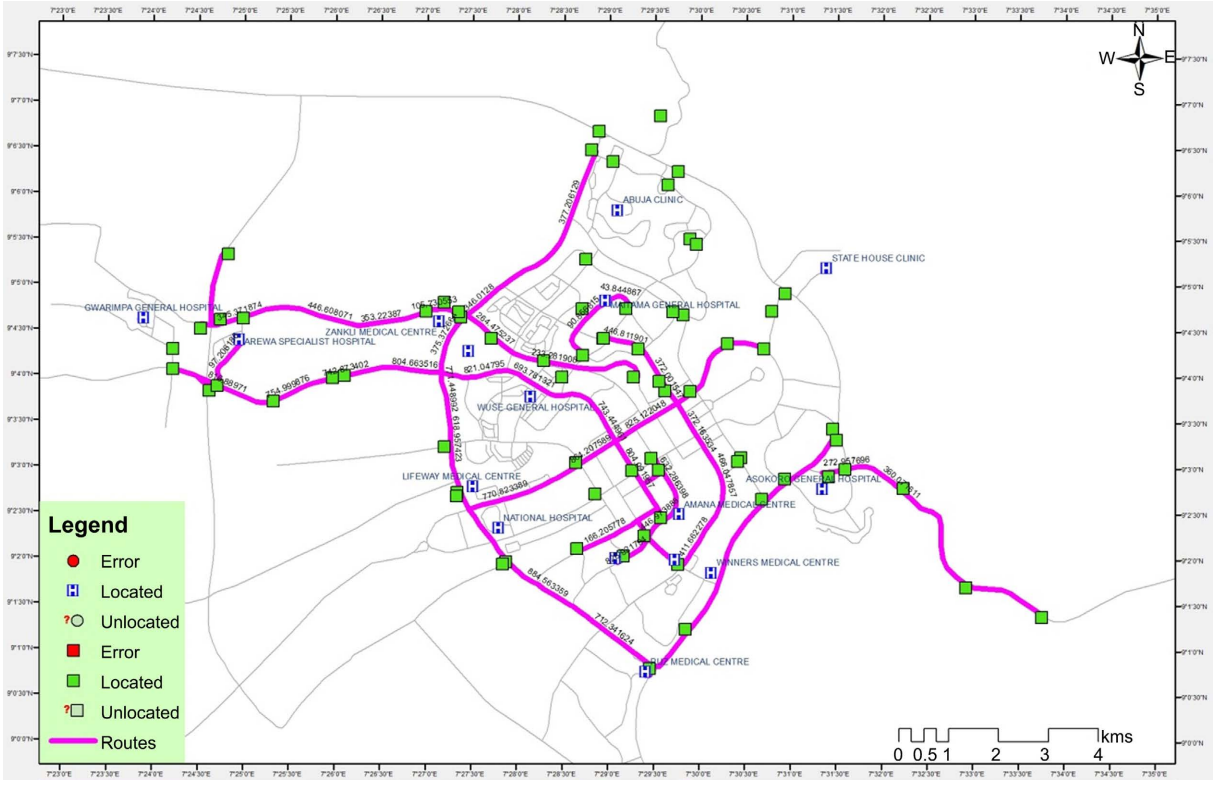

Figure 6. Network analysis: closest facilities within 15 mins from the RTC black spots. Source: Field work (2013).

Ahmadu Bello Way, location 9 and Life Camp Junction. This depicts the different route distance from each accident spot to the nearest facility using the closest

route in relation to time.

Emerging trend for 5 mins, 10 mins and 15 mins travel time indicates that the higher the travel time, the higher the number of emergency health facilities that can be accessed from RTC black spots. That is, time and distance are of upmost importance in terms of conveyance of RTC victims to emergency health facilities and saving life. This means that the health centers in the study area can sufficiently service RTC black spots in FCC.

3.4. Travel Time from Zebra Points to RTC Black Spots

The network travel time from FRSC zebra points to the RTC black spots was routed to determine the distance and time of response of these vehicles from their locations to the points of the RTC black spots. Figure 7 shows that within five minutes time frame, zebra vehicles at Area 10 old parade ground, Federal secretariat and Kugbo can conveniently navigate to some RTC black spots at Independent Avenue, Three Arms zone, Tafawa Balewa way, Muhammad Buhari way, Nnamdi Azikiwe road and circular road.

Figure 8 shows the routes traveled by the FRSC zebra vehicles between 0 - 10 minutes. Zebra points that can service RTC black spots within 10 minutes time frame include Area 10 parade ground, Federal secretariat, Gwarinpa by Kubwa

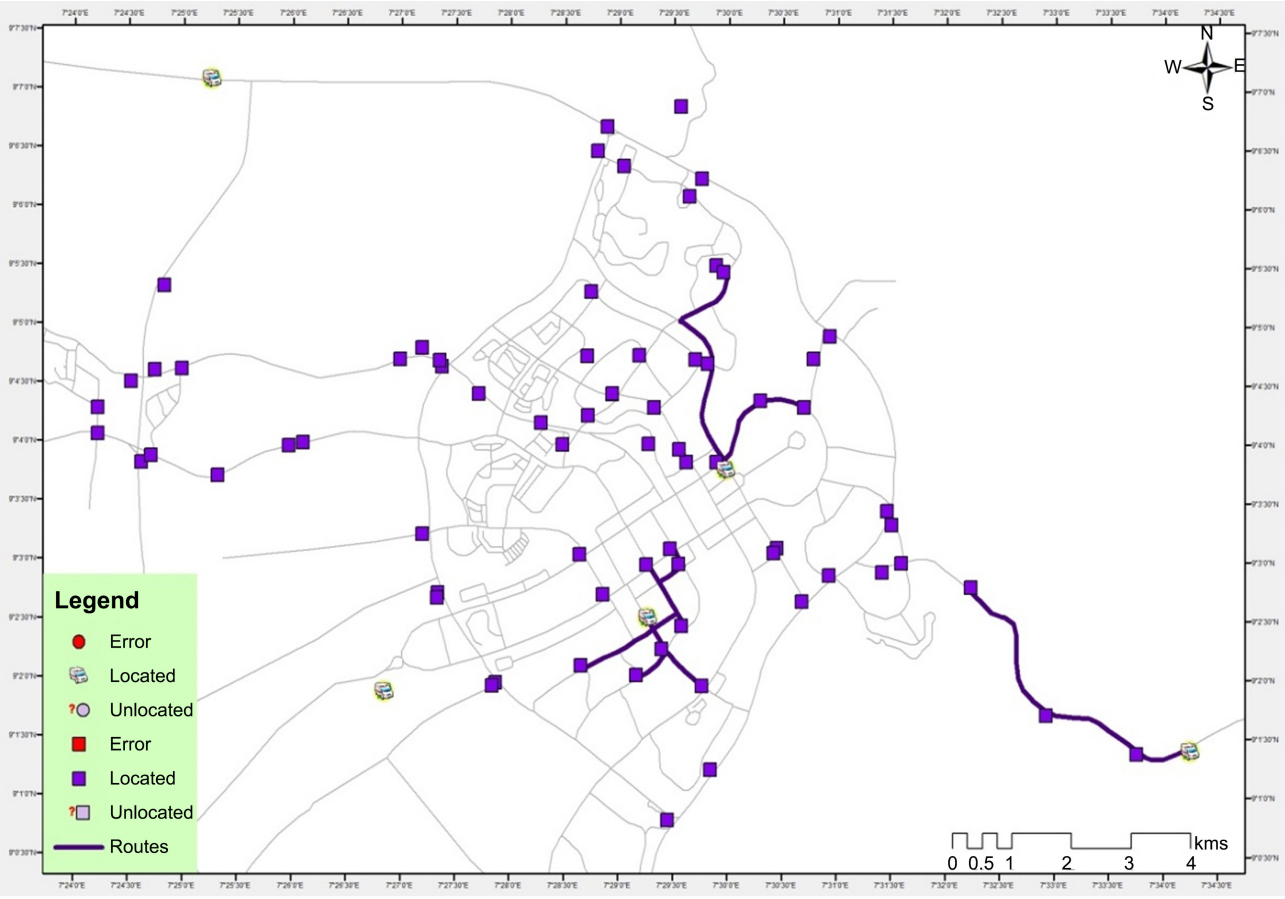

Figure 7. Network analysis: 5 mins drive from zebra points to RTC black spots. Source: Field work (2013).

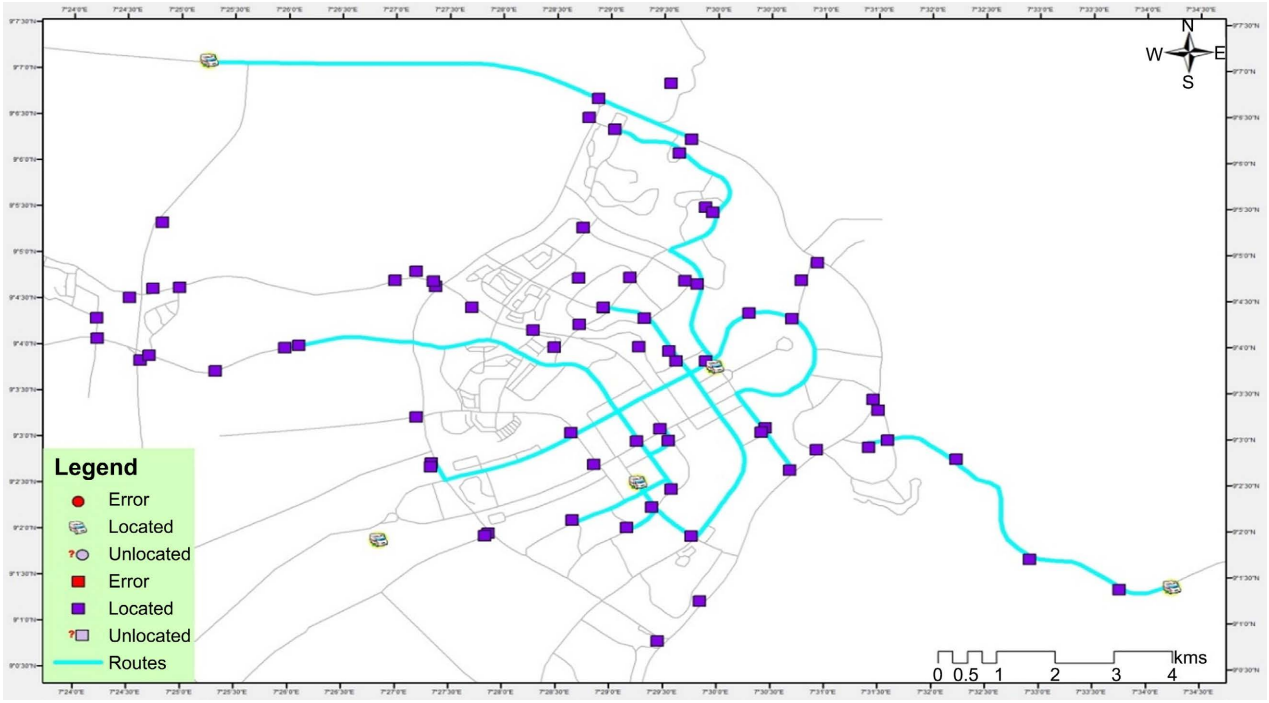

Figure 8. Network analysis: 10 mins travel time from zebra points to RTC black spots. Source: Field work (2013).

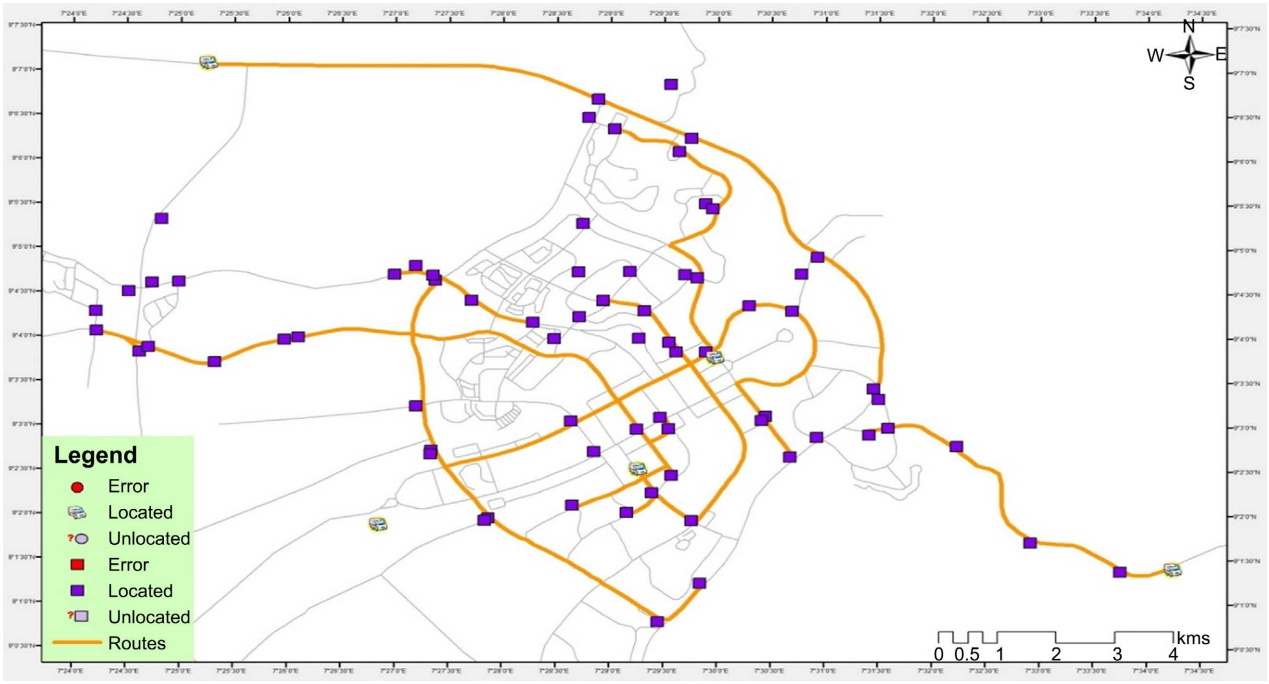

Figure 9. Network analysis: 15 mins drive from zebra points to RTC black spots. Source: Field work (2013).

and Kugbo. Routes covered by these vehicles include IBB Way, Tafawa Balewa Way, Limpopo Street, Circular Road, Nnamdi Azikiwe Express Way, Independence Avenue, Muhammad Buhari Way, Murtala Mohammed Way, Yakubu Gwon Way, Ahmadu Bello Way, AYA Round About and Obafemi Awolowo Way.

The 15 minutes' drive distances were analyzed from the zebra locations to RTC black spots. Result of the analysis displayed includes Shehu Yaradua Way, Sani Abacha Way, Life Camp Junction, IBB Way, Tafawa Balewa Way, Limpopo Street, Circular Road, Nnamdi Azikiwe Express Way, Independence Avenue, Muhammad Buhari Way and Murtala Mohammed Way, Yakubu Gwon Cresent, Ahmadu Bello Way, AYA Round About and Obafemi Awolowo Way. The routes can be accessed by FRSC rescue vehicles from federal secretariat by national assembly, Area 10 old parade ground, Kugbo and Gwarimpa.

Emerging trend for 5 mins, 10 mins and 15 mins travel time indicates that the higher the travel time the higher the number of RTC black spots that can be covered by FRSC vehicles from the various zebra points (**Figures 7-9**). That is, time and distance are of upmost importance in terms of coverage of RTC black spots rescue operations by action agencies. From the analysis above it is glaring that there is a wide gap in the distribution of zebra vehicles amongst districts. Wuse, Jabi and Maitama districts have no zebra vehicle along its routes and as well the city gate lies dormant except it will be allocated for the airport road which is not part of the study areas, therefore allocation of more zebra vehicles will be necessary.

4. Discussion of Findings

This study found geospatial network analysis very useful in identifying the origins of Road Traffic Crash (RTC) and determining the destinations of RTC victims for rescue services in the Federal Capital City (FCC), within the Federal Capital Territory (FCT). Network analysis is highly efficient in solving transport network problems. It has high potentiality in analyzing the closest facility and service areas in a transport network. In many cases, where distance is considered as impedance factor, it has been seen that the shortest route in terms of distance doesn't always mean the shortest one in terms of time. This research therefore, considered time as impedance factor, both for assessing the spatial relationship between RTC black spots and health care facilities as well as that between the former and FRSC zebra points. Five minutes, Ten minutes and Fifteen minutes travel times were considered to assess the duo in agreement with (Pour & Yue, 2012; Balogun, 2013).

The black spots representation indicates that RTC occurs mostly at intersecting roads or junctions of major roads in the Federal Capital City. Emerging trends indicate that the longer the travel time, the higher the number of emergency health facilities that can be accessed from RTC black spots and the higher the number of RTC black spots that can be covered by FRSC vehicles from the various zebra points. That is, time is of utmost importance in terms of coverage of RTC black spots rescue operations by action agencies and conveyance of RTC victims to emergency health facilities and saving lives. This implies that access to RTC black spots and emergency health facilities increases as the travel time increases. The road network also expands creating alternative routes to RTC black

spots as the travel time increases.

From the analysis, it is also glaring that the health centers in the study area can sufficiently service RTC black spots in FCC. However, there is a wide gap in the distribution of zebra vehicles amongst districts. Thereby confirming the assertion of Pasha (2006) that, the problem of time travel can be addressed if emergency health care facilities are spatially distributed which can be achieved through the combination of spatial and non-spatial data to derive meaningful information. Wuse, Jabi and Maitama districts have no zebra vehicle along its routes and as well the city gate lies dormant. Except it will be allocated for the airport road vehicles which are not part of the study areas, therefore allocation of more zebra vehicles will be necessary.

Although most accidents occur within the average travel time of 10 minutes of general emergency health care facilities, FRSC emergency response units are insufficient. It is obvious from the analysis that time is of essence in RTC accessibility to emergency facilities in FCC. This corroborates the findings of (Pour and Yue 2012) that time is a crucial factor in dealing with medical emergencies resulting from road traffic accidents. This Further indicates that, there is a creative and realistic graphical presentation of the RTC black spots where FRSC rescue zebra points and emergency health care facilities in the study area were overlaid using GIS software program (ArcGIS 10.0) to provide stakeholders with a better understanding of the RTC accessibility to emergency facilities. To apply the findings of Pour and Yue (2012), the study further analyzed the proximity of FRSC zebra points to black spots and from the black spots to health centers and as well determine areas that could be accessed within 5 mins, 10 mins and 15 mins travel time using speed limits and taking delay into consideration so as to establish the coverage of existing emergence health centers and rescue vehicles.

5. Conclusion

The research demonstrated that GIS and Remote Sensing can be used successfully in carrying out a network analysis of RTC black spots and emergency health centers. It also portrays the sufficiency of GIS and Remote Sensing in route optimization and carrying of accident victims by the FRSC response team. The work has developed a foundation for the analysis and presentation of the RTC emergency situation in the Federal Capital City using geospatial techniques by examining the spatial distribution of emergency health care facilities and zebra points as well as their proximity to RTC black spots with the logical conclusion that health centers in the study area can sufficiently service RTC black spots in FCC, but the FRSC zebra points are insufficient which renders rescue operation inefficient and thereby exposes RTC victims to more danger. It suggests the need for the creation of additional zebra points to ensure that there is sufficient coverage for response times.

Recommendations

In view of the foregoing, it is therefore recommended that:

1) The Federal Road Safety Commission should be staffed with trained professionals and be responsible for accident data surveillance and analysis.

2) More zebra points should be created to service areas found outside the zebra points 2 km response target.

3) Since passers-by are usually involved in RTC rescue operations, good Samaritan programs and training for community persons in first aid should be developed and sustained.

4) Further analysis of the RTC in relation to emergency response can be embarked upon for the entire FCT using an Excel spreadsheet and presentation of the situation with the application of the ArcGIS Desktop or another GIS software program with similar or advanced capabilities.

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Conflicts of Interest

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

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