



ROAD-NETWORK MORPHOLOGY, ACTIVITY CLUSTERING, AND URBAN-PLANNING PRIORITIES IN KAFANCHAN METROPOLIS, NIGERIA

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Abstract

The access to resources, settlement growth, infrastructure efficiency and dispersal of urban opportunities can be affected by road-network structure. The morphology, hierarchy and activity-related pattern of Kafanchan Metropolis, Kaduna State, Nigeria road network was studied. A planning-related investigation differs significantly from related works on developing a road construction monitoring application and the limiting factors of GIS and remote sensing implementation. A descriptive geospatial case-study adopted overlay of satellite images, GPS readings, prior morphological and infrastructural maps and field-verification. Road features were spatially automated, processed, classified and displayed within a unified GIS framework. Direction, distance, area, hotspot and network-traversal analyses were applied to interpret the orientation, hierarchy, connectivity, flow direction and activity density of road features. The resulting network is mainly a radial-corridor based network. Two major routes traversed the central business district to inter-city neighborhoods while interlinking route segments of the same hierarchy. Around commercial and administrative nodes higher aggregation of roads and activity was observed with the rest of the periphery having lower alternatives. The pattern enables movement inward but may lead to traffic and service centralisation along few intertwined corridors and nodes. Implication of the results is that construction should be monitored by the number of extra links in the existing network, hierarchy, geodesicity, redundancy, multimodal alternatives and compatibility to present and anticipated land uses. It is recommended that a topologically accurate road geo-database is produced, strategic corridor alignment preserved, cross-links implemented between radial corridors, junctions and activity aggregations upgraded and accessibility and centrality measures routinely computed. As the stored thesis document presents no numerical but reproducible network indices, the implications are interpreted as qualitative visual proof and should be complemented with graph theory calculations before generalisability.

Keywords: Road-network Morphology; Urban Accessibility; Activity Clustering; GIS; Transport Planning.

1. Introduction

Urban roads are also spatial systems. The pattern of different roads affects the investment in different parts of the city by spatially effective households and firms, the access to jobs and public services, the cost of infrastructure and urban capacity for expansion or shock. Road-network form is thus an increasingly important input for urban and regional planning. Because a city with a network that provides fast direct and alternative routes for activity can disperse activity and encourage accessible development, a network that depends heavily on a limited number of radial flows may intensify urban congestion and fragment marginal districts.

Road configuration is particularly important in secondary cities. These settlements are often the receivers of rapid population growth and public investment, yet lack extensive existing transport data networks that exist within larger metropolitan areas. New roads may be funded as standalone projects, not as part of a coherent network of routes. It is here that more roads does not equal better accessibility, but network coherence, functional arrangements, intersection levels, route redundancy, provision for pedestrians, and land use integration are as important.

Recent studies have modeled road networks as spatial graphs with intersections and dead-end streets as nodes and street

segments as edges. The geometric form indicates physical characteristics, while the network relationships measured through network topology are represented using metrics including node degree and circuitry and network connectivity, closeness, and betweenness. Kabanda (2023) provided evidence of key insights enabled by these techniques to examine travel accessibility and inequality in a secondary city in South Africa. Deng et al. (2023) found a similar connection between structure and function in urban roads as well. Chen et al. (2024) have revealed great variation in road-network patterns between cities, showing that forms of radial, grid, or hybrid are associated with different development and planning histories.

Kafanchan is an important urban centre for administration, trade and transport in south Kaduna State. However, urban up- grading and road construction are a threat to the existing network and present an opportunity to investigate if the network, as it is, can sustain development in a balanced way. The main thesis of the parent work comprised mapping of Road network using GIS (Geographic Information System) and remote sensing, designing a monitor display for various road and interfacing of the technology, along with the challenges of implementation. Two preliminary paper works have already been done, to investigate specifically how the technology can be integrated as well as various institutional and environmental challenges hampering the processes. This, therefore, is to examine a different aspect, i.e., the shape of the road network of Kafanchan and how this affects accessibility, land use concentration, corridor management and future development.

The study addresses three questions:

1. What features of morphology and hierarchy can be observed in the road network of Kafanchan as it is represented on the map?
2. How do road concentrations correspond with major urban activity areas?
3. What intervention strategies to planning arise from the configuration?

2. Literature Review

2.1 Road networks, urban form, and accessibility

Roads organize the flow of people, freight, services and information and set the pattern for physical development. Studies in urban morphology acknowledge this duality: roads are a prerequisite for development but, a process of demand stimulation ensues from network development. In peri-urban areas, Haldar et al. (2023) demonstrated a strong correlation between development and transport network accessibility, which occurs along accessibility 'front runners'. This role of roads in inducing development has implications for transport planning.

Accessibility is not the same as mobility. Mobility, however, is a function of the rate or capacity of movement, while accessibility is related to the ease of getting to where one wants to go. A high-speed arterial road may facilitate movement within the entire city, but on a local scale it may diminish accessibility if crossing it turns out to be difficult, if

no pedestrian facilities are provided, or if services are bypassed. UN-Habitat (2021) recommends integrated planning for land use and transport and streets tailored to different users.

Accessibility is affected by the network form. For example, graphical networks offer many route alternatives, short blocks, but may permit through-traffic on local roads. Multiple route forms such as tree- or highly hierarchical networks shield neighborhoods from districts, but result in longer walk distances and many collector streets. Radial networks connect outlying areas to the centre, but cause congestion at the radial point and inadequate cross-city connections. Hybrid networks have characteristics of multiple network types, so their viability must be studied within the local context.

2.2 Geometric and topological analysis

Maps used to interpret visual maps can determine if design is radial, linear, grid, or irregular in pattern; but the additional numerical indicators allow for reproducibility and comparison. In a network, density refers to the amount of street infrastructure present. The number of decision points can be expressed as a measure of intersection density. This is associated with route choice and walkability. Mean node degree refers to the number of intersections. Link-node ratios, -alpha, beta, and -gamma indices relate to the level of development of connections, completeness of connections, and circuitry (network distance/path distance).

Indicators of centrality show how functional they are. Betweenness finds those routes that are on many shortest paths and thus may channel more flow or develop into bottlenecks. Closeness shows how easily a location can ultimately access any other location in the network. Kabanda (2023) underlined that geometric and topological methods allows planners to recognize inequality in connectivity and fragile network arrangements. However, these indices perform accurately when road data has proper topology, the intersections are modelled correctly and direction of roads and the study limits are known.

2.3 Land-use clustering and corridor pressure

Commercial and administrative activities support accessible places and might build positive feedback loops of the network, traffic, and existing development. Concentration can enhance agglomeration economies and public-transport prospects, but also means pressure on junctions, less pedestrian security, and equity gaps for hinterland residents. Ahmadzai et al. (2020) highlighted the value of combining measures of land-use and the road-network in accessibility assessment. The conclusion is that a road-density peak does not, in itself, constitute urban planning success: its success hinges upon traffic flow, intermodal access, public-space quality, and links to underserved territory.

The pattern of road extension influences peri-urban land conversion as well. Radial routes servicing land areas that lack lateral links tend to develop along strips of open space while connecting open space is left unlinked. This pattern leads to longer trips, higher costs and the increased use of the

same thoroughfares. City planners can balance these consequences by safeguarding future links, aligning subdivision plots and reserving street widths until development is fully built up.

2.4 Research gap

Road-network studies of African cities are more frequently applying open data and network science principles, though evidence for secondary cities in Nigeria is sparse. Much of the published evidence for the subject is focused on monitoring or analysing highway condition, construction, and route optimisation, without offering much in the way of a morphology and planning structure interpretation. The Kafanchan thesis does offer mapped evidence and a separate map-based interpretation of the morphology, but not as a unique urban-morphology document. This paper provides this.

3. Materials and Methods

3.1 Study Area

Kafanchan Metropolis is situated south of Kaduna State, Nigeria. It is the capital of Jema'a LGA, Nigeria. The approximate location of the city as given in the thesis is 10 14 17.2 N 8 59 45.6 E while the approximate terrain covered in the study area is about 50 km² (see figure 1). Kafanchan Metropolis is an administrative and commercial center. Kafanchan is linked to neighboring settlements by road and rail.

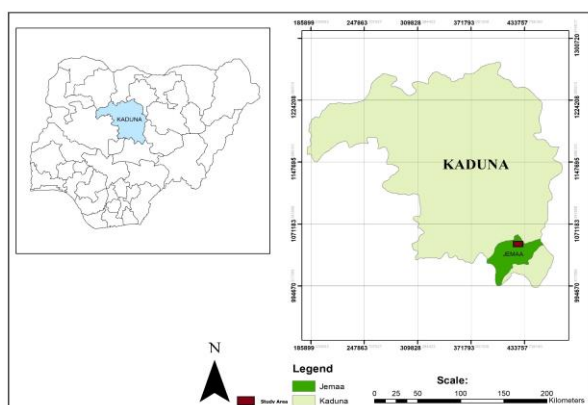


Figure 1: Map of the Study Area

3.2 Research design and data sources

The research design was a descriptive Geo-spatial case-study approach. Spatial data were collected from satellite images, field GPS surveys, existing topographical and infrastructural maps and (ground-truthing). Road alignments, junctions, water bodies, railway infrastructure and the study boundary were collated in a GIS database.

The thesis itself does not tell us the dates of images acquired, the sensors used, the estimated positional accuracy, the number of observations collected from GPS or the entire data dictionary. These details were not provided, and so are acknowledged rather than included with spurious data.

3.3 Data preparation

The spatial data was geometrically corrected as needed, transformed into valid and duplicate free data formats and projected in a uniform co-ordinate system. Road centrelines

were digitized as lines and categorized. These datasets were then imported into ArcGIS Online for viewing and analysis.

In order to produce a completely reproducible network analysis, line features should be split at genuine intersections, grade separated crossings should be differentiated, dangling links should be checked and one-way restrictions should be recorded. This thesis does not record completing all of these topological tests, thus this paper represents the map descriptively, rather than unsupported graph metrics.

3.4 Spatial Analysis and Interpretation

The main study used direction, distance, area, hotspot and network analysis functions. In this article, the outputs were arranged into four analytical dimensions:

Table 1: Spatial Analysis and Interpretation

Dimension	Evidence Examined	Planning Interpretation
Network form	Overall alignment and direction of road links	Radial, linear, grid, irregular, or hybrid morphology
Road hierarchy	Relationship among principal, secondary, and local roads	Continuity of movement and distribution of access
Activity clustering	Concentrations of mapped roads and urban activities	Pressure on commercial and administrative nodes
Peripheral connectivity	Availability of alternative links outside the core	Redundancy, cross-town access, and growth management

Source: Authors' Analysis, 2025

Is also very exploratory. Terms such as "radial", "concentrated," and "limited alternative connection" describe apparent spatial relationships and findings reported in the thesis, but are not replacements for calculating centrality or accessibility indices.

4. Results

4.1 Road-network Form

The network drawn is primarily radial and composed of a number of corridors. The major routes emanate from or lead into the town center and axial extensions from this. The radial network structure can be explained by the position of Kafanchan in its past, as an organisational, transport and service node, funneling is the flow of movement from the outer neighborhoods and peripheral settlements into the core (see figure 2).

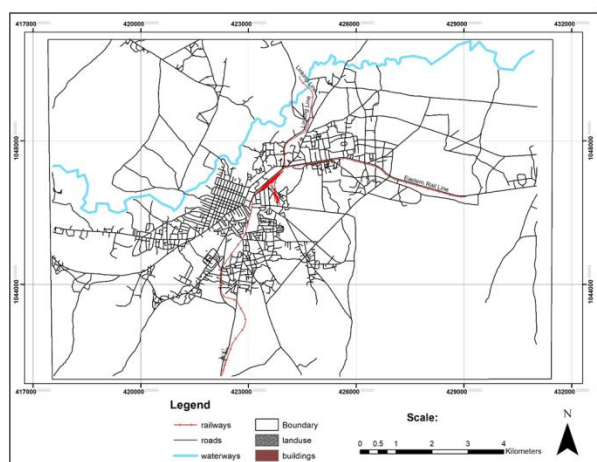


Figure 2: Road-network Form

The form is not a regular radial system with evenly spaced spokes. It is better interpreted as a radial-irregular hybrid: the dense central fabric contains numerous short links, whereas longer outer corridors have fewer lateral connections. This structure supports centre-bound travel but provides limited evidence of continuous circumferential or cross-town routes.

4.2 Functional Hierarchy

As reported in the thesis there are two primary corridors of movement passing through the central business district and connecting it with the suburbs. Local streets serve secondary roads emanating from the principal corridors. Such a hierarchy of streets creates a clear movement system, but also means that local accessibility hinges on the success of a limited number of higher order corridors.

The hierarchies observed are outlined in Table 2 below.

Table 2. Road-network characteristics and inferred planning implications

Observed Characteristic	Spatial Interpretation	Likely Planning Implication
Principal routes connect the core and outer areas	Strong centre-periphery movement	High dependence on radial corridors
Secondary roads branch into local streets	Hierarchical feeder structure	Local trips concentrate at collector junctions
Dense network in the central area	Fine-grained access around major activities	Potential for congestion and pedestrian conflict
Sparse lateral connections in outer areas	Limited cross-corridor route choice	Longer trips and weak network redundancy
Rail and water features intersect the urban structure	Physical constraints and crossing points	Need to protect bridges, crossings, and alternative routes

Source: Author's Analysis, 2025

These are because-points, propositions based on spatial form rather than measured traffic performance. For example, to directly test them by traffic counts, travel-time measurements, turn-count and junction-delay surveys, or origin destination data would be needed.

4.3 Activity clustering

The parent analysis revealed a grouping of road activity in the commercial and administrative areas. Accumulation supports accessibility to functions such as markets, civil service, public functions, businesses, and transport facilities. The high density of central roads enhances local accessibility, but concentrates movement in a narrow zone.

The road to centre relation appears to be a feedback mechanism. Places that are accessible attract development which in turn will generate more trips and even more movement makes the importance of the same corridors/junctions even greater. Without co-ordinated land-use control this can lead to a spiral of development along the roadside, informal stopping and parking pressure, and conflict between through traffic, local traffic, pedestrians and commercial interests.

4.4 Peripheral accessibility and growth

The way the periphery has been mapped results in longer lengths of link roads and fewer alternative links than in the centre. Radial roads are channels that extend the influence of the city into the surrounding area, but if there is poor lateral accessibility this can lead to corridor based growth, meaning that new development on certain routes can be physically proximate but poorly connected to development on other routes.

This pattern has two implications. Firstly, emergency, public-transport and service trips may be using limited access points. Secondly, it can be expensive to retro-fit cross-links following land subdivision, as buildings and plot boundaries may block potential alignments. It is therefore important to future-proof these connections through structure plans and development control.

5. Discussion

Kafanchan's radial-irregular network is not an indication of ineffective transportation, but instead a manifestation of the combined influences of transport routes, CBD, administrative as well as suburban development. Radial network need not be bad but they direct movement strong corridors between the centre and the outer circle. Radial networks can be useful to public transport systems if used along supports jugular for efficient movement of larger traffic.

The activity centres found in both commercial and administrative areas support the present argument that road form and land use should be studied in relation to each other. In the Yangtze River Delta, Haldar et al. (2023) show how accessibility can be used to predict built-up growth, Ahmadzai et al. (2020) found how road and land-use metrics can together be used to accounts for urban accessibility. In

Kafanchan, which has an accessibility centre, people in the city centre are more likely to be able to access opportunities than those on the peripheries, which are less accessible. Achieving a measure of balanced development, however, does not necessarily mean applying the same road density in all parts of city, but requires minimum acceptable access levels and strategic links connecting areas of new suburban development to employment, education, health, and retail facilities, and to public transport.

The apparent hierarchy presents a resilience problem as well. In the case where many local roads drain to relatively few collector roads, failure at a single strategic inter-change can reverberate through a much larger zone of affect. Network redundancy (the option of using other, viable paths) thus becomes a planning benefit. Unfortunately, this research cannot begin to locate the exact bridge or nodal links which are most critical because betweenness centrality and route-failure results were not stored and archived. A future research project needs to develop and then evaluate the judgment I used to define feasible path scenarios and then construct a validated network graph and locate the key centrality links, bridges, and rail crossings.

5.1 Urban-planning priorities

From this five conclusions emerge: (A) first of all the metropolis needs a complete topologically validated database of metropolitan road network, with class, width, surface, condition and bearing of every road, junction type, pedestal amenities, drainage and right-of-way system. (B) Formation of several cross links in between of radial corridors has to be planned already before peripheral land extension. (C) The offices, commercial areas have to be gear, not only up to a rack of roads connected together.

Fourth, the access analysis can be applied to figure out where the new public facilities should be established and where the urban-renewal investments should focus on. Travel time surface and service area analysis could potentially help to identify the communities on the same street grid that are divided by natural or man-made barriers. Fifth, the road plan should take into consideration to work in conjunction with water drainage, rail crossings, watercourse, land-use zoning, and emergency access, particularly because the network quality depends on factors other than roads.

6. Conclusion

The road network of Kafanchan shows a radial structure and a corridor-oriented character, with a hierarchy where most of the secondary and local roads depend on a few main axes and a higher concentration of road activity in the commercial and administrative areas. This pattern points to a good access to the city but a lack of lateral links in the peripheral areas. The future road building process should be regarded as a network development, not as a collection of independent projects.

The preference would be for safeguarding strategic rights of way, finishing cross corridor links, improving multimodal conditions in core activity areas and adopting graph-based measures of accessibility and centrality to guide investment.

While the current thesis map provides a valuable descriptive base, it lacks the quantitative data necessary to make confident statements about connectivity, congestion or resilience. Moreover, prior to journal publication the co-authors ought to obtain the file sources for shape files, and publish length by road category, intersection density, link-node ratio, circuitry, centrality and accessibility to vital services.

Limitations and Future Research

This analysis depended on one mapped period and cannot tell how the network changed over time. Imagery date, GPS accuracy, traffic counts, road conditions, and public-transport routes were inconsistently recorded in the archived thesis. Hotspots were identified but the limits and statistical output were not. Future potential is enhanced through the integration of multi-temporal imagery, OpenStreetMap or other official road datasets, in-situ topology validation, traffic counts, and land use or population datasets. Scenario testing should include the comparison of accessibility improvements by potential future cross-links, junction improvements, and public-transport corridors.

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