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Geospatial Modelling of Emergency Healthcare Accessibility: Travel Time Analysis and Service Catchment Delineation of Tertiary Health Facilities in Calabar Metropolis, Nigeria

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Abstract
This study assessed the accessibility of emergency healthcare services to tertiary healthcare facilities in Calabar Metropolis, Cross River State, Nigeria, using geospatial modelling techniques. The study examined travel time patterns, service catchment areas, and the spatial distribution of tertiary healthcare facilities to assess the accessibility residents enjoy. Spatial data on healthcare facility locations, road networks, settlements, and administrative boundaries were integrated within a Geographic Information System (GIS) environment. Network analysis and travel-time modelling techniques were employed to generate accessibility maps and delineate service catchment areas. Also, Average Nearest Neighbour (ANN) analysis was used to evaluate the spatial distribution pattern of tertiary healthcare facilities. The findings revealed that 75.5% of respondents resided within 1 km of a healthcare facility, while 76.1% could access healthcare services within 30 minutes. Travel-time maps showed that most parts of the metropolis fall within favourable accessibility zones, although some peripheral communities experience relatively longer travel times and reduced service coverage. The ANN analysis produced a nearest neighbour ratio of 0.843, a z-score of -2.808, and a p-value of 0.00497, indicating a statistically significant clustered distribution of tertiary healthcare facilities. The study concludes that while emergency healthcare accessibility is generally satisfactory within the urban core, spatial inequalities exist in outlying areas. It recommends the strategic expansion of healthcare infrastructure, improvement of transportation networks, and integration of GIS-based decision-support systems into healthcare planning to enhance equitable access to emergency healthcare services.

Keywords: Geospatial Modelling, Emergency Healthcare Accessibility, Travel Time Analysis, Service Catchment Delineation, Tertiary Healthcare Facilities.

Introduction

Access to emergency healthcare services is a fundamental component of sustainable health systems and a critical determinant of population health outcomes. In emergencies such as road traffic accidents, obstetric complications, cardiovascular emergencies, infectious disease outbreaks, and other

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life-threatening conditions, timely access to appropriate healthcare facilities significantly influences survival rates and recovery outcomes. The effectiveness of emergency healthcare systems is therefore not solely dependent on the quality of medical care provided, but also on the ability of patients to reach healthcare facilities within an acceptable time frame (Averik et al., 2025). Consequently, healthcare accessibility has emerged as an important area of research within health geography, public health, and spatial planning due to its direct implications for health equity and healthcare service delivery (Choolayil & Jabir, 2025; Dassah, 2025).

Healthcare accessibility is increasingly recognized as a multidimensional concept encompassing spatial, temporal, economic, and organizational dimensions (Yang et al., 2024; Njoku et al., 2022; Uttah et al., 2026). Among these dimensions, spatial accessibility remains particularly important because it determines the geographical ease with which populations can obtain healthcare services (Omwenke et al., 2026; Akintoye et al., 2022). Geographic factors such as distance, travel time, transportation infrastructure, and settlement patterns significantly influence healthcare utilization and emergency response effectiveness (Banke-Thomas et al., 2024; Moses et al., 2018). Previous studies have demonstrated that populations residing farther from healthcare facilities often experience delayed treatment, higher morbidity rates, and increased mortality risks, compared to populations located within closer proximity to healthcare services (Fluck et al., 2025; Majebi et al., 2024; Ubugha et al., 2017). As a result, understanding spatial accessibility has become central to healthcare planning and resource allocation.

Recent advances in Geographic Information Systems (GIS), remote sensing, Global Positioning Systems (GPS), and spatial modelling techniques have transformed the assessment of healthcare accessibility (Fatkhutdinova & Zalyalov, 2025; Biu et al., 2024). These technologies provide robust analytical frameworks for examining the spatial relationships between healthcare facilities and populations, enabling researchers to move beyond traditional measures such as physician-to-population ratios and administrative service boundaries. Geospatial modelling allows for the integration of healthcare infrastructure data, transportation networks, demographic information, and environmental variables to generate realistic accessibility assessments (Nikolova & Aleksandrova, 2025). Such approaches provide valuable insights into healthcare service coverage, travel impediments, and geographic inequalities in healthcare access (Labban et al., 2023; Afni, 2023).

Travel time analysis has become one of the most widely accepted approaches for evaluating emergency healthcare accessibility because it reflects the actual effort required to reach healthcare facilities. Unlike straight-line distance measures, travel time models account for transportation routes, road conditions, traffic congestion, terrain characteristics, and other factors that influence movement. In emergency medicine, where delays of even a few minutes can significantly affect patient outcomes, travel time serves as a more meaningful indicator of healthcare accessibility. Consequently, healthcare planners increasingly employ travel time analysis to identify populations located beyond recommended emergency response thresholds and to guide healthcare infrastructure development (Balsa-Barreiro et al., 2025; Ongesa et al., 2025).

Closely related to travel time analysis is the concept of service catchment delineation, which refers to the identification of geographic areas served by specific healthcare facilities. Service catchments provide critical information regarding healthcare service coverage, facility utilization patterns, and population demand. Delineating healthcare catchments enables planners to determine whether healthcare facilities adequately serve surrounding communities and to identify areas experiencing service deficiencies. In emergency healthcare planning, catchment analysis supports the optimization of healthcare resources, ambulance deployment strategies, and facility location decisions aimed at maximizing accessibility and minimizing response times (Nahata et al., 2024).

Calabar Metropolis, located in Cross River State, Nigeria, has experienced considerable demographic expansion and spatial development over recent decades. As the administrative and commercial hub of the state, the metropolis continues to attract population influxes that place increasing pressure on existing healthcare infrastructure. Although tertiary healthcare facilities within the metropolis provide specialized medical services to residents of Cross River State and neighbouring regions, concerns remain regarding the spatial distribution of healthcare services and the ability of residents to access

emergency care within acceptable travel times. Variations in road network connectivity, urban growth patterns, and transportation conditions may create disparities in emergency healthcare accessibility among different communities within the metropolis.

Despite the strategic importance of tertiary healthcare facilities in providing advanced emergency medical care, limited empirical studies have comprehensively examined their accessibility using geospatial modelling approaches in Calabar Metropolis. This study therefore applies travel time analysis and service catchment delineation techniques to assess emergency healthcare accessibility to tertiary health facilities within the metropolis. By integrating spatial data on healthcare facilities, transportation networks, and population distribution, the study provides insights into patterns of healthcare accessibility, identifies underserved areas, and offers evidence-based recommendations for improving emergency healthcare planning and healthcare service delivery.

Methodology

This study adopted a geospatial analytical approach to assess emergency healthcare accessibility to tertiary healthcare facilities within Calabar Metropolis, Cross River State, Nigeria. Spatial data comprising the locations of tertiary healthcare facilities, road network data, settlement locations, and administrative boundaries were obtained from field surveys, Global Positioning System (GPS) observations, and relevant secondary sources. The geographic coordinates of the selected tertiary healthcare facilities, namely the University of Calabar Teaching Hospital, University of Calabar Medical Centre, and Nigerian Navy Reference Hospital, were integrated into a Geographic Information System (GIS) environment for spatial analysis. Road network data were processed and used to develop a transportation network database for the study area. Using GIS-based Network Analyst tools, travel time analysis was performed to determine the time required for residents from different parts of the metropolis to access the selected healthcare facilities through the existing road network. The analysis generated travel-time zones and service catchment areas based on specified accessibility thresholds, thereby identifying areas with high, moderate, and low levels of emergency healthcare accessibility. The resulting maps were used to visualize spatial variations in access to tertiary healthcare services and to evaluate the adequacy of healthcare coverage across Calabar Metropolis.

Results and discussions

Spatial distribution of HCFs in Calabar Metropolis

Spatial distribution based on locations revealed variation in the number of HCFs in Calabar Metropolis. Within the area, there were differences in the number of HCFs in the two local government areas. As can be seen in Figure 1, there are more HCFs in Calabar Municipality than Calabar South. Hence, there is more attraction of development to the area, including HCFs. However, it is worthy to note that even with the small size of Calabar South in terms of landmass (33.9 sqkm.) compared to Calabar Municipality (103.4 sqkm), there is a seemingly clustered spatial pattern of the HCFs in Calabar South due to its area coverage. While 65 percent of HCFs are domiciled in the Municipality, 35 percent are in Calabar South. Furthermore, the nature of concentration of the HCFs was examined using the mean center spatial analyst tool for measuring geographic distribution.

The mean center assessment identifies the geographic center (or the center of concentration) of HCFs in the Metropolis. The output of the analysis showed that the mean center of HCFs in Calabar is around Ediba Road in Calabar Municipality, specifically at 8º 20′ 2.117″ E, 4º 58′ 36.33″ N (see Figure 2). The implication is that there will be a higher level of physical accessibility to HCFs in the vicinity of Ediba Road in the study area. The mean centre location in the study area can be explained by the higher number of facilities in the Municipality. Notably, HCFs are concentrated in the center of the city, with a dearth of facilities in the southern corner and from the Federal Housing area up to the northern fringes of the metropolis.

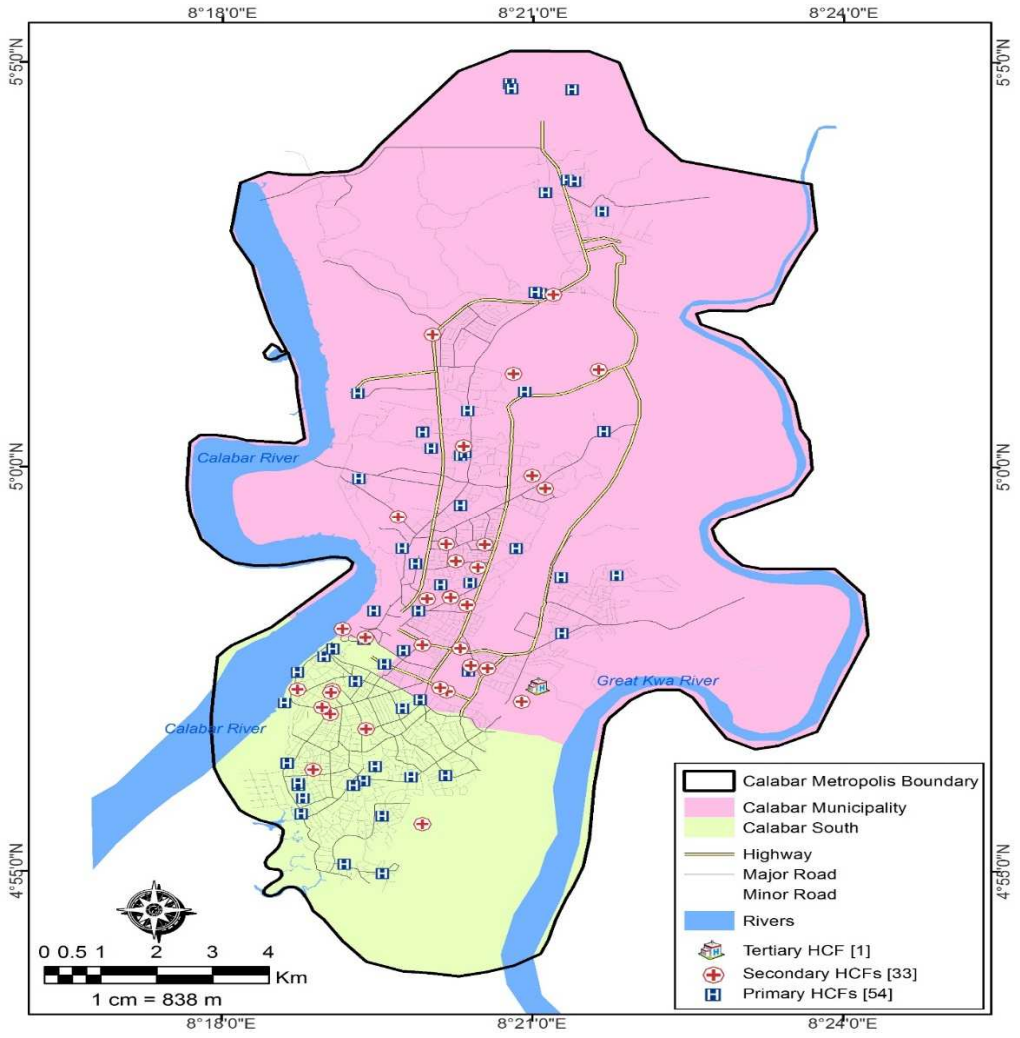

FIG 1: Distribution of HCFs in Calabar Metropolis.

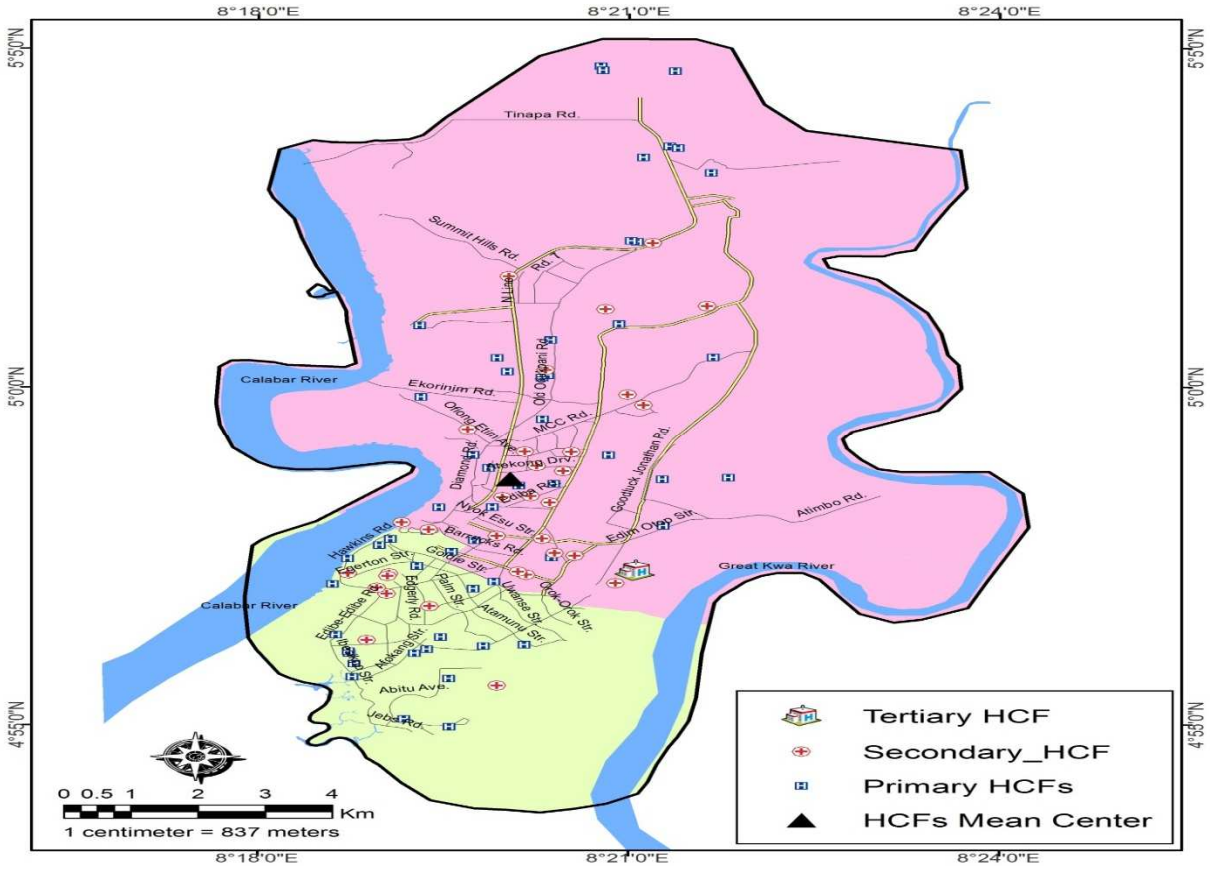

FIG 2: Mean Center of the HCFs in Calabar Metropolis.
Source: Authors field work, 2026

Hypothesis Testing

The hypothesis tested in this study stated that the spatial distribution of tertiary healthcare facilities in Calabar Metropolis is not significantly different from a random distribution. To evaluate this hypothesis, the geographic coordinates (latitude and longitude) of the tertiary healthcare facilities were subjected to Average Nearest Neighbour (ANN) analysis within a Geographic Information System (GIS) environment. The analysis was undertaken to determine whether the observed distribution of tertiary healthcare facilities exhibits a clustered, dispersed, or random spatial pattern and how such a pattern influences emergency healthcare accessibility, travel time, and service catchment coverage within the metropolis.

The results of the ANN analysis revealed an Average Nearest Neighbour Ratio of 0.843, which is less than 1.0, indicating a clustered spatial pattern among the tertiary healthcare facilities FIG 3. Furthermore, the analysis produced a z-score of -2.808 and a p-value of 0.00497. Since the p-value is less than the 0.05 level of significance and the z-score falls beyond the critical threshold of ±1.96, the null hypothesis was rejected and the alternative hypothesis accepted. This indicates that the spatial distribution of tertiary healthcare facilities in Calabar Metropolis is significantly clustered and is unlikely to have occurred by random chance. The probability that the observed pattern resulted from random spatial processes is less than 1 percent.

The observed clustering pattern suggests that tertiary healthcare facilities are concentrated within specific parts of the metropolis, particularly around the urban core where population density, transportation infrastructure, educational institutions, and administrative activities are concentrated. While such clustering may promote operational efficiency, specialization, and resource sharing among healthcare providers, it also has important implications for emergency healthcare accessibility. The travel-time and service

catchment analyses revealed that communities located closer to the clustered facilities enjoy shorter travel times and better emergency healthcare access, whereas residents in peripheral and less-developed sections of the metropolis may experience longer travel times and reduced accessibility to tertiary healthcare services. Therefore, the significant clustering of tertiary healthcare facilities highlights the need for strategic healthcare planning aimed at improving spatial equity in emergency healthcare access and expanding service coverage to underserved areas within Calabar Metropolis.

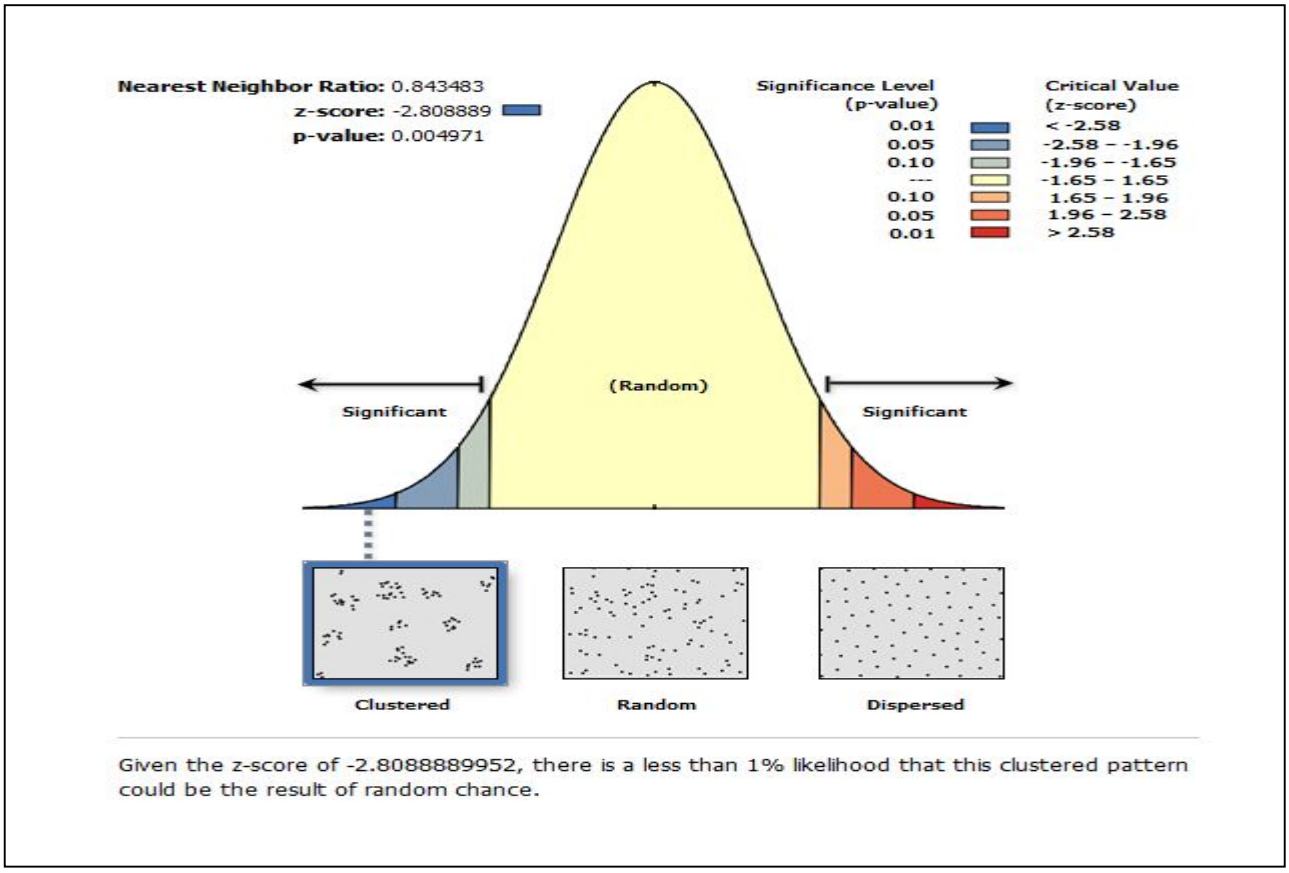

FIG 3: ANN analysis output
Source: Authors fieldwork, 2026

Geospatial access to Healthcare Facilities in Calabar Metropolis

The findings presented in Table 1 indicate a relatively favourable pattern of geographic accessibility to healthcare facilities within Calabar Metropolis. Out of the 400 respondents surveyed, 302 (75.5%) reported that a healthcare facility was located within a 1-kilometre radius of their residence, while only 98 (24.5%) indicated otherwise. This suggests that healthcare infrastructure is reasonably distributed across much of the metropolis, particularly within the densely populated urban areas of Calabar Municipality and Calabar South. The GIS-generated travel-time map further supports this observation by showing extensive areas of the metropolis falling within short travel-time zones to tertiary healthcare facilities as seen in FIG 4. Areas located around major transportation corridors and central urban districts were predominantly characterized by high accessibility levels, reflecting the concentration of healthcare services and relatively good road connectivity. These findings imply that a substantial proportion of

residents can reach healthcare facilities with minimal travel burden, which is particularly important during medical emergencies when rapid access to care can significantly influence patient outcomes.

The analysis of travel duration reveals that 304 respondents (76.1%) could reach a healthcare facility within 30 minutes, while only 20 respondents (4.9%) required more than 45 minutes to access healthcare services. This finding corresponds with the spatial pattern observed on the accessibility map, where most neighbourhoods were located within favourable travel-time catchments of the tertiary healthcare facilities. However, the map also identified peripheral communities situated farther from the urban core as experiencing relatively longer travel times, largely due to increased distance from tertiary healthcare facilities and variations in road network connectivity. Although the proportion of residents experiencing extended travel times is relatively small, these areas represent potential pockets of healthcare vulnerability during emergencies. The existence of such spatial disparities highlights the importance of continuous healthcare infrastructure planning and transportation network improvements to ensure equitable access to emergency healthcare services across all parts of Calabar Metropolis. The GIS-based travel-time analysis therefore demonstrates the usefulness of geospatial modelling in identifying both well-served and underserved areas, thereby providing valuable information for healthcare planning and emergency response optimization.

Table 1: Measures of Geographic Access to Healthcare Facilities in Calabar Metropolis

Variable	**Category**	**Frequency**	**Percent (%)**	**Percent (%)**
Healthcare Facility within 1 km of Residence	Yes	302	75.5	75.5
	No	98	24.5	100.0
	Total	400	100.0	
Duration to Arrive at Healthcare Facility	<15 minutes	153	38.3	38.3
	15–30 minutes	151	37.8	76.1
	31–45 minutes	76	19.0	95.1
	46–60 minutes	16	4.0	99.1
	>60 minutes	4	0.9	100.0
	Total	400	100.0	

Source: Authors' fieldwork, 2026

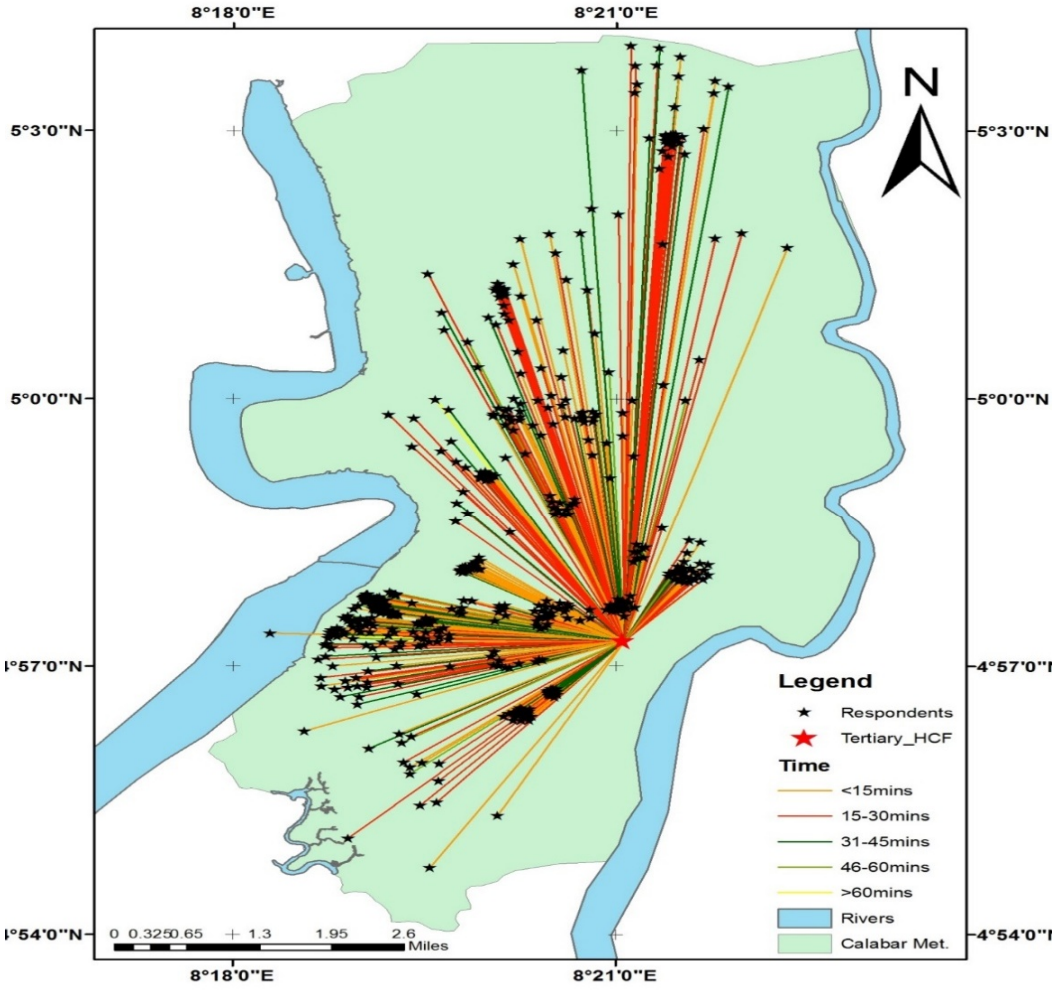

FIG 4: Time of travel from home to tertiary healthcare facility in Calabar.
Source: Authors fieldwork, 2026

Conclusion

The study assessed emergency healthcare accessibility to tertiary healthcare facilities in Calabar Metropolis using geospatial modelling techniques, particularly travel time analysis, service catchment delineation, and spatial pattern analysis. The findings revealed that the majority of residents enjoy relatively good access to tertiary healthcare services, with over three-quarters of the population residing within 1 km of a healthcare facility and approximately 76% able to reach a healthcare facility within 30 minutes. The GIS-based travel-time maps further demonstrated that large portions of the metropolis fall within favourable accessibility zones, indicating that the existing road network and concentration of tertiary healthcare facilities provide substantial healthcare coverage for most urban residents.

However, the study also identified notable spatial disparities in emergency healthcare accessibility. The Average Nearest Neighbour analysis confirmed that tertiary healthcare facilities exhibit a statistically significant clustered distribution pattern, resulting in better healthcare access within the urban core while some peripheral communities experience comparatively longer travel times and reduced service coverage. The service catchment analysis highlighted pockets of underserved areas located farther from the major

tertiary healthcare facilities. These findings underscore the importance of geospatial technologies in healthcare planning and demonstrate the need for strategic interventions aimed at improving spatial equity, reducing travel-time barriers, and enhancing emergency healthcare accessibility across all parts of Calabar Metropolis.

Recommendations

The following recommendations were made based on study findings:

1. The Cross River State Government and healthcare planning authorities should establish additional emergency care centres in peripheral areas identified by the GIS analysis as having relatively long travel times and limited service coverage.
2. Urban planners and transportation agencies should prioritize the improvement of road connectivity and traffic management systems in underserved communities to reduce emergency travel times and enhance access to tertiary healthcare facilities.
3. Healthcare policymakers should institutionalize the use of Geographic Information Systems (GIS) and periodic travel-time accessibility assessments as decision-support tools for healthcare infrastructure planning, emergency response management, and future healthcare facility location decisions.

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