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Spatial Accessibility Analysis of Tertiary Healthcare in the Awka Metropolitan Area, Anambra State, Nigeria

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Abstract

Background: Access to tertiary healthcare is a critical determinant of health outcomes, yet in many Nigerian cities the spatial distribution of specialist facilities has not kept pace with urban growth. The Awka Metropolitan Area, comprising six Local Government Areas (LGAs) in Anambra State — Awka South, Awka North, Dunukofia, Njikoka, Anaocha, and Orumba North — has undergone rapid population expansion as the seat of the Anambra State capital, raising concerns about equitable access to specialist and referral level care.

Objective: This study assesses the spatial accessibility of tertiary healthcare facilities across the Awka Metropolitan Area using a network based service area analysis within a Geographic Information System (GIS) environment, and quantifies the degree of spatial equity in access using statistical measures.

Methods: Gridded population data (GRID3 Nigeria, ~100 m resolution), road network data from OpenStreetMap, and tertiary health facility locations from the GRID3 Health Facilities Registry were processed in ArcGIS Pro. A network dataset was constructed with travel time impedance derived from road classification, and drive time service areas were generated at 30, 60, and 80 minute thresholds using the Service Area Analysis tool. Population within each catchment was aggregated using the Summarize Within tool. Spatial equity was tested using a chi square goodness of fit test comparing observed population distribution to an area proportional expectation, and a location quotient (LQ) analysis.

Results: Of an estimated 1,805,737 residents in the metropolitan area, only 30,902 people (1.71%) reside within 30 minutes of a tertiary facility, and 481,845 (26.68%) within 60 minutes. Beyond the network's maximum reachable extent of approximately 81 minutes, 1,292,985 residents (71.61%) fall into a healthcare "service desert." The chi square test (χ^2 = 668,681, df = 3, p <.001) confirmed that the population distribution across catchment zones deviates significantly from an area proportional expectation, while location quotients (6.17 for the 30 minute zone versus 0.80 for the service desert) indicate a strong concentration of accessible population in the urban core.

Conclusion: Tertiary healthcare access in the Awka Metropolitan Area is highly centralized and spatially inequitable. The majority of residents, particularly in the peri urban and rural LGAs, lack timely access to specialist care. Strategic siting of new facilities, investment in peripheral road infrastructure, and complementary outreach mechanisms are recommended to improve equity of access.

Keywords: spatial accessibility, tertiary healthcare, GIS, service area analysis, network analysis, Awka, Anambra State, Nigeria, health equity

1. Introduction

Access to healthcare is the most common determinant for population health, impacting aspects as broad ranging as the rates of death in pregnancy, the effectiveness of managing chronic health conditions and the survival rate of people following health crisis situations [1]. However the reach and level of intervention which tertiary services available at teaching centres and specialized centers and referral points can provide (diagnostic work, surgery, specialized care), is unable to be offered at earlier

stages of healthcare in the system. Due to the scarcity, and the capital requirements of developing tertiary health centers, as well as high cost for provision, (such high resource development needs a considerable patient base), this service is highly patchy, and largely focused in capitals and the largest urban areas of a State or Territory; resulting in increased travel distances to access specialist services by peri urban and rural communities. Healthcare accessibility is influenced not only by the geographic distribution of health facilities but also by broader institutional and structural factors that affect healthcare utilization and the quality of care (Ansari *et al*., 2025).

Nigeria operates a three tier healthcare system comprising primary, secondary, and tertiary levels of care, with tertiary institutions principally teaching hospitals and federal or state specialist centres — positioned at the apex of the referral chain. In practice, however, the siting of these institutions has historically reflected administrative and political considerations more than a systematic assessment of population distribution or transport accessibility. This mismatch between where tertiary facilities are located and where people actually live is a well documented source of health inequity in low and middle income countries, where poor road infrastructure compounds the problem of physical distance [2,3]. Effective healthcare delivery also depends on adequate workforce planning, appropriate allocation of human resources, and organizational capacity to support efficient healthcare services (Tasleem, 2026).

The Awka Metropolitan Area, situated in Anambra State in Nigeria's South East geopolitical zone, exemplifies this challenge. As the seat of the Anambra State capital, Awka has experienced sustained in migration, residential expansion, and commercial growth over the past two decades. The metropolitan area, as operationally defined in this study, extends beyond the historic urban core of Awka South and Awka North to encompass four additional, functionally linked Local Government Areas — Dunukofia, Njikoka, Anaocha, and Orumba North — which together form a contiguous zone of commuter flow, economic interdependence, and shared reliance on the tertiary health facilities concentrated within the capital territory. Despite this expanding population base, the number and distribution of tertiary healthcare facilities serving the metropolitan area has not grown proportionately, and the road network connecting outlying communities to these facilities remains, in many areas, underdeveloped.

Geographic Information Systems (GIS) and network based accessibility analysis provide a robust methodological framework for examining this kind of spatial mismatch. By combining high resolution gridded population data with road network topology and facility locations, it is possible to model realistic travel times rather than simple straight line distances and to delineate the actual catchment areas served by tertiary facilities within specified time thresholds [4]. This approach has been applied extensively in both high income and resource constrained settings to identify underserved populations, inform facility siting decisions, and evaluate the equity of existing health infrastructure [5,2].

1.1. Statement of the Problem

Anecdotal and administrative evidence suggests that tertiary healthcare facilities within the Awka Metropolitan Area are concentrated in the urban core, while residents of the surrounding peri urban and rural LGAs must travel considerable distances, often over poorly maintained roads to reach specialist care. However, this perception has not been rigorously quantified using empirical, network based spatial analysis. Without a clear, data driven understanding of which populations are well served, moderately served, or effectively excluded from timely access to tertiary care, health planners and policymakers lack the evidence base needed to prioritize new facility siting, road investment, or outreach interventions. This study addresses that gap.

1.2. Aim and Objectives

The aim of this study is to assess the spatial accessibility of tertiary healthcare facilities across the Awka Metropolitan Area using GIS based network analysis, and to statistically evaluate the degree of spatial equity in the resulting pattern of access. The specific objectives are to:

1. map the distribution of tertiary healthcare facilities and the road network within the Awka Metropolitan Area;
2. generate drive time service area catchments around tertiary facilities using network analysis;
3. quantify the population residing within each accessibility catchment and identify areas falling outside the maximum reachable extent (the service desert);
4. statistically test whether the observed population distribution across catchment zones departs significantly from an area proportional expectation; and
5. recommend evidence based interventions to improve equity of access to tertiary healthcare within the study area.

1.3. Significance of the Study

The findings of this study are intended to support the Anambra State Ministry of Health, hospital planning authorities, and urban development agencies in identifying priority areas for new tertiary health infrastructure, ambulance and referral services, and road network upgrades. The study also contributes to the growing body of GIS based health accessibility literature focused on Nigerian urban agglomerations, and provides a replicable methodological template for similar assessments in other Nigerian metropolitan areas.

1.4. Scope and Limitations

The study covers the six LGAs constituting the Awka Metropolitan Area and focuses exclusively on physical (geographic) accessibility to tertiary level facilities, measured as network travel time under free flow conditions. It does not assess facility capacity, quality of care, staffing levels, or affordability, nor does it model public transportation or walking as alternative travel modes. These and other methodological limitations are discussed in detail in Section 3.9.

2. Study Area

The Awka Metropolitan Area is operationally defined in this study as the contiguous zone covering six Local Government Areas (LGAs) of Anambra State, Nigeria: Awka South, Awka North, Dunukofia, Njikoka, Anaocha, and Orumba North. This delineation reflects the continuous urban and peri urban sprawl radiating from Awka the Anambra State capital together with the well documented commuter flow, economic interdependence, and shared service catchment linking these six LGAs. Awka South and Awka North form the historic administrative and commercial core of the metropolitan area,

while Dunukofia, Njikoka, and Anaocha form an inner ring of peri urban LGAs directly bordering the capital territory, and Orumba North represents a more distal but functionally linked LGA within the wider metropolitan commuter shed.

The study area lies within Anambra State's Central and South senatorial districts in Nigeria's South East geopolitical zone. Based on official administrative area figures for the six constituent LGAs, the total land area of the Awka Metropolitan Area is approximately 1,104.9 km² (Table 1). It should be noted that this administrative area figure is provided as descriptive context for the study area; the network based service area analysis in Section 3 operates on the road network and population surface actually clipped for the GIS workflow, whose effective reachable extent (approximately 81 minutes of travel time) is discussed in Section 4.

Table 1: Local Government Areas Comprising the Awka Metropolitan Area

LGA	Headquarters	Area (km²)	Role in Metropolitan Area
Awka South	Amawbia	164.2	Urban core
Awka North	Achalla	347.5	Urban core
Dunukofia	Ukpo	75.0	Inner peri urban ring
Njikoka	Abagana	84.4	Inner peri urban ring
Anaocha	Neni	113.2	Inner peri urban ring
Orumba North	Ajalli	320.6	Outer metropolitan LGA
Total	—	1,104.9	—

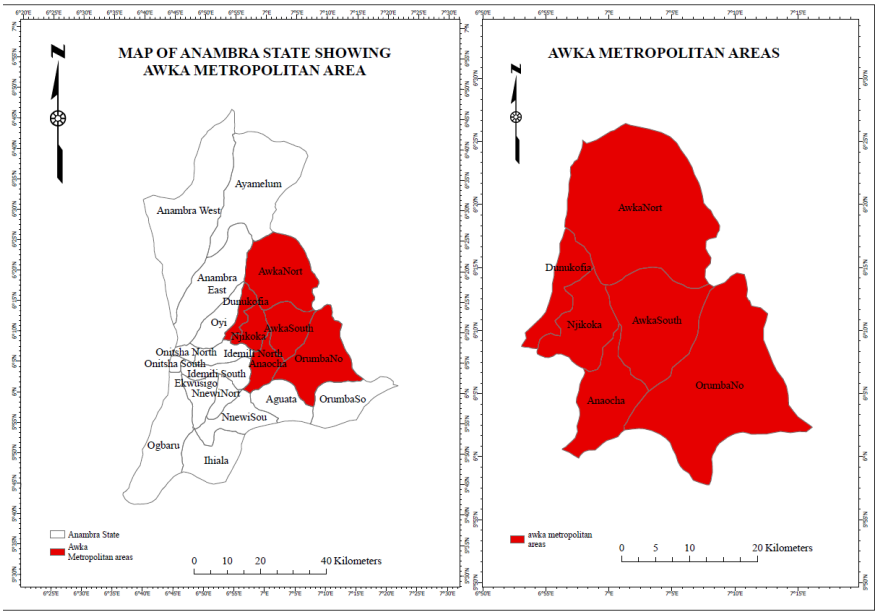


Fig 1: Study Area Map of the Awka Metropolitan Area

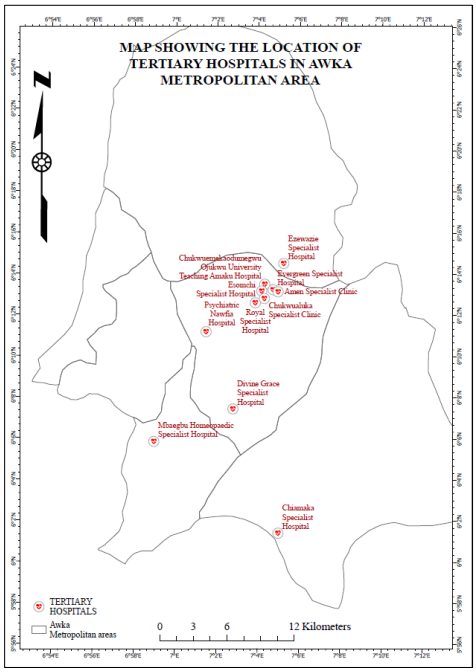


Fig 2: Map Showing the Location of Tertiary Hospitals in the Awka Metropolitan Area

The terrain across the study area is generally undulating lowland characteristic of south central Anambra State, with elevations gently rising from the Niger Delta influenced western fringe toward the higher plains around Awka and Orumba North. The climate is tropical, with a pronounced wet season (April–October) and dry season (November–March), and vegetation transitions from derived savanna in the more urbanized core to secondary rainforest and farmland in the outer LGAs. Population within the metropolitan area is unevenly distributed, with the highest densities concentrated in Awka town and its immediate environs, and progressively lower densities toward the peri urban and rural fringes of Awka North, Dunukofia, and Orumba North — a pattern that, as shown in Section 4, correlates closely with the observed pattern of healthcare accessibility.

3. Materials and Methods

3.1. Study Area Delineation

As described in Section 2, the Awka Metropolitan Area was operationally defined as the contiguous area covering six Local Government Areas (LGAs) of Anambra State — Awka South, Awka North, Dunukofia, Njikoka, Anaocha, and Orumba North. This delineation is based on the continuous urban and peri urban sprawl and commuter flow linking the six LGAs, which collectively serve as the primary economic, administrative, and healthcare service hub of Anambra State.

3.2. Data Sources

3.2.1. Population Data

Population data were obtained from the GRID3 (Geo Referenced Infrastructure and Demographic Data for Development) Nigeria Bottom up Gridded Population Estimates, Version 2.0 [6]. This dataset provides high resolution gridded population estimates at a spatial resolution of approximately 100 metre grid cells for Nigeria. Populations were mapped into areas where residential settlements were detected based on satellite imagery. The data were produced by the WorldPop Research Group at the University of Southampton in collaboration with Nigeria's National Population Commission, as part of the GRID3 programme.

3.2.2. Road Network Data

Road network data were obtained from OpenStreetMap (OSM) via the Humanitarian Data Exchange (HDX) platform. The dataset includes road classifications (trunk, primary, secondary, tertiary, residential, unclassified, service, track, and path) required for assigning travel speeds and constructing the network dataset for accessibility analysis.

3.2.3. Healthcare Facility Data

Tertiary healthcare facility locations were obtained from the GRID3 Nigeria Health Facilities Registry. The dataset was filtered to include only tertiary level facilities (teaching hospitals and specialist centres) within the study area. Facility locations were verified and used as destination points (facilities) for the service area analysis.

3.2.4. Administrative Boundary Data

Administrative boundaries for the six constituent LGAs (Awka South, Awka North, Dunukofia, Njikoka, Anaocha, and Orumba North) were obtained from the Humanitarian Data Exchange (HDX) Nigeria Administrative Boundaries dataset.

3.3. Data Preprocessing

3.3.1. Coordinate System Standardization

All datasets were projected to WGS 1984 UTM Zone 32N (EPSG: 32632) to ensure accurate distance and area calculations. This projected coordinate system is appropriate for Nigeria and provides linear units in metres, which are essential for travel time estimation.

3.3.2. Study Area Extraction

The Awka Metropolitan Area boundary was created by selecting and merging the six constituent LGAs from the Nigeria administrative boundary dataset. All subsequent datasets (roads, population, and health facilities) were clipped to this boundary to ensure spatial consistency.

3.3.3. Population Data Processing

The GRID3 population raster was first clipped to the Awka Metropolitan Area boundary. The clipped raster was then converted to point features using the Raster to Point tool. Each point represents a 100 m × 100 m grid cell and contains an attribute field (grid_code) storing the estimated population count for that cell. This point based representation enabled subsequent spatial overlay and population aggregation within catchment areas.

3.3.4. Road Network Preparation

Road speeds were assigned based on road classification using the following schema:

- **Trunk roads:** 80 kilometres per hour
- **Primary roads:** 60 kilometres per hour
- **Secondary roads:** 40 kilometres per hour
- **Tertiary roads:** 30 kilometres per hour
- **Residential and unclassified roads:** 20 kilometres per hour
- **Service and track roads:** 15 kilometres per hour
- **Paths:** 5 kilometres per hour

A travel time field (travel_time) was calculated for each road segment using the formula:

$$\text{TravelTime} = (\text{Shape_Length} \div \text{Speed}) \times 60$$

where Shape_Length is in metres, Speed is in kilometres per hour, and the result is in minutes. This field served as the impedance (cost) attribute for network analysis.

3.4. Network Dataset Construction

A network dataset was constructed to enable network based accessibility analysis. The network dataset serves as the foundation for calculating travel times along actual road networks rather than straight line (Euclidean) distances.

3.4.1. Feature Dataset Creation

A feature dataset named Transportation was created within the project geodatabase, using the WGS 1984 UTM Zone 32N coordinate system. The prepared road feature class was imported into this feature dataset.

3.4.2. Network Dataset Creation

The Create Network Dataset tool was used to build the network dataset with the following specifications: Name — Awka_Roads_ND; Source Feature Class — the projected road layer; Connectivity Policy — Any Vertex (ensuring roads connect at all intersection points, including where lines cross or overlap); Elevation Model — None.

3.4.3. Impedance Attribute Configuration

A Time cost attribute was added to the network dataset with the following properties: Name — Time; Units — Minutes; Data Type — Double; Evaluator Type — Field; Evaluator Value — travel_time (the calculated travel time field from the road attribute table). A travel mode was then created within the network dataset, specifying Time as the impedance attribute. This travel mode was used for all subsequent network analyses.

3.4.4. Network Building

The network dataset was built using the Build Network tool, which creates the necessary network topology and indexes for efficient routing.

3.5. Service Area Analysis

Service area analysis was conducted to delineate the geographic extent of tertiary healthcare accessibility within specified travel time thresholds.

3.5.1. Analysis Layer Creation

The Make Service Area Analysis Layer tool was used to create a service area network analysis layer with the following parameters: Input Network Dataset — Awka_Roads_ND; Travel Mode — the custom travel mode with Time as impedance; Travel Direction — Away From Facilities (modelling patient travel from homes to hospitals).

3.5.2. Facility Location Loading

Tertiary hospitals were added as facilities using the Add Locations tool. Each facility was snapped to the nearest road network node to ensure accurate routing.

3.5.3. Cutoff Thresholds

Based on the maximum reachable extent of the network (approximately 81 minutes) and following established healthcare accessibility guidelines, the following cutoff thresholds were applied: 30 minutes (urban core — highly accessible); 60 minutes (peri urban — moderately accessible); and 80 minutes (maximum network extent — poorly accessible). The choice of 80 minutes as the upper threshold reflects the empirical maximum travel time achievable within the connected road network of the study area, avoiding the imposition of arbitrary thresholds that exceed the network's physical extent.

3.5.4. Polygon Generation

The analysis was solved using the Solve tool, generating service area polygons for each cutoff value. The polygons were generated using Generalized polygon geometry to produce simplified, non overlapping catchment boundaries.

3.6. Catchment Classification and Dissolution

3.6.1. Classification of Catchment Zones

The service area polygons contained ToBreak values representing the actual travel time to the edge of each polygon. A new integer field (ZONE) was added to the polygon attribute table and calculated using the classification logic: values of 30 minutes or less were classified as 30; values from 31 to 60 minutes were classified as 60; and all remaining values (61–80 minutes) were classified as 80. This classified all polygons into three discrete catchment zones.

3.6.2. Dissolution

The classified polygons were dissolved using the Dissolve tool, with the ZONE field as the dissolve field. This merged all individual polygon fragments into three contiguous catchment zones (30, 60, and 80 minutes), eliminating internal boundaries and producing a clean, simplified representation of each catchment.

3.7. Population Coverage Analysis

Population coverage analysis was conducted to quantify the number of people residing within each catchment zone and to identify the population residing outside the maximum reachable threshold (the “Service Desert”).

3.7.1. Population Aggregation

The Summarize Within tool was used to overlay the dissolved catchment polygons with the population points. The tool was configured with Input Polygons — the dissolved catchment zones; Input Summary Features — the population points; Summary Field — grid_code (population count); Statistic Type — Sum. This operation aggregated the total population count of all points falling within each catchment polygon.

3.7.2. Total Population Calculation

The total population of the study area was obtained by calculating the Sum statistic on the grid_code field of the population points layer. This yielded a total population of approximately 1,805,737 persons for the Awka Metropolitan Area.

3.7.3. Service Desert Quantification

The population residing outside the 80 minute catchment was classified as the Service Desert — areas with no effective access to tertiary healthcare within the maximum reachable travel time. This was calculated as: Service Desert Population = Total Population − Population inside 80 minute catchment.

3.8. Statistical Analysis of Spatial Equity

To move beyond descriptive reporting of population counts per zone and assess the degree of spatial equity in tertiary healthcare accessibility, two complementary statistical measures were applied to the population coverage results derived in Section 3.7.

3.8.1. Chi Square Goodness of Fit Test

A chi square (χ^2) goodness of fit test was used to test the null hypothesis that population is distributed uniformly with respect to the land area of each accessibility zone (i.e., that population density does not vary systematically with proximity to tertiary facilities). For each zone i, the expected population (E_i) under an area proportional (uniform density) distribution was calculated as:

$$E_i = (Area_i \div Total\ Area) \times Total\ Population$$

The test statistic was then computed as $\chi^2 = \Sigma[(O_i - E_i)^2 \div E_i]$, where O_i is the observed population in zone i. The test was

applied across four mutually exclusive zones — the 30 minute, 60 minute, and 80 minute catchments, and the service desert area beyond the network's maximum reachable extent — giving three degrees of freedom. A statistically significant result (rejecting the null hypothesis) would indicate that the observed pattern of access is not explained by area alone, and reflects genuine spatial concentration or exclusion.

3.8.2. Location Quotient (LQ) Analysis

To characterize the direction and magnitude of over or under representation in each zone, a location quotient was calculated as the ratio of a zone's share of total population to its share of total study area land:

$$LQ_i = (Population\ Share_i) \div (Area\ Share_i)$$

An LQ greater than 1.0 indicates that a zone holds a disproportionately large share of the population relative to its land area (i.e., population is "over represented" in accessible zones), while an LQ below 1.0 indicates under representation. This measure provides an intuitive, zone by zone complement to the aggregate chi square test.

3.9. Methodological Limitations

Several limitations should be acknowledged:

1. **Road Network Completeness:** The OpenStreetMap road network may not capture all local roads, particularly in peri urban and rural areas, potentially underestimating accessibility in some locations.
2. **Uniform Speed Assumptions:** Average speeds were assigned based on road classification without accounting for real time traffic conditions, road quality, or seasonal variations.
3. **Population Data Resolution:** The GRID3 population data at 100 m resolution may not capture the exact distribution of population at the household level.
4. **Healthcare Facility Capacity:** This study measured spatial accessibility (travel time) only and did not consider hospital capacity (beds, staff, equipment) or quality of care.
5. **Single Mode Analysis:** The analysis considered only private vehicle travel and did not account for public transportation or walking, which may be relevant for certain population groups.
6. **Study Area Boundary Refinement:** The metropolitan area boundary used for population totals and administrative area figures (Section 2) was refined during the course of this study to reflect all six constituent LGAs rather than Awka South and Awka North alone. Readers should note that the underlying road network and service area geoprocessing reflect the network's own connected extent (≈ 81 minute maximum reachable travel time) rather than the full administrative boundary, and that a full re run of the network analysis on the complete six LGA road network is recommended as a direct extension of this study to refine the precision of the reported figures.

Despite these limitations, the methodology provides a robust, data driven assessment of spatial accessibility to tertiary healthcare in the Awka Metropolitan Area, following established GIS based accessibility analysis frameworks [1,4].

4. Results

4.1. Population Distribution in the Awka Metropolitan Area

The GRID3 population data estimated the total population of the Awka Metropolitan Area at approximately 1,805,737 persons. This population is unevenly distributed across the study area, with higher concentrations in the urban core of Awka town (Awka South and Awka North) and progressively lower densities toward the peri urban and rural LGAs of Dunukofia, Njikoka, Anaocha, and Orumba North.

4.2. Service Area Catchments

The network based service area analysis generated three distinct catchment zones for tertiary healthcare facilities, summarized in Table 2.

Table 2: Service Area Catchment Zones

Zone	Travel Time	Description
30 minutes	≤ 30 minutes	Urban core (highly accessible)
60 minutes	31–60 minutes	Peri urban (moderately accessible)
80 minutes	61–80 minutes	Maximum network extent (poorly accessible)

The maximum reachable travel time within the connected road network was approximately 81 minutes. This indicates that the road network, as represented in the OpenStreetMap dataset, does not extend meaningfully beyond this threshold within the study area, likely reflecting road network fragmentation in the peri urban and rural fringes.

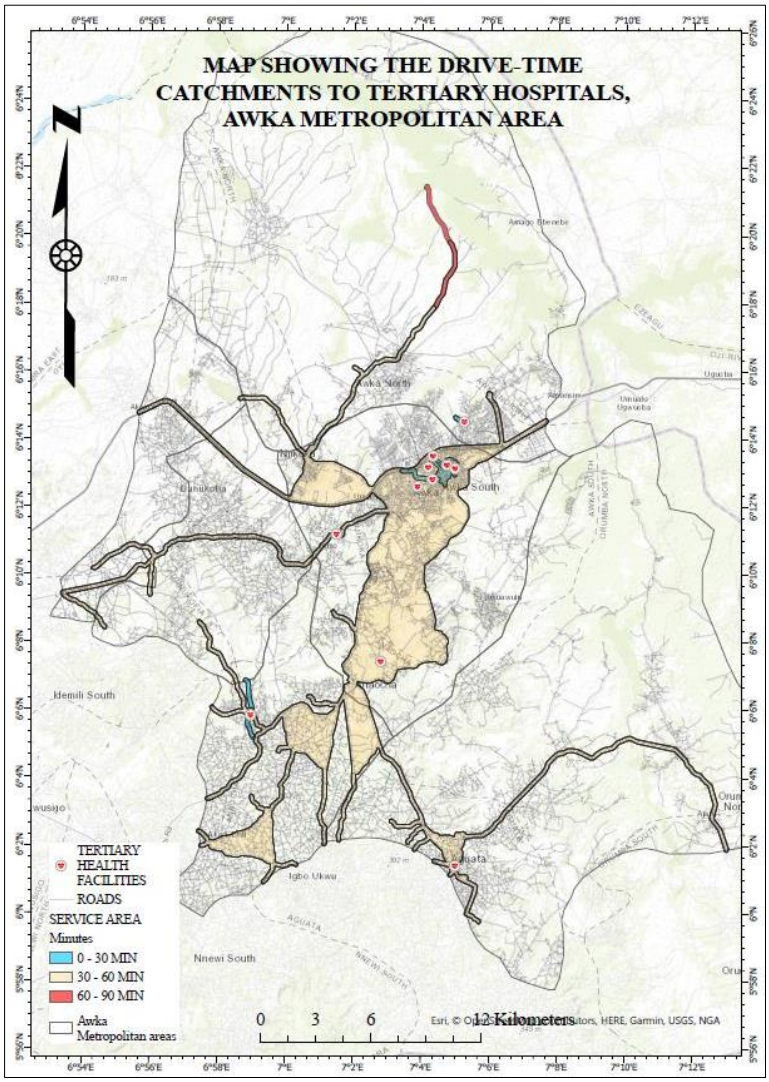


Fig 3: Service Area Catchments Showing the 30, 60, and 80 Minute Drive Time Zones Around Tertiary Hospitals

4.2.1. Geographic Extent of Catchments

1. The 30 minute catchment is limited to the immediate urban core surrounding the tertiary hospitals, covering a relatively small geographic area (approximately 3.06 km²).
2. The 60 minute catchment extends across the main metropolitan area, covering approximately 114 km² and capturing the largest population.
3. The 80 minute catchment is minimal (approximately 1.65 km²), confirming that the road network effectively ends beyond 60 minutes.

4.3. Population Coverage Analysis

The population coverage analysis revealed the number of people residing within each catchment zone, summarized in Table 3 and illustrated in Figures 4 and 5.

Table 3: Population Coverage by Accessibility Zone

Zone	Population	Percentage
30 minutes	30,902	1.71%
60 minutes	481,845	26.68%
80 minutes	5	0.0003%
Total within 80 minutes	512,752	28.39%
Service Desert (> 80 minutes)	1,292,985	71.61%
Total Population	1,805,737	100.00%

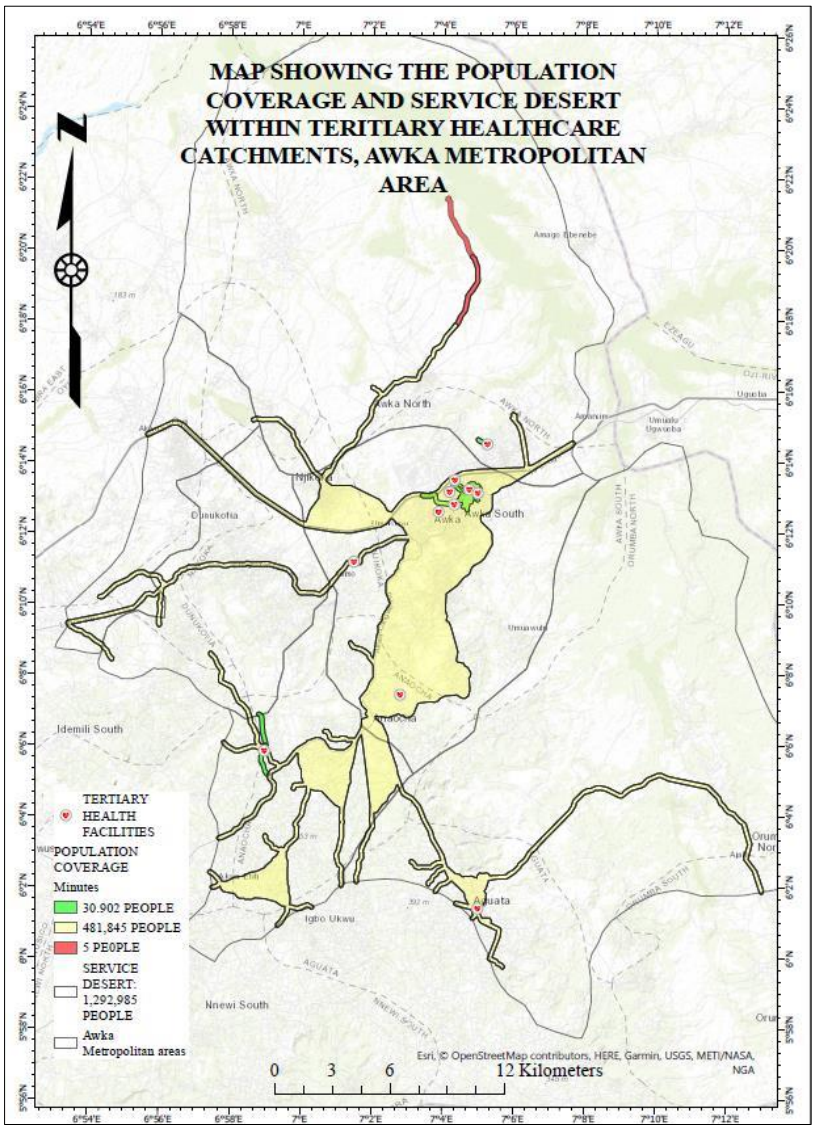


Fig 4: Population Coverage Showing the Number of People Within Each Catchment Zone and the Service Desert Area

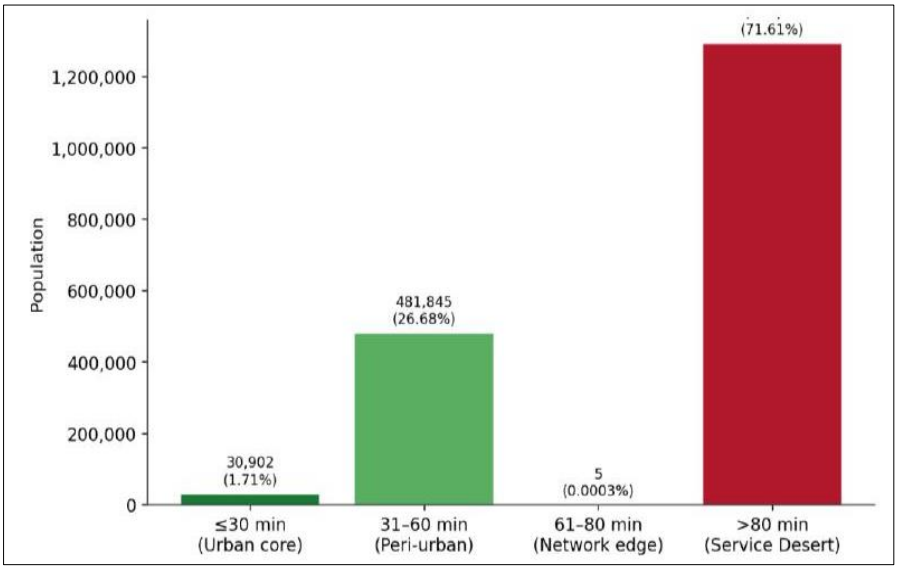


Fig 5: Population Distribution by Travel Time Catchment Zone to Tertiary Healthcare Facilities

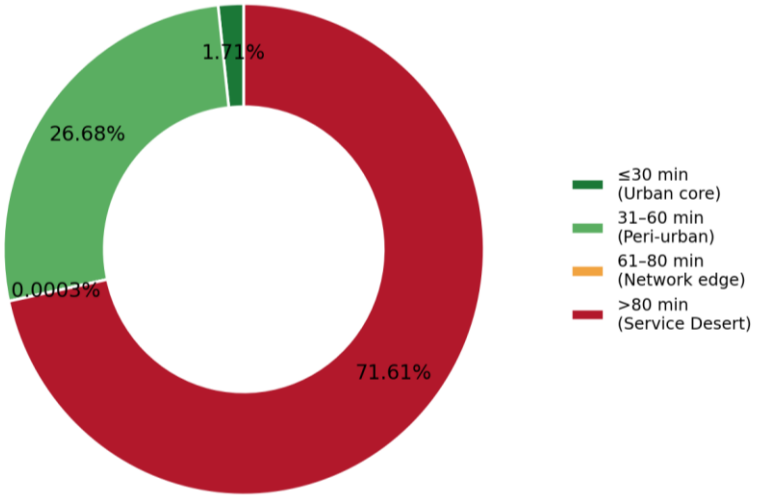


Fig 6: Percentage Share of Population by Healthcare Accessibility Zone

4.3.1. Population Served

1. Approximately 30,902 people (1.71%) live within the 30 minute catchment, representing the highly accessible urban core.
2. Approximately 481,845 people (26.68%) live within the 60 minute catchment, indicating a moderately accessible peri urban zone.
3. The 80 minute catchment contains only 5 people (0.0003%), confirming that the road network effectively ends beyond the 60 minute threshold.

4.3.2. Service Desert (Population Excluded)

Approximately 1,292,985 people (71.61%) fall outside the 80 minute threshold, constituting a significant Service Desert with no access to tertiary healthcare within the maximum reachable travel time.

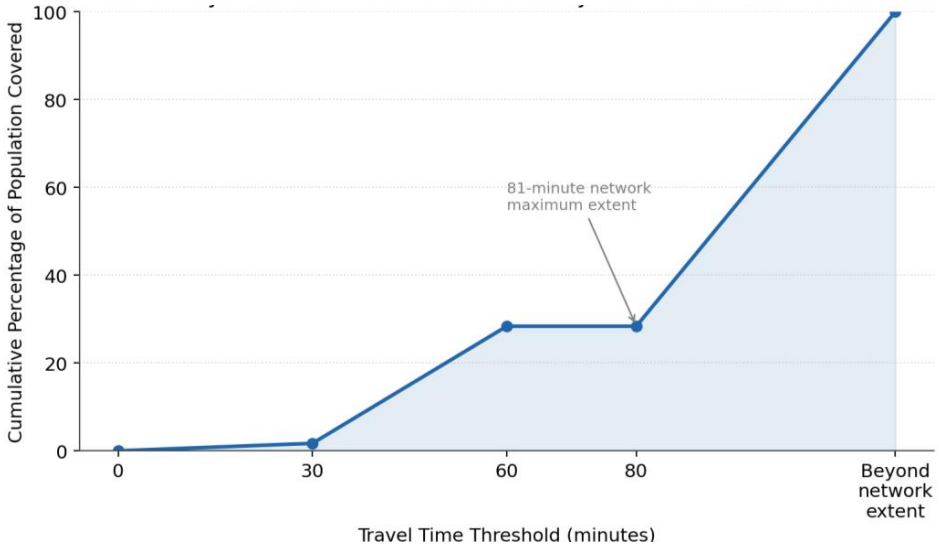


Fig 7: Cumulative Population Coverage Curve by Travel Time Threshold

Figure 7 illustrates how sharply population coverage plateaus once the 60 minute threshold is passed: only an additional 0.0003 percentage points of the population are added between 60 and 80 minutes, and the curve does not resume until the entire remaining 71.61% of the population is captured in the undifferentiated service desert category beyond the network's reachable extent. This step like pattern is itself evidence of a sharply bounded, rather than gradually declining, zone of effective access.

4.4. Statistical Analysis of Spatial Equity

4.4.1. Chi Square Goodness of Fit Test

Applying the method described in Section 3.8.1, the expected population in each zone under an area proportional (uniform density) distribution was calculated from each zone's share of the total study area land (1,104.9 km²) and the total metropolitan population (1,805,737). The results are presented in Table 4.

Table 4: Observed vs. Expected Population Under an Area Proportional Distribution

Zone	Area Share	Observed Population	Expected Population	$(O - E)^2 \div E$
30 minutes	0.277%	30,902	5,002	134,108
60 minutes	10.318%	481,845	186,300	468,850
80 minutes	0.149%	5	2,690	2,680
Service Desert	89.256%	1,292,985	1,611,745	63,043

The resulting chi square statistic was $\chi^2 = 668{,}681$ with 3 degrees of freedom ($p < .001$), several orders of magnitude above the critical value required for significance at the 0.001 level ($\chi^2_{0.001,3} = 16.27$). The null hypothesis of an area proportional (uniform density) distribution of population across accessibility zones is therefore firmly rejected: the observed pattern of access is not a statistical artifact of zone size, but reflects a genuine, pronounced spatial concentration of the accessible population within a very small share of the metropolitan area's land.

It should be noted that with a very large population base (N = 1,805,737), the chi square statistic is highly sensitive and will register statistical significance even for comparatively small deviations; the magnitude of χ^2 observed here, however, is large enough that the substantive conclusion — a severe mismatch between population distribution and area proportional access — is not an artefact of sample size alone. This is corroborated by the location quotient analysis below.

4.4.2. Location Quotient Analysis

Location quotients, calculated per Section 3.8.2, are presented in Table 5 and Figure 8.

Table 5: Location Quotients by Accessibility Zone

Zone	Population Share	Area Share	Location Quotient
30 minutes	1.71%	0.277%	6.17
60 minutes	26.68%	10.318%	2.59
80 minutes	0.0003%	0.149%	0.02
Service Desert	71.61%	89.256%	0.80

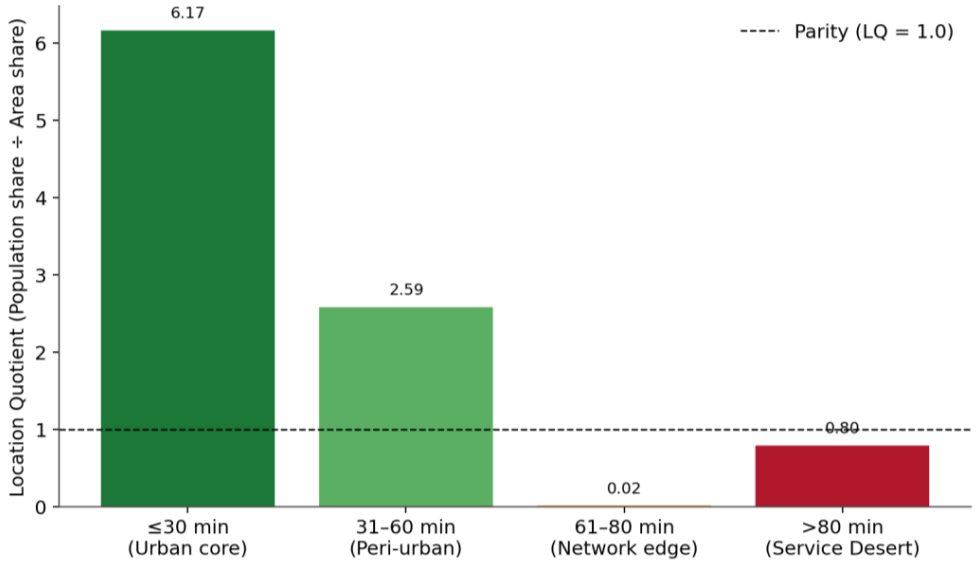


Fig 8: Location Quotient of Population Representation Across Healthcare Accessibility Zones

The 30 minute zone shows an LQ of 6.17, meaning that this zone's share of the metropolitan population is more than six times greater than its share of land area — a strong indication that population is concentrated precisely where access is best, consistent with historical development patterns clustering around the urban core and its health infrastructure. The 60 minute zone (LQ = 2.59) is likewise over represented, though less markedly. The 80 minute zone (LQ = 0.02) is almost entirely depopulated relative to its area, consistent with it representing marginal, sparsely settled land at the network's edge. Most notably, the service desert zone — despite containing 71.61% of the metropolitan population — registers an LQ of only 0.80, indicating that this population is somewhat under represented relative to the area's share of land, but not as extremely under represented as the raw population percentage alone might suggest. Read together, the chi square and LQ results indicate a metropolitan area where accessible land is scarce and densely populated, while the great majority of residents are spread across a much larger, and comparatively lower density, area with no effective tertiary healthcare access within the network's maximum reachable extent.

4.5. Summary of Key Findings

Table 6: Summary of Key Findings

Finding	Value	Implication
Total Population	1,805,737	Awka Metropolitan Area population
Population within 30 min	30,902 (1.71%)	Highly accessible urban core
Population within 60 min	481,845 (26.68%)	Moderately accessible peri urban zone
Population within 80 min	5 (0.0003%)	Maximum network extent
Service Desert Population	1,292,985 (71.61%)	No access to tertiary healthcare
Chi square statistic	$\chi^2 = 668{,}681$, df = 3, $p < .001$	Significant deviation from area proportional access
Location Quotient (30 min zone)	6.17	Population strongly concentrated near facilities

4.6. Spatial Patterns of Accessibility

The analysis reveals a pronounced centralization of tertiary healthcare services within the Awka urban core. The 30 and 60 minute catchments are largely confined to the central metropolitan area, with significant portions of the peri urban and outer LGAs — particularly Dunukofia, Anaocha, and Orumba North — falling outside the maximum reachable threshold. The spatial pattern demonstrates that:

1. Tertiary hospitals are concentrated in the city centre, resulting in unequal geographic distribution of services across the six LGA metropolitan area.
2. Peri urban and rural areas are systematically excluded from the catchment zones, a pattern confirmed statistically by both the chi square goodness of fit test and the location quotient analysis.
3. The majority of the population (71.61%) lacks timely access to specialist healthcare, highlighting a critical spatial inequity that road investment and facility decentralization could help address.

5. Discussion

5.1. Interpreting the Pattern of Spatial Inequity

The results presented in Section 4 confirm, with strong statistical support, what administrative observation had long suggested: tertiary healthcare access within the Awka Metropolitan Area is highly centralized. Only 28.39% of the metropolitan population resides within the network's maximum reachable extent of tertiary facilities, and even this figure is dominated by the 60 minute zone; the immediately accessible 30 minute zone contains less than two percent of the population. This pattern is consistent with the broader literature on spatial accessibility to specialist care, which consistently finds that referral level facilities — being few, costly, and historically sited according to administrative rather than demographic logic — tend to produce steep accessibility gradients between urban cores and their peripheries [1,4].

The chi square goodness of fit test provides a rigorous confirmation that this pattern cannot be explained merely by the differing sizes of the catchment zones. If population were distributed uniformly with respect to land area, the 30 minute zone would be expected to contain roughly 5,000 people; it instead contains over 30,000 — more than six times the area proportional expectation, as reflected in its location quotient of 6.17. This is not, in itself, an undesirable pattern per se: some concentration of population around urban service centres is expected and even efficient. What is concerning is the corollary: 71.61% of the metropolitan population lives in the service desert zone beyond the network's maximum reachable extent, with no meaningful network based route to a tertiary facility within a reasonable travel time envelope.

5.2. Comparison with Regional and International Evidence

The magnitude of exclusion identified in this study is broadly consistent with findings from other GIS based accessibility studies conducted in Sub Saharan African contexts. Tanser *et al.* [2], in a comparable network based analysis of primary healthcare access in rural KwaZulu Natal, South Africa, found that clinic utilization declined sharply beyond an 85 minute travel time threshold — a distance decay effect closely mirroring the near total absence of population within the Awka network's 80 minute catchment observed in this study. Similarly, Wang's [3] methodological review of health care accessibility measurement emphasizes that raw distance or travel time thresholds, when combined with population weighted analysis, routinely reveal concentration effects of the kind captured here by the location quotient results.

What distinguishes the Awka case is the sheer steepness of the drop off: population coverage effectively plateaus at 60 minutes, with only a negligible increment added by 80 minutes, before the entire remaining majority of the population falls into an undifferentiated “beyond network” category. This suggests that the constraint is not primarily one of travel time tolerance among residents — as modelled through distance decay functions in the South African case — but of road network fragmentation itself: much of the outer metropolitan area, particularly in Dunukofia, Anaocha, and Orumba North, appears to lack the connected, classified road infrastructure needed for the network dataset to route a feasible path to a tertiary facility at all.

5.3. Urban–Peri Urban Divide and Its Drivers

Several interacting factors likely underlie the observed spatial mismatch. First, the historical siting of tertiary hospitals in Nigeria has generally followed administrative rather than demand based logic, with teaching hospitals and specialist centres established in state capitals largely irrespective of the subsequent growth trajectory of surrounding peri urban LGAs. Second, road infrastructure investment in Anambra State — as in many Nigerian states — has historically prioritized arterial corridors connecting major towns over the finer grained secondary and tertiary road networks needed to connect rural settlements to those corridors, a pattern reflected in the road speed classification scheme applied in this study's network dataset. Third, the rapid population growth experienced by Awka as state capital has not been matched by a proportional expansion of specialist health infrastructure, meaning that even the existing facilities are increasingly strained relative to the metropolitan population they nominally serve.

5.4. Implications for Health Equity and Policy

These findings carry direct implications for the principle of health equity, understood as the fair distribution of health resources relative to population need [3]. A situation in which nearly three quarters of a metropolitan area's population lies outside the effective reach of specialist care represents a substantial equity concern, with likely downstream consequences for maternal mortality, delayed treatment of medical emergencies, and poorer management of chronic and complex conditions among peri urban and rural residents. The concentration of access within a small, already well served urban core, without a coherent policy response, risks entrenching rather than narrowing rural–urban health disparities as the metropolitan area continues to grow.

5.5. Study Limitations and Their Bearing on Interpretation

The limitations outlined in Section 3.9 warrant particular attention when interpreting these results. Most importantly, the underlying network analysis reflects the connectivity of the OpenStreetMap road dataset as captured at the time of analysis; given the acknowledged incompleteness of OSM road mapping in peri urban and rural Nigeria, some of the apparent service desert extent may reflect gaps in the road data rather than genuine physical inaccessibility. This possibility, however, does not undermine the study's central

finding — it may, if anything, suggest that even the true extent of the service desert as experienced by residents travelling on unmapped or informal routes is difficult to characterize with precision, reinforcing rather than weakening the case for targeted infrastructure and health facility investment in these areas. The exclusion of walking and public transport as travel modes also means the reported catchments likely represent a best case accessibility scenario for residents without private vehicle access, who make up a substantial share of the population in peri urban Anambra State.

6. Conclusions

This study applied a network based GIS accessibility analysis, combined with formal statistical testing, to assess spatial accessibility to tertiary healthcare across the six LGA Awka Metropolitan Area of Anambra State, Nigeria. The findings demonstrate a pronounced and statistically confirmed pattern of spatial inequity: only 28.39% of the metropolitan population resides within the maximum reachable travel time extent (approximately 81 minutes) of a tertiary healthcare facility, with the great majority of this coverage concentrated in a 60 minute zone occupying just over one tenth of the study area's land. The remaining 71.61% of residents — more than 1.29 million people — fall into a healthcare service desert with no effective network based access to specialist care.

The chi square goodness of fit test ($\chi^2 = 668{,}681$, df = 3, $p < .001$) confirmed that this pattern cannot be attributed to chance or to the differing sizes of the catchment zones alone, while the location quotient analysis quantified the degree of concentration, showing population representation in the best served zone to be more than six times greater than would be expected under an area proportional distribution. Together, these results provide a rigorous, quantitative evidence base confirming what has long been suspected qualitatively: that tertiary healthcare in the Awka Metropolitan Area is accessible to a small, geographically concentrated share of the population, while the majority — particularly residents of the peri urban and outer LGAs of Dunukofia, Njikoka, Anaocha, and Orumba North — face substantial, and in many cases effectively insurmountable, barriers to timely specialist care.

These findings underscore the urgency of coordinated intervention across health facility planning, road infrastructure investment, and health system decentralization if the Awka Metropolitan Area is to achieve equitable tertiary healthcare access commensurate with its rapid population growth as Anambra State's capital region.

7. Recommendations

7.1. Immediate Interventions

1. **Mobile and Outreach Clinics:** Deploy mobile specialist clinics and scheduled outreach programmes to serve the peri urban and outer LGAs identified as the service desert, particularly in Dunukofia, Anaocha, and Orumba North, pending longer term infrastructure solutions.
2. **Emergency Referral and Ambulance Services:** Strengthen emergency referral protocols and ambulance coverage for communities beyond the 60 minute catchment, prioritizing routes identified as critical gaps in the network analysis.
3. **Telemedicine Pilot Programmes:** Introduce telemedicine links between primary health centres in underserved LGAs and tertiary facilities in the urban core, to extend specialist consultation without requiring travel.

7.2. Long Term Strategic Interventions

1. **Strategic Siting of New Tertiary Facilities:** Use the location quotient and service desert findings from this study to inform the siting of new secondary to tertiary referral infrastructure in underserved LGAs, reducing the population currently outside the network's reachable extent.
2. **Road Network Investment:** Prioritize the upgrading and classification of secondary and tertiary roads connecting Dunukofia, Njikoka, Anaocha, and Orumba North to the urban core, directly extending the network's reachable extent for emergency and routine referral travel.
3. **Health System Decentralization:** Strengthen secondary level hospitals within the peri urban LGAs so that a larger share of specialist adjacent care can be delivered closer to where the underserved population resides, reducing dependence on travel to the urban core.

7.3. Monitoring, Research, and Data Improvement

1. **Continuous Accessibility Monitoring:** Establish periodic re runs of this GIS accessibility analysis (e.g., every two to three years) to track the impact of new facility siting and road investment on the extent of the service desert.
2. **Improved Road Network Data:** Support systematic ground truthing and community mapping initiatives to improve OpenStreetMap road coverage in peri urban and rural areas of the metropolitan area, addressing the data completeness limitation identified in Section 3.9.
3. **Multi Modal and Demand Side Research:** Extend future accessibility research to incorporate public transportation, walking accessibility, and facility capacity and quality indicators, to complement the purely geographic accessibility measures used in this study.
4. **Full Six LGA Network Re Analysis:** As identified in Section 3.9, a direct extension of this study should re run the network dataset construction and service area analysis using the complete road network and population surface for all six constituent LGAs, to refine and validate the population and area figures reported here.

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