https://doi.org/10.5281/zenodo.20799572

Geospatial Analysis of Fire Station Accessibility to Markets for Disaster Management in Akure South, Nigeria

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Abstract

Access to a fire station is crucial for the effectiveness of emergency responses and public safety in urban areas. This study investigates fire station distribution patterns and their proximity to commercial market centers in Akure South Local Government Area, Ondo State, Nigeria. Kernel density estimation, Average Nearest Neighbor (ANN) analysis, and Euclidean distance measurement were deployed within an ArcGIS 10.4.1 environment, supplemented by QGIS 3.28.2. The study directly supports Sustainable Development Goal 11 by examining spatial inequities in emergency response coverage. ANN analysis revealed that markets exhibit a statistically significant dispersed pattern (NNR = 1.426, p = 0.014). In contrast, fire stations are also highly dispersed (NNR = 36.022, p < 0.001). However, the extremely high NNR and z-score for fire stations are partly attributable to the very small number of facilities (n = 3), which limits the inferential scope of this statistic. Euclidean distance analysis identified an average market-to-nearest-fire-station distance of 3.7 km, with a maximum exceeding 8.7 km. Hotspot analysis identified the southern and eastern areas as areas with critical service deficits. Proposed fire station locations were evaluated using service area analysis and travel distance modeling, demonstrating substantial improvements in coverage equity and reductions in response times. The study demonstrates that GIS can be deployed effectively to identify emergency infrastructure challenges and support evidence-based disaster management planning, thereby providing actionable recommendations to optimize fire station placement and improve disaster resilience in Akure and similar urban areas.

Keywords: GIS, fire station, spatial analysis, emergency response, disaster management

Introduction

Fire outbreaks represent one of the most destructive and dangerous disasters globally, causing significant loss of life, property damage, and economic devastation (Souissi et al., 2020). In Nigeria, fire incidents are particularly prevalent due to multiple compounding factors, including poor infrastructure, inadequate fire prevention measures, insufficient firefighting equipment, and limited access to fire services. Akure, the capital city of Ondo State, exemplifies these urban vulnerabilities, having experienced multiple documented fire emergencies that underscore the severity of the fire hazard problem.

Several fire incidents in Akure illustrate the gravity of these gaps. In December 2016, a midnight fire outbreak at Odopetu Market destroyed open stalls and locked stores containing foodstuffs and locally made goods, affecting more than fifty traders (Tribune Online, 2016). In June 2018, inadequate fire service resources prevented a timely response to a fire incident that destroyed 30 lock-up stores and offices, with firefighters unable to reach the scene due to a lack of fuel in service vehicles (Sahara Reporters, 2018). In June 2020, fire engulfed a market around Oba Nla Junction, with residents reporting a delayed response from the fire service at Alagbaka (Sahara Reporters, 2020a). Additionally, in November 2020, a fire incident at Ijomu Street affected ten stores and destroyed goods valued at over N300 million, hospitalizing one affected trader (Sahara Reporters, 2020b). These recurring incidents demonstrate that

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fire emergencies threaten both property and human life while revealing critical gaps in emergency response capacity.

Geographic Information Systems (GIS) have proven effective in facility location analysis and emergency service accessibility assessment. With regards to emergency management, GIS-based approaches have been applied to evaluate fire station coverage (Aktaş et al., 2013; Chevalier et al., 2012), optimize ambulance deployment (Başar et al., 2012), and assess police service distribution (Luen & Al-Hawamdeh, 2001). Maximum Coverage Location Models (MCLP) and p-median models have been widely adopted for optimizing the placement of emergency facilities to minimize response times and maximize population coverage (Ly et al, 2025; Zhang, et al, 2024). In the Nigerian context, GIS-based spatial analysis has been applied to flood risk mapping (Eludoyin et al., 2007; Olatona et al., 2018; Oyinloye et al., 2013) and microfinance bank accessibility (Nnamani & Olaoluwa, 2025), but comprehensive spatial analysis of fire station accessibility to commercial centres remains limited.

The rapid urbanization and commercial expansion of Akure have intensified fire hazard exposure, particularly in congested market areas. While fire stations exist within the city, their spatial relationship to market areas and consequently their capacity to provide timely emergency response remains inadequately documented and analyzed. This knowledge gap represents a critical impediment to effective disaster management planning. This study addresses this critical gap through mapping and spatial analysis of fire station proximity to markets in Akure, Ondo State, Nigeria. The objectives of this study are to: (1) identify and map the precise locations of fire stations and markets within Akure; (2) analyze spatial proximity relationships between these facilities using distance-based and network analysis; (3) evaluate the impact of current fire station proximity configurations on fire disaster management effectiveness; and (4) assess whether the locations of existing fire stations enable adequate emergency response to market areas. By employing GIS-based spatial analysis to quantify accessibility disparities and identify service gaps, this study provides empirical evidence to support informed decision-making by policymakers, fire service administrators, and urban planners.

Literature Review

Emergency Facility Location Theory and GIS

The problem of optimally locating emergency facilities such as fire stations, ambulance depots, and police posts has been extensively studied in the operations research and urban planning literature. Classical location-allocation models include the Location Set Covering Problem (LSCP), which seeks the minimum number of facilities to cover all demand points within a specified response time (Zhang et al, 2024), and the Maximum Covering Location Problem (MCLP), which maximizes the population covered given a fixed number of facilities (Ly, 2025).

These models have been combined with GIS to utilize spatial data and generate effective siting suggestions (Murray, 2010; Tao et al., 2022). The use of GIS for proximity and accessibility evaluations has become a common practice in planning for emergency services. Network analysis using GIS systems allows for the determination of realistic travel-time service areas by taking into account factors such as the road network's structure, speed limits, and traffic restrictions—features that surpass basic Euclidean distance calculations (Jia et al., 2006). Multiple studies have shown that Euclidean distance often underrepresents actual travel lengths by 20–50% in urban settings, highlighting the significance of network-based methods where applicable (Phibbs & Luft, 1995; Apparicio et al., 2008).

GIS Applications in Fire Station Location and Accessibility

A growing body of literature applies GIS to assess and optimize fire station distribution. Aktaş et al. (2013) utilized GIS and multi-criteria decision analysis to pinpoint ideal locations for fire stations in Istanbul, showing that strategic relocation could significantly decrease average response times. Chevalier et al. (2012) used location-allocation models to assess fire station coverage in Belgium, determining that the current setups left considerable gaps in rural and peri-urban areas. Research in sub-Saharan Africa has indicated that rapid urban growth is outpacing infrastructure development, leading to spatial inequalities in emergency service availability (Oppong et al., 2016). Kernel Density Estimation (KDE) has been extensively used to illustrate the spatial distribution of emergency facilities and to pinpoint areas lacking sufficient coverage (Bui et al., 2016; Chainey & Ratcliffe, 2005). Average Nearest Neighbor (ANN) analysis provides a complementary statistical description of point distribution patterns, distinguishing clustered, random, and dispersed configurations, though it is most reliable with larger sample sizes (Mitchell, 2005).

Fire Hazard and Market Accessibility in Nigeria

Nigerian urban marketplaces are highly susceptible to fires due to factors such as high population density, insufficient electrical systems, informal construction practices, and poor enforcement of fire safety regulations (Ishaya et al., 2008; Rahman et al., 2015). Research conducted in Akure has reported frequent fire incidents and highlighted a spatial concentration of at-risk commercial activities (Tribune Online, 2016; Sahara Reporters, 2018, 2020a, 2020b). Nevertheless, there is a lack of comprehensive GIS-based assessments regarding the accessibility of fire stations to these commercial areas, especially in terms of proximity and service area analysis, which is the crucial gap this study aims to fill.

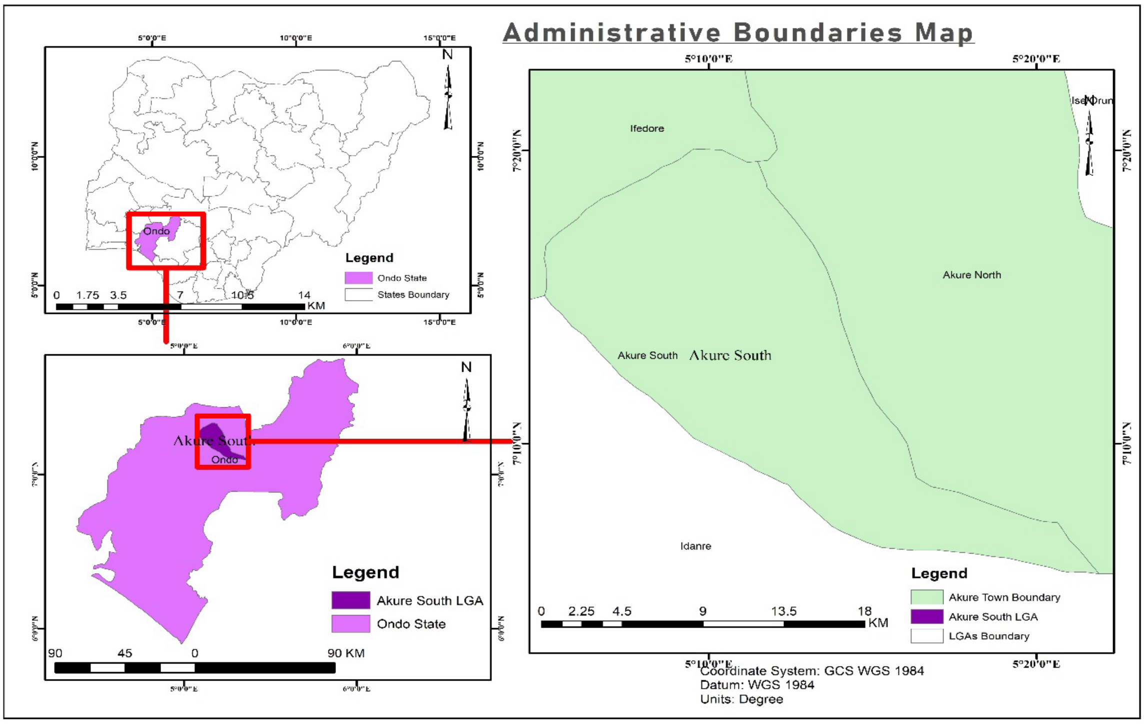
Study Area

Akure is a city located in Ondo State, Nigeria. It is the capital city of the state and lies within the tropical rainforest zone of Nigeria. The city has a population of over 1.3 million people, according to the 2006 national population census. Akure is situated in the south-western region of Nigeria and is bordered by Ekiti and Owo towns to the north, Ondo City to the east, and Ode Irele and Ore towns to the south. The city has a total land area of approximately 50.36 square kilometers (Nohani et al., 2019). The climate in Akure is tropical, with distinct dry and wet seasons. The dry season usually lasts from November to March, while the wet season spans from April to October. The city has an annual rainfall of about 1,500-1,800 mm, with heavy downpours often resulting in flooding (Paul et al., 2019). The terrain of Akure is quite rugged, with hills and valleys scattered throughout the city. The city's natural resources include timber, palm trees, rubber trees, and other forest products (Dano et al., 2019). The primary language spoken in Akure is Yoruba, which is widely spoken throughout the Southwestern region of the country. English, the official language of Nigeria, is also spoken and understood by most residents and is used for official communication and business transactions.

The city has several tertiary institutions, including Adekunle Ajasin University and the Federal University of Technology, Akure.

The city is characterized by a diverse network of markets that serve as commercial hubs, attracting people from different parts of the state and beyond. These markets are particularly vulnerable to fire hazards due to high population density, congestion, and the nature of stored goods. Akure South LGA constitutes the primary administrative and commercial core of the city and was selected as the study area due to its concentration of both market activities and fire service infrastructure.

Figure 1: Map of Study Area - Akure, Ondo State, Nigeria



Methodology

The methodology comprised five phases: reconnaissance, data acquisition, data processing, quality assurance, and spatial analysis. Figure 2 presents a flowchart of the methodological framework adopted for this study.

Figure 2: Flowchart of methodology

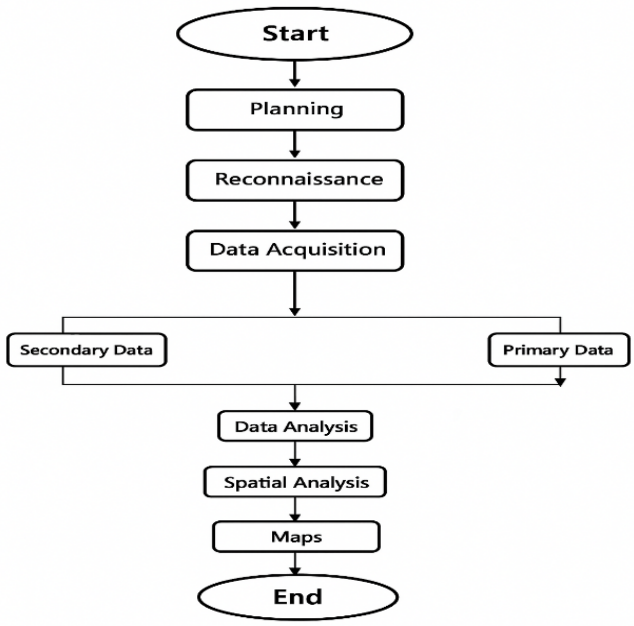


Figure 3.1 Flowchart of Methodology Adopted for this Study

Reconnaissance Phase

The reconnaissance encompassed preliminary survey activities to identify the precise locations of fire stations, market centers, and key infrastructural features within Akure South L.G.A. This direct observation provided firsthand information regarding the spatial distribution of these facilities and their accessibility relative to the road network. Existing road networks, transportation corridors, and other physical features facilitating emergency response were documented and assessed for their relevance to fire station deployment effectiveness.

Data Acquisition

The study employed both primary field-based data collection and secondary geospatial data sources. Primary data were collected using a Garmin 76 Handheld GPS device to acquire accurate coordinates of the fire station and market locations in Akure. GPS coordinates were recorded in Northings (N) and Eastings (E) format and subsequently converted to latitude and longitude coordinates for compatibility with GIS applications. Secondary geospatial data were obtained from multiple credible sources including satellite imagery from Google Earth Pro, shapefiles from OpenStreetMap, and official records from government agencies. Data sources specifically included the Ondo State Fire Service, Ondo State Ministry of Commerce and Industry, and local government authorities. In total, three fire stations and nine market locations were identified and validated within the study area.

Equipment and Software

Hardware components include a Garmin 76 Handheld GPS device for location data acquisition, and a Laptop computer for data entry, storage, and analysis. Software applications used for the study include the following:

i. Microsoft Office Suite 2010 (data organization and documentation)

ii. Google Earth Pro (satellite imagery and spatial reference)

iii. ESRI ArcGIS Desktop 10.4.1 (primary GIS analysis platform)

iv. QGIS 3.28.2 (supplementary GIS processing)

v. USGS GIS tools (spatial analysis support)

The dual GIS software approach (ArcGIS and QGIS) provided comprehensive spatial analysis capabilities, including kernel density mapping, proximity analysis, and network analysis.

Data Processing

Raw coordinate data acquired in the field required transformation to standardized formats compatible with GIS analysis workflows. Processed coordinate data were converted from Microsoft Excel format (.xlsx) to comma-separated values format (.csv) to enable direct importation into GIS platforms. This standardized format facilitates geocoding procedures and attribute table generation within ArcGIS and QGIS environments.

QGIS Implementation

QGIS 3.28.2 software was used for initial data visualization and supplementary spatial analysis. Processed .csv files containing market and fire station coordinate data were imported into QGIS using the WGS84 reference system. Basemap layers containing road networks, transportation networks, and land use information were extracted from Google Earth Pro and integrated into the project workspace. Point features representing fire stations and markets were symbolized using distinctive icons and labeled with facility names. This visual differentiation enabled clear identification of facility types and spatial relationships within map displays. Kernel density estimation was applied to generate continuous surface representations of fire station and market distribution intensity across the study area. This technique revealed clustering patterns and identified areas of high and low facility concentration.

ArcGIS Implementation and Network Analysis

ArcGIS Desktop 10.4.1 served as the primary platform for proximity analysis, closest facility assessment, and service area delineation. ArcMap was initialized with a blank project template. Basemap layers of Nigeria and Akure South L.G.A were added, and the coordinate data were imported from processed .csv files and georeferenced to the WGS84 coordinate reference system. The Network Analyst extension was activated within ArcMap to enable network-based spatial analysis. The extension was accessed through Customize > Extensions and the Network Analyst toolbar was enabled for specialized analytical tools.

Existing fire station locations were loaded as network facilities using the "Load Locations" function, drawing from the georeferenced fire station point feature layer. Market locations were geocoded using the address-based location identification, enabling the analysis to model response scenarios from fire stations to specific market locations.

Spatial Analysis Methods

Kernel Density Estimation (KDE): To create continuous surface representations of market and fire station distribution intensity, KDE was used in both ArcGIS and QGIS. Following the conventional procedure for urban facility analysis, a search radius (bandwidth) of 1,500 m was chosen based on the spatial breadth of the research region and the density of point features (Chainey & Ratcliffe, 2005). Output cell size was set to 30 m to balance computational efficiency with spatial resolution.

Average Nearest Neighbor (ANN) Analysis: ANN analysis was used to classify distribution patterns as dispersed, random, or clustered in both markets and fire stations. With values more than 1.0 denoting dispersion and values less than 1.0 denoting clustering, the ANN ratio (NNR) compares the observed mean nearest-neighbor distance to the anticipated distance under a hypothetical random distribution (Mitchell, 2005). It must be noted that with only three fire stations, the ANN result for fire stations (NNR = 36.022) is heavily influenced by the small sample size and the geometric relationship between the three points relative to the study area boundary; accordingly, this statistic should be interpreted as a descriptive indicator of wide spatial spacing rather than a robust inferential finding. The ANN results for markets (n = 9) similarly carry caveats regarding sample size but provide a reasonable characterization of spatial pattern.

Euclidean Distance Analysis: Euclidean (straight-line) distance was calculated between each market and its nearest fire station using ArcGIS. Service area thresholds of 0–1 km (well-served), 1–3 km (moderately served), 3–5 km (underserved), and >5 km (critically underserved) were applied, based on standard fire emergency response benchmarks.

Service Area Analysis: Network Analyst in ArcGIS was used to delineate service area polygons for both existing and proposed fire stations across travel distance bands of 0–1, 1–2, 2–3, 3–4, and 4–5 km. Proposed fire station locations were identified through iterative spatial evaluation aimed at maximising market coverage within the 0–3 km band and minimising the maximum distance to any market, prioritising southern and eastern areas identified as service gaps through the KDE hotspot analysis.

Data Quality Assurance

Data quality constitutes a critical determinant of GIS analysis reliability and result validity. GPS-acquired coordinates and secondary source data were cross-validated against Google Earth Pro satellite imagery and official government records. This approach minimized positional errors and enhanced locational precision. Data were systematically obtained from all relevant administrative sources and verified to confirm comprehensive geographic representation. All spatial data were referenced to the WGS84 coordinate system throughout.

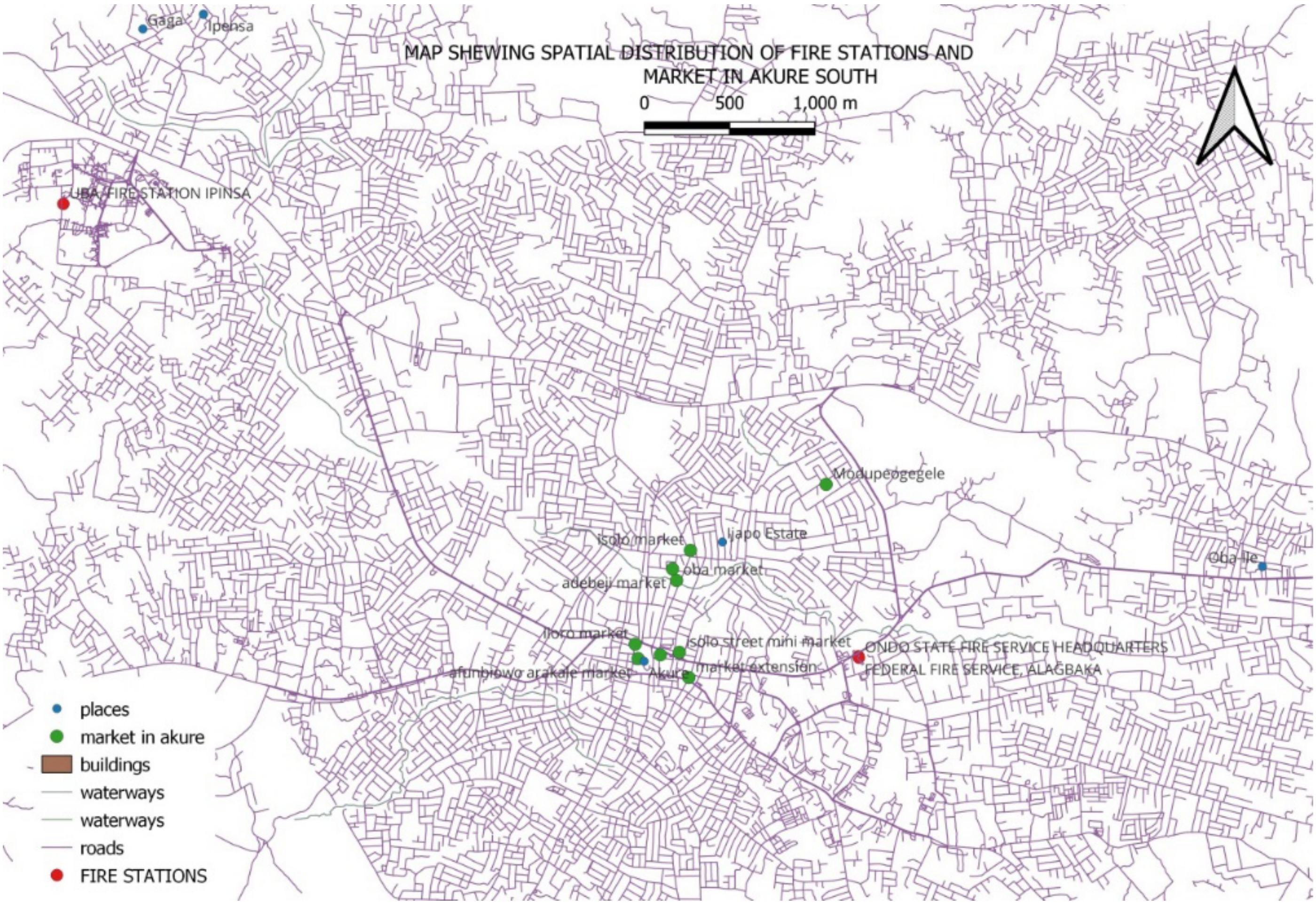
Results

This section presents the spatial analysis results obtained through GIS processing using ArcGIS, QGIS, and Microsoft Excel. The findings are visualized through maps and statistical charts that illustrate the spatial relationship between fire stations and markets in Akure South Local Government Area (L.G.A), Ondo State, Nigeria.

Spatial Distribution of Fire Stations and Markets

Figure 3 shows the spatial distribution of fire stations and major markets in Akure South LGA. It also shows the relative locations of existing fire stations in relation to major markets within the study area.

Figure 3: Spatial Distribution of Fire Stations and Markets in Akure South L.G.A



The spatial pattern reveals that fire stations in Akure South are unevenly distributed, with a higher concentration along the central and eastern parts of the city. Major markets such as Oja-Oba, Shasha, and Isikan are relatively close to existing fire stations, indicating good accessibility. However, some markets located toward the western and northern sections, such as Ijoka and Ipinsa, are farther away from any fire station, suggesting inadequate coverage and potential response delays in case of emergencies.

Table 1: Market Locations and their addresses

S/N	Market	Eastings (m)	Northings (m)	Address
1	NEPA Ultra-Modern Market, Akure	742397	801981	753V+7XP, 340283, Akure, Ondo, Nigeria
2	Foodstuff Market, Akure	743427	801324	66V3+FWX, Igbatoro Road, 340283, Akure, Ondo
3	Isolo Street Mini Market	742875	801653	753W+9Q2, 340283, Akure, Ondo
4	Adebeji Maket, Akure	743183	801775	3, Deji's Palace Road, 340110, Akure, Ondo
5	Isolo Market	743260	802181	757X+P7H, 340110, Akure, Ondo, Nigeria
6	Market Extension	743030	801252	752X+666, Iloro Street, 340283, Akure, Ondo
7	Afunbiowo Market, Arakale	744267	801955	Eru Oba Street, 340283, Akure, Ondo
8	Modupeogegele Market	741810	802392	Ijapo Estate Road, Opposite Ijapo Shopping Complex, Estate, 340110, Akure, Ondo
9	Iloro Market	742637	801971	Alafia Tayo Street, 340001, Akure, Ondo

Table 2: Fire Station Locations

S/N	Fire Station	Eastings (m)	Northings (m)	Address
1	Federal Fire Service, Alagbaka	743401	802173.4	7638+6C2 Alagbaka, 340106, Akure, Ondo
2	Ondo State Fire Service Headquarters, Alagbaka	737226	807918	7638+47F, Alagbaka 340106, Akure, Ondo
3	UBA Fire Station, Ipinsa	739846	803864.9	842J+JMJ, Ipinsa, 340110, Ondo

Spatial Analysis of Market Distribution and Fire Station

The first step in the spatial analysis involved mapping the spatial distribution of markets within the study area. Kernel Density Analysis (KDA) was applied to visualize the concentration of markets based on their geographic locations. The results revealed that markets were unevenly distributed across the study area (Figure 3), with clusters of high density observed in certain locations, while other areas exhibited sparse distribution. Two prominent market clusters were identified: the Oja Oba 1 market cluster and the Oja-Oba 2 market cluster, indicating significant commercial nodes within the L.G.A. Furthermore, the result showed that fire stations were located in the central and southern parts of the study area and that some markets were located far from any fire station. These findings align with previous research that employed kernel density techniques to analyze urban market patterns (Bui et al., 2016).

Average Nearest Neighbor Summary

The Average Nearest Neighbor (ANN) statistical test was applied to determine whether the observed market distribution follows a random, clustered, or dispersed pattern.

Markets: The ANN analysis for market locations yielded an NNR of 1.426, a z-score of 2.446, and a p-value of 0.014 (Table 3). An NNR greater than 1.0 indicates that the observed mean nearest-neighbour distance (0.0035°) exceeds the expected distance under a random distribution (0.0024°), signifying a dispersed spatial pattern. The result is statistically significant at the 5% level, meaning there is less than a 5% probability that this level of dispersion occurred by chance. This pattern reflects the deliberate distribution of markets across different neighbourhoods of Akure South to serve spatially separated residential and commercial communities.

Table 3: Nearest Neighbor Analysis of Markets in Akure South LGA

parameter	Value	Interpretation
Observed Mean Distance	0.0035	Actual average distance between markets
Expected Mean Distance	0.0024	Average distance expected under random distribution
Nearest Neighbor Ratio	1.426	NNR > 1 indicates dispersed pattern
z-score	2.446	Statistically significant deviation from randomness
p-value	0.014	Significance level indicating whether the pattern is random or not

Fire Stations: The Nearest Neighbor Ratio of 36.022 is far greater than 1, indicating a highly dispersed spatial pattern of fire stations in Akure South. The z-score of 116.047 and p-value of 0.000 (< 0.05) confirm that this dispersion is statistically significant and did not occur by random chance. This means fire stations are widely spaced. This confirms a highly dispersed pattern of fire stations across the study area. Similar spatial disparities in urban emergency service distribution have been noted in prior studies (Akay & Erdoğan, 2017).

Table 4: Nearest Neighbor Analysis of Fire Stations in Akure South LGA

Parameter	Value	Interpretation
Observed Mean Distance	0.0325	Actual average distance between fire stations
Expected Mean Distance	0.0009	Average distance expected if fire stations were randomly distributed
Nearest Neighbor Ratio	36.022	NNR >> 1 indicates a highly dispersed pattern.
z-score	116.047	Statistical measure of deviation from randomness
p-value	0	Significance level indicating whether the pattern is random or not

Assessment of Fire Station Proximity to Markets

The third stage focused on assessing the proximity of fire stations to markets using GIS-based proximity analysis. Euclidean distance analysis was employed to quantify the spatial relationship between markets and fire stations. Results are summarized in Table 5. The analysis calculated the shortest straight-line distance between each market and its nearest fire station.

Table 5: Summary of Distance between Markets and Nearest Fire Stations in the Study Area

Distance Measure	Value (km)	Interpretation
Mean distance	3.7	Average market-to-nearest-fire-station straight-line distance
Maximum distance	8.7	Most remote markets are located in the southern and eastern zones
Minimum distance	< 1.0	Well-served markets near the Alagbaka fire station cluster

The mean distance of 3.7 km indicates that, on average, markets are at a moderate distance from fire stations, though this average masks considerable variation. The maximum distance of 8.7 km highlights critically underserved markets in the southern and eastern parts of the LGA. Markets within 1 km of a fire station located primarily in the Alagbaka corridor can be considered well-served for basic emergency response. The wide range between minimum and maximum distances (spanning approximately 7.7 km) reflects significant geographic inequity in fire service accessibility across the LGA.

This analysis identified a bimodal service pattern, with some markets located within optimal emergency response distance while others face critical service gaps. This variation in proximity also underscores the uneven accessibility of fire services across the area, which has important implications for emergency preparedness and disaster response.

Hotspot Analysis and Service Deficit Zones

Kernel density analysis was applied to identify hotspot areas where fire station proximity was critically inadequate. The most pronounced service deficits were located in the southern and eastern portions of the study area, where market-to-fire-station distances exceeded 5 km. These hotspot regions represent priority areas for emergency services infrastructure expansion.

Proposed Fire Station Assessment

To address identified service gaps, proposed fire station locations were evaluated through service area analysis and travel distance modeling. Figures 4–7 illustrate the spatial layout and projected service areas of proposed stations.

Figure 4 shows the spatial layout of markets and proposed fire stations, highlighting the areas currently underserved.

Figure 5 shows the service areas generated for the proposed network, demonstrating improved spatial coverage compared to existing facilities.

Figure 6 depicts the service area analysis (coverage improvements), emphasizing how the inclusion of proposed fire stations significantly reduces the distance between markets and emergency response facilities.

Finally, Figure 7 compares the travel distance and area coverage between proposed and existing fire stations, clearly showing that the proposed stations enhance accessibility, especially in the southern and eastern parts of the study area where previous analyses identified critical service gaps.

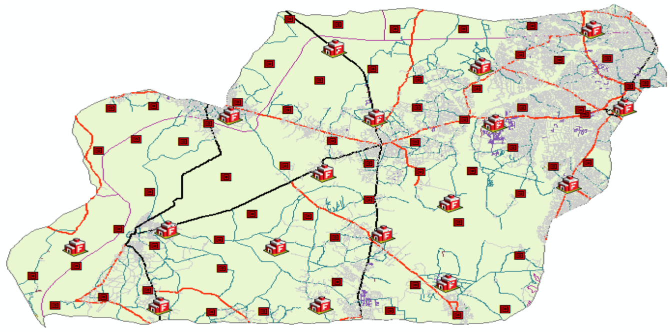


Figure 4: Spatial configuration of proposed fire stations relative to market locations

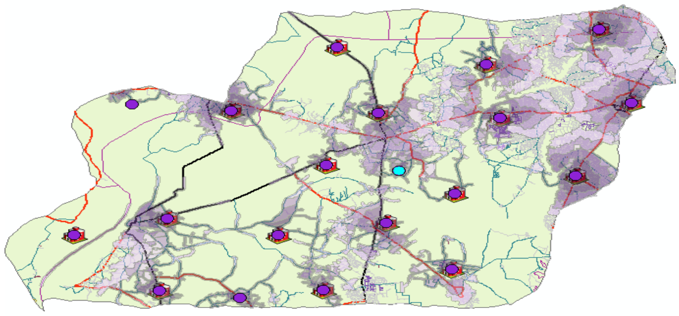


Figure 5: Service area coverage polygons for proposed fire station network

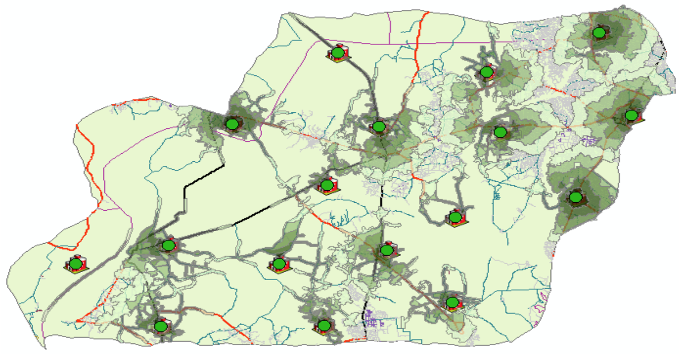


Figure 6: Service area analysis showing coverage improvement and overlap optimization

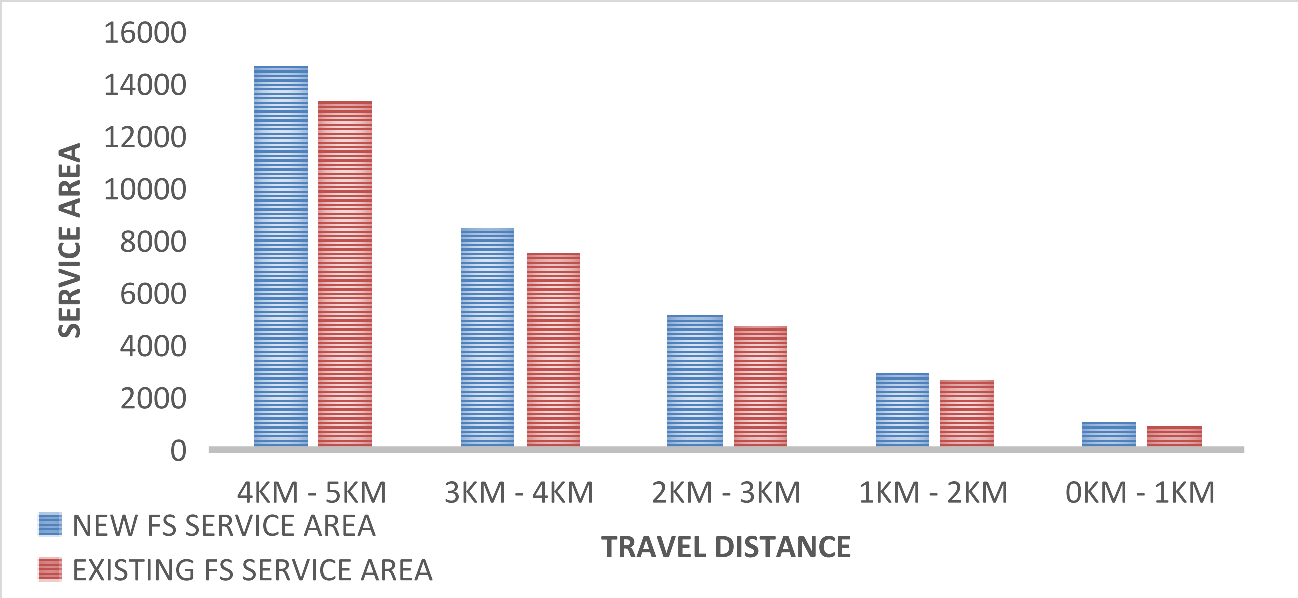


Figure 7: Areas Covered by Existing and Proposed Fire Stations at Different Travel Distances

The chart in Figure 7 illustrates the distribution of service areas for existing and proposed (new) fire stations across varying travel distance ranges (0–5 km). The proposed fire stations significantly expand coverage, especially within the 4–5 km and 3–4 km distance bands, indicating improved accessibility and reduced underserved zones.

The analysis reveals that both existing and proposed fire stations expand their service areas as the travel distance increases. However, the proposed fire stations (new FS) contribute to a substantial increase in total service coverage across all distance ranges. The largest coverage improvement occurs between 4–5 km, followed by 3–4 km, suggesting that establishing new fire stations in strategic locations would effectively enhance emergency response reach, particularly in previously underserved regions. Conversely, service coverage within 0–1 km and 1–2 km remains relatively limited, reflecting fewer markets or facilities located very close to fire stations.

Overall, these maps reinforce the analytical results by visually confirming that the addition of strategically located fire stations would minimize response time, improve market safety, and ensure more equitable distribution of emergency services across the study area. The proposed fire station network demonstrates substantial improvements in geographic coverage equity, reducing response time disparities and extending adequate service to previously underserved market areas. These recommendations provide a data-driven foundation for emergency services infrastructure planning and resource allocation (Roodposhti et al., 2016).

Discussion

The findings reveal significant spatial inequities in the accessibility of fire stations across Akure South LGA. The dispersed distribution of markets (NNR = 1.426) across the LGA means that fire service demand is not concentrated in a single zone but rather spread across multiple commercial nodes. Against this background, the extremely wide spacing of the three fire stations, as evidenced by an NNR of 36.022 and a mean market-to-station Euclidean distance of 3.7 km, creates a structural mismatch between demand distribution and supply location.

These findings are broadly consistent with the literature on emergency service distribution in rapidly urbanizing African cities. Oppong et al. (2016) similarly identified spatial disparities in fire station coverage in Kumasi, Ghana, attributing gaps to urban expansion outpacing infrastructure investment.

Aktaş et al. (2013) demonstrated that strategic repositioning of fire stations using GIS-based location-allocation modelling could reduce average response times by up to 40% in Istanbul. The Akure findings suggest comparable gains could be realized through the proposed station locations.

A key methodological limitation of this study is its reliance on Euclidean distance rather than network-based travel time analysis. Euclidean distance systematically underestimates actual travel distances; previous studies have found that road network distances are typically 20–50% greater than straight-line equivalents in urban areas (Apparicio et al., 2008; Phibbs & Luft, 1995). Consequently, the 3.7 km mean Euclidean distance likely corresponds to actual travel distances of 4.4–5.6 km, and the 8.7 km maximum to actual distances of 10.4–13.1 km.

Future analyses in Akure should incorporate a validated road network dataset within ArcGIS Network Analyst to generate time-based service areas, which would provide a more operationally meaningful measure of accessibility.

The ANN analysis results for fire stations carry a further important caveat: with only three stations, the ANN statistic is highly sensitive to sample size and the choice of study area boundary, producing extreme z-scores that have limited inferential value beyond confirming that the facilities are widely spaced. This limitation does not undermine the core finding—that fire station coverage in Akure South is spatially inadequate relative to market distribution—but cautions against over-interpreting the precise magnitude of the NNR. Future expansion of the fire station network, combined with repeat ANN analysis on a larger sample, would yield more robust inferential statistics.

The proposed fire station locations identified through service area optimization would substantially improve coverage equity, particularly in the 3–5 km deficit zones. However, siting decisions in practice must account for factors beyond spatial coverage, including land availability, infrastructure costs, population vulnerability, road network capacity for emergency vehicle deployment, and the existing institutional framework of the Ondo State Fire Service. An integrated multi-criteria location analysis incorporating these variables, using approaches such as the Analytic Hierarchy Process (AHP) combined with GIS-based MCLP, would strengthen the operational applicability of siting recommendations (Tao et al., 2022).

This study contributes a replicable GIS-based methodology for emergency service gap analysis in medium-sized Nigerian cities. The combination of Kernel Density Estimation hotspot identification, ANN distributional analysis, Euclidean proximity measurement, and service area modelling provides a scalable framework that can be applied to other urban centres facing similar infrastructure challenges.

Conclusion

This study examined the spatial relationship between fire stations and markets in Akure, Ondo State, Nigeria, utilizing GIS-based mapping and proximity analysis. The research was motivated by the critical role that fire station placement plays in disaster response effectiveness and public safety outcomes.

Three major findings emerge from this study. Firstly, the markets show a statistically significant dispersed distribution (NNR = 1.426, p = 0.014) across the LGA, creating varying fire service demand. Second, the three existing fire stations are widely spaced, generating a mean Euclidean distance of 3.7 km and a maximum of 8.7 km from the nearest fire station. These distances likely translate to actual travel times to these facilities. Thirdly, the hotspot analysis identifies southern and eastern areas as priority zones for infrastructure expansion. In these areas, proposed stations would achieve the largest reductions in market-to-station distances.

This research directly addresses Sustainable Development Goal 11 (SDG 11): Sustainable Cities and Communities, particularly the target of ensuring safe, inclusive, and accessible public services and infrastructure. By examining spatial inequities in emergency response coverage, this study contributes to building more resilient and sustainable urban communities where all residents have equitable access to life-saving emergency services.

This study has demonstrated the use of GIS-based spatial analysis to identify infrastructure deployment challenges and inform evidence-based solutions. This methodology also provides a replicable framework for emergency services planning, enabling policymakers, fire service administrators, and urban planners to make data-informed decisions regarding resource allocation and disaster management policy development. The research contributes substantially to the intersection of GIS technology and disaster management, offering practical insights that can enhance emergency response efficiency, reduce fire-related property damage and casualties, and improve overall community resilience in Akure and similar urban contexts. The study recommends establishment of new fire stations particularly in underserved areas for increased disaster preparedness.

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