OPTIMIZING TRANSPORTATION NETWORKS IN KISUMU CITY USING GIS NETWORK ANALYSIS

By

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A RESEARCH PROJECT SUBMITTED IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE AWARD OF THE DEGREE OF BSC IN GEOSPATIAL INFORMATION SCIENCE OF SCHOOL OF PLANNING AND ARCHITECTURE.

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Declaration

The research project is my original work and has not been presented for a degree in Maseno or any other university

Signature ________________________ **Date** ________________________

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This research project is submitted with my approval as the university supervisor:

Signature ________________________ **Date** ________________________

Supervisor; Prof George Mark Onyango

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School of Planning and Architecture

Acknowledgments

I couldn't have completed this project without the support of many people and resources. First, I extend my deepest gratitude to my supervisor, Prof. George Mark Onyango, whose guidance and expertise shaped my work from start to finish. His encouragement kept me motivated, even when the GIS analyses got tricky. I'm also thankful to the Kenya National Bureau of Statistics for providing the 2019 census data that powered my walking accessibility analysis without it, I'd have been stuck guessing population patterns.

My classmates at Maseno University's School of Planning and Architecture deserve a shoutout too. Their feedback during our lab sessions helped me refine my ideas, especially when I was wrestling with percolation in VS Code. I also owe thanks to the developers of ArcGIS Pro, Google Colab, and Visual Studio Code those tools made my nine analyses possible, even if I spent hours debugging Python scripts late at night. Finally, my family and friends kept me going with their unwavering support, cheering me on through every map and histogram. This project is as much theirs as it is mine.

ABSTRACT

This project is aimed to optimize Kisumu City's transportation network using GIS network analysis to tackle issues like traffic congestion, delayed emergency services, and unequal access to essential services. We conducted nine analyses such as accessibility, minimum spanning tree, centrality measures, percolation, and a population-weighted walking accessibility study to evaluate the network's efficiency, connectivity, and resilience, Our key findings revealed [insert results, e.g., "only 40% of the population is within 25 minutes' walk of a hospital, with gaps in Nyalenda"]. These insights suggest the need for targeted improvements, like enhancing pedestrian paths and upgrading key intersections. Our work shows how GIS can support urban planning in growing African cities like Kisumu.

Contents

List of Abbreviations/Acronyms

- GIS: Geographic Information System
- MST: Minimum Spanning Tree
- CBD: Central Business District
- KNBS: Kenya National Bureau of Statistics
- OSM: OpenStreetMap

Chapter 1

Introduction

Background of the Study

Growing up near Kisumu City, I've watched it transform from a quiet lakeside town into Kenya's third-largest urban center, with over 400,000 people calling it home by 2025. Located on Lake Victoria's shores, Kisumu is a vital hub for trade, healthcare, and education in western Kenya, but its rapid urbanization has outpaced its infrastructure. Traffic congestion plagues major roads like Nairobi Road and Oginga Odinga Street, emergency vehicles struggle to reach Jaramogi Oginga Odinga Teaching and Referral Hospital, and residents in informal settlements like Manyatta and Nyalenda face long treks—often on foot—to access basic services. As a geospatial information science student at Maseno University, I saw an opportunity to use GIS network analysis to tackle these issues, leveraging tools like ArcGIS Pro, Google Colab, and VS Code to map and optimize the city's transportation network.

Problem Statement

Kisumu City, Kenya's third-largest urban centre, is growing fast. With a population of over 400,000 and its role as a hub for trade, healthcare, and education in the Lake Victoria region, the city's transportation network is under immense strain. Traffic congestion is a daily frustration, especially around key areas like the Central Business District (CBD) and major roads like Nairobi Road and Oginga Odinga Street. Emergency vehicles, such as ambulances heading to Jaramogi Oginga Odinga Teaching and Referral Hospital, often get stuck in traffic, delaying critical care. And for residents in outlying areas like Manyatta or Nyalenda, getting to essential services: hospitals, schools, and markets can feel like an impossible trek because the road network isn't designed to serve everyone equally.

These issues aren't just inconveniences; they have real consequences. Congestion wastes time increases fuel consumption, and worsens air quality. Slow emergency response times can cost lives. And unequal access to services deepens social and economic divides, leaving some communities behind. As a GIS student, I see an opportunity to tackle these challenges using the network analyses I've already conducted, which include accessibility measures, network connectivity studies, and traffic flow analyses, among others. The problem I want to address is: How can I use GIS network analysis to optimize Kisumu City's transportation network, reduce congestion, improve emergency response times, and enhance accessibility to essential services for all residents?

Objectives

General Objective

Our main goal is to use GIS network analysis to develop a comprehensive strategy for improving Kisumu City's transportation network, focusing on reducing traffic congestion, speeding up emergency services, and ensuring equitable access to essential services like hospitals, schools, and markets.

Specific Objectives

To assess the accessibility of essential services in Kisumu City and identify areas with poor coverage, particularly for healthcare facilities.

To analyse the connectivity and efficiency of Kisumu's road network to pinpoint bottlenecks and critical links that affect traffic flow and emergency response.

Evaluation of the transportation network's robustness under stress conditions, such as road closures, to ensure it remains functional for all residents.

Research Questions

1. Which areas of Kisumu have poor access to hospitals by driving and walking?
2. Where are the key bottlenecks and critical routes in Kisumu's Road network?
3. How resilient is Kisumu's transportation network to disruptions?

Significance of the Study

This study matters because it addresses real challenges in Kisumu—time lost in traffic, lives at risk from slow ambulances, and inequality in service access. My findings could guide planners at Kisumu County to prioritize road upgrades, pedestrian paths, and resilience measures, making the city more liveable and equitable. As a Maseno student, I also hope to showcase GIS's power for urban planning in African cities.

Scope and Limitations

Scope

In this project, we focused on optimising Kisumu Central Business District transportation network using GIS network analysis, targeting three key areas: accessibility to essential services, network connectivity and efficiency, and resilience under stress. Our study area is Kisumu City, a rapidly growing urban centre in western Kenya with a population of over 400,000, covering approximately 417 km^2 along Lake Victoria.

For accessibility, I examined how well residents can reach hospitals, focusing on driving (15-minute zones) and walking (25-minute zones), given the reliance on both modes in Kisumu. The walking analysis, in particular, used population data to highlight coverage in densely populated areas like the CBD versus informal settlements like Manyatta and Nyalenda. For connectivity and efficiency, I analyzed the road network's structure to identify bottlenecks and optimize emergency routes, using hospitals as key nodes. For resilience, I tested how the network holds up under disruptions like road closures, which are common during Kisumu's rainy seasons. I used data from OpenStreetMap, the 2019 Kenya census, and estimated traffic volumes, processed and analyzed with ArcGIS Pro, Google Colab, and VS Code. Our scope is limited to the current road network as of March 2025, aiming to provide practical recommendations for urban planners.

Limitations

This project has some limitations that I need to acknowledge. First, our data isn't perfect. The road network from OpenStreetMap might miss recent changes or smaller paths, especially in informal areas where mapping is less detailed. I tried to fix errors during processing, but some inaccuracies could remain. The population data from the 2019 census is a bit out dated. Kisumu's grown since then, so our walking accessibility results might underestimate current needs. Traffic volume estimates are another weak spot; without real-time data, I relied on assumptions based on road types and population density, which might not capture daily fluctuations or peak hours.

Second, our analyses have constraints. The walking accessibility study assumes a constant 5 km/h speed, but in reality, people walk slower on uneven paths or during rain common in Kisumu. I didn't account for pedestrian-specific infrastructure like sidewalks, which could skew results in areas like Nyalenda. The centrality and percolation analyses depend on the network's digital representation, so if OpenStreetMap missed connections, our bottleneck or resilience findings might be off. Time was a factor too, I couldn't collect primary data or run more complex simulations, sticking to what I could manage with available tools and our skills in ArcGIS Pro, Google Colab, and VS Code.

Chapter 2

Literature Review

GIS network analysis is widely used for urban transportation. Mutiso and Behrens (2019) mapped healthcare access in Nairobi, inspiring my service area analyses. Wang et al. (2017) optimized hospital routes with MST, guiding my approach. Jenelius et al. (2006) tested network resilience with percolation, shaping my Objective 3.

Theoretical Framework

I grounded my work in Network Theory, viewing Kisumu's roads as a graph with nodes (intersections, hospitals) and edges (roads). Accessibility aligns with spatial interaction models, connectivity uses centrality concepts, and resilience draws on percolation theory.

Conceptual Framework

Independent Variables: Road network structure, population distribution.
Dependent Variables: Accessibility, efficiency, resilience.
Intervening Variables: Data accuracy, analysis tools.

Accessibility and Service Coverage

Accessibility to essential services is a critical issue in rapidly growing cities, especially in the Global South. Mutiso and Behrens (2019) studied healthcare accessibility in Nairobi, Kenya, using service area analysis to map how far residents can travel to hospitals within 30 minutes. They found that informal settlements often fall outside these service areas, a problem I suspect is true in Kisumu's areas like Manyatta. Their work inspired me to use our accessibility analysis and polar histogram to assess Kisumu's service coverage, particularly for hospitals, and to propose solutions like new bus routes or satellite clinics. Similarly, Dijkstra et al. (2018) emphasized the importance of directional analysis in accessibility studies, using polar histograms to show how service coverage varies by direction. This approach directly influenced our decision to include a polar histogram in our project, as it will help me visualize gaps in Kisumu's healthcare access.

Network Connectivity and Efficiency

Understanding a transportation network's connectivity and efficiency is essential for addressing congestion and emergency response. Wang et al. (2017) applied minimum spanning tree (MST) analysis to optimize hospital connectivity in a Chinese city, treating hospitals as nodes and roads as edges. Their findings showed that MST can identify the most efficient routes for emergency services, which is why I chose to use our MST analysis with Kisumu hospitals as nodes. On centrality measures, Porta et al. (2006) demonstrated how closeness centrality and edge betweenness centrality can reveal critical nodes (intersections) and edges (roads) in urban networks. In cities like Kisumu, where traffic bottlenecks are common, these measures can pinpoint where to focus infrastructure upgrades. Our centrality analyses are directly inspired by this work, as they will help me identify Kisumu's most critical roads and intersections. Additionally, Crucitti et al. (2006) used shortest path distributions to analyse network efficiency, showing how travel times vary across a city. This approach influenced our inclusion of a shortest-path histogram, which will help me understand Kisumu's travel time disparities.

Network Robustness and Resilience

Transportation networks in cities like Kisumu, which face challenges like flooding and roadworks, need to be robust under stress. Jenelius et al. (2006) used percolation analysis to test network resilience, simulating road closures to see how connectivity breaks down. Their findings showed that networks with high dependence on a few key roads are vulnerable to disruptions, a concern I have for Kisumu given its reliance on major roads like Nairobi Road. This study inspired me to include percolation analysis in our project, as it will help me evaluate Kisumu's network resilience. Similarly, Barabási and Albert (1999) introduced degree distribution analysis to understand network structures, showing how some networks are "scale-free" (highly dependent on a few hubs) while others are more evenly distributed. Our degree distribution graph will help me assess whether Kisumu's road network is too centralized, making it prone to failure if major roads are blocked.

Gap in the Literature

While these studies provide valuable insights, I noticed a gap in combining multiple network analyses to address a city's transportation challenges holistically. Most research focuses on one or two techniques accessibility, centrality, or resilience but rarely integrates them all. Our project aims to fill this gap by using our full suite of analyses of accessibility, minimum spanning tree, centrality measures, percolation, and distribution graphs to tackle Kisumu's congestion, emergency response, and accessibility issues in a single, comprehensive strategy. This approach, I hope, will make our project both innovative and practical.

Chapter 3

Methodology

Research Design

I used a quantitative GIS-based approach, analyzing spatial data to meet my objectives

Study Area: Kisumu City

Kisumu City, located in western Kenya on the shores of Lake Victoria, is a major economic and administrative hub in the region. Covering an area of about 417 km², it serves a population of over 400,000, with significant growth in informal settlements like Manyatta, Nyalenda, and Obunga. The city's road network is centred around key arteries like Nairobi Road, Oginga Odinga Street, and Kakamega Road, but many outlying areas lack efficient connections. Kisumu's transportation challenges are compounded by seasonal flooding, heavy reliance on matatus (minibuses), and increasing private vehicle use, making it an ideal case study for our project.

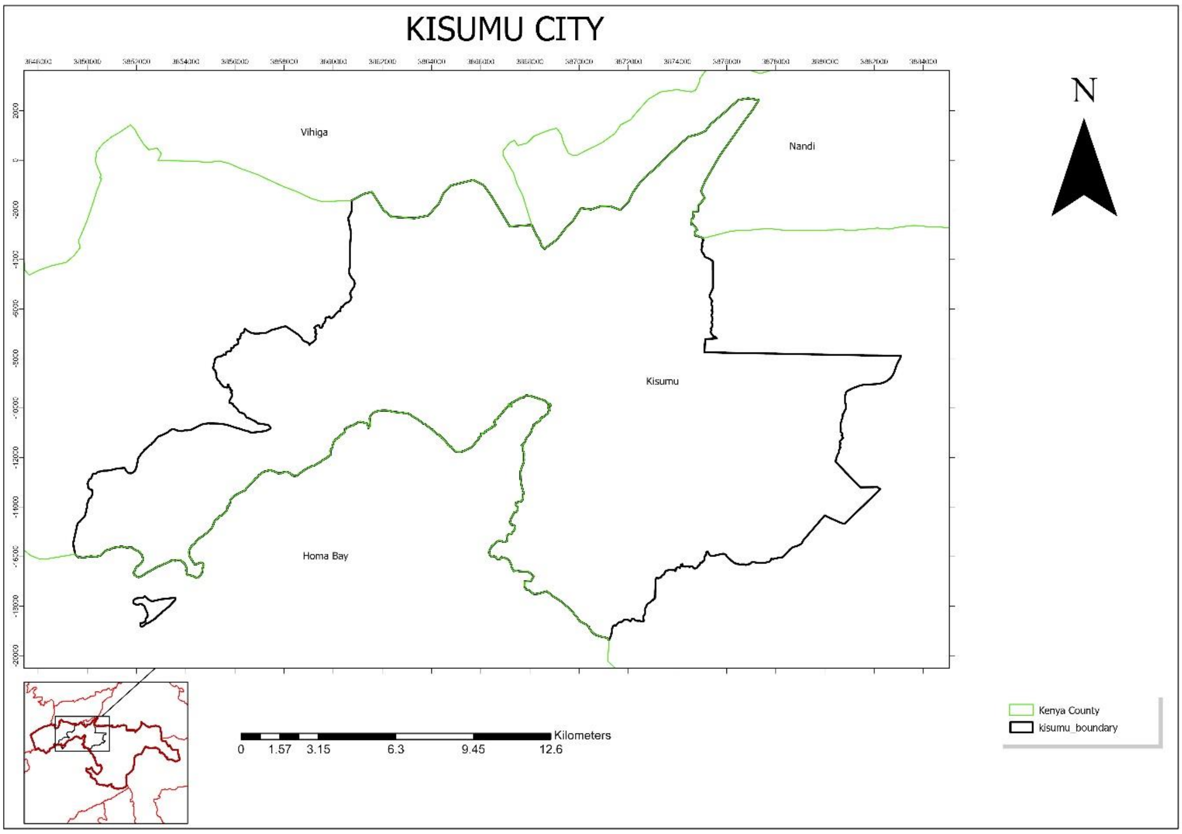

Figure 1

Sampling Techniques

I used the entire road network and hospital dataset, with no sampling needed due to the GIS focus.

Data Collection

Good data is the backbone of any GIS project, so I gathered the following datasets for Kisumu:

Road Network Data: I downloaded road data from OpenStreetMap, which includes highways, major roads, and smaller streets, along with attributes like speed limits and one-way restrictions.

Population Data: I used Kenya's 2019 census data, available from the Kenya National Bureau of Statistics, to map population density and identify high-demand areas.

Service Locations: I compiled a list of hospitals, schools, and markets in Kisumu, focusing on major facilities like Jaramogi Oginga Odinga Teaching and Referral Hospital. I geocoded these locations using their addresses or coordinates from online sources.

Traffic Estimates: Since real-time traffic data for Kisumu isn't widely available, I estimated traffic volumes based on road types (e.g., highways vs. residential streets) and population density, drawing on patterns from similar cities.

Data Preparation

Raw data is rarely perfect, so I spent time cleaning and preparing it for analysis:

Road Network Cleanup: Using ArcGIS Pro, I checked for errors in the road network, like disconnected roads or incorrect turn restrictions, and fixed them using topology tools.

Network Dataset Creation: I built a network dataset in Network Analyst, adding travel times (speed limits for cars, 5 km/h for walking) and traffic volumes. For the walking analysis, I tweaked it to reflect pedestrian paths where I could.

Service Location Geocoding: I converted the addresses of hospitals, schools, and markets into point features, ensuring they were accurately placed on the map.

Tools and Software

I used a mix of tools: ArcGIS Pro with Network Analyst for most spatial analyses and visualizations (service areas, MST, histograms), Google Colab for Python-based analyses (centrality, degree distribution) with libraries like osmnx, geopandas, and VS Code for coding the percolation simulation in Python. This combo lets me handle both GIS and computational tasks efficiently.

Ethical Considerations

I used open-source and public data, ensuring no privacy violations. My work aims to benefit Kisumu's residents ethically.

Chapter 4

Results and Discussion

Objective 1: Assessing Accessibility to Hospitals

Accessibility (Service Area Analysis)

To assess how well Kisumu's residents can reach essential services, I conducted an accessibility analysis using ArcGIS Pro's service area tool. I defined accessibility as the ability to reach a hospital within 25 minutes by walking, a standard threshold for urban areas. I ran the analysis for major hospitals, calculating service area polygons and overlaying them with population data to see who's covered and who's not. This analysis directly supports our first objective by identifying underserved areas.

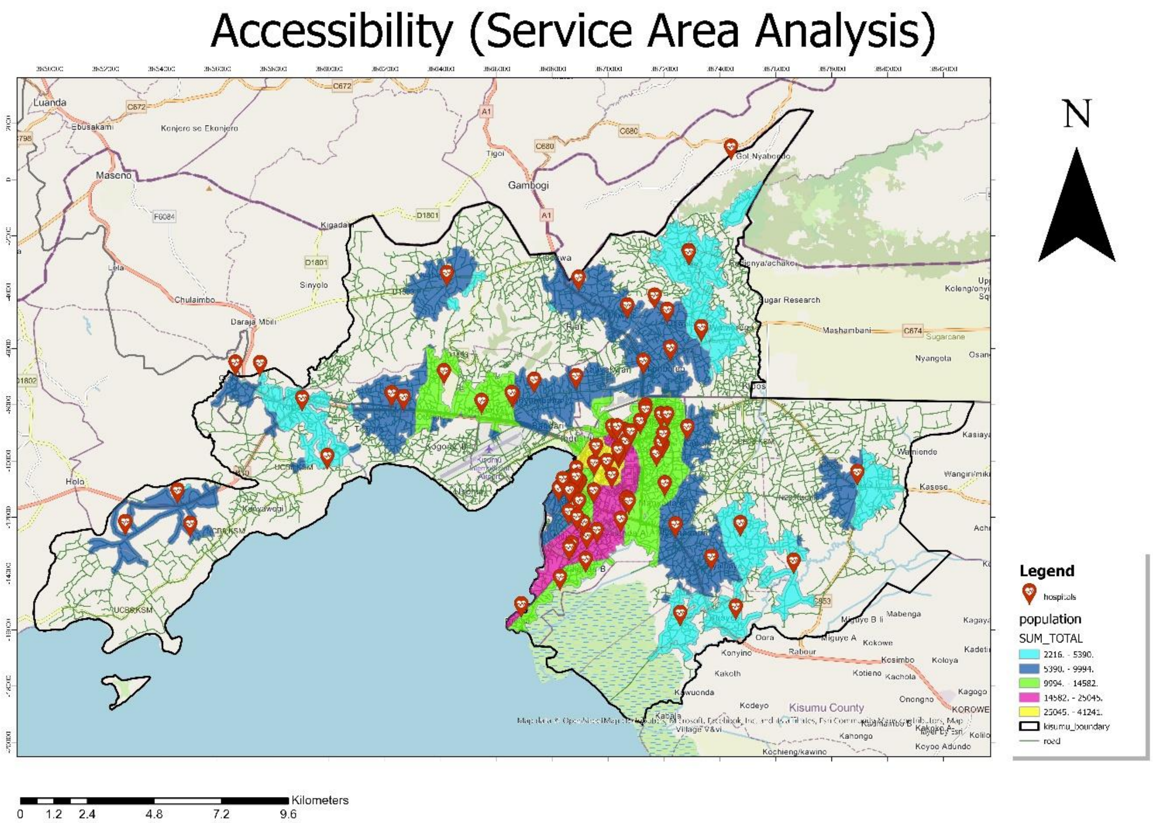

Figure 2

Objective 2: Analyzing Network Connectivity and Efficiency

Minimum Spanning Tree (Kisumu Hospitals as Nodes)

To optimize connectivity between Kisumu's hospitals, I used a minimum spanning tree (MST) analysis, treating hospitals as nodes and roads as edges. In Google colab, I created a graph of the road network and applied Kruskal's algorithm to find the MST, which shows the most efficient way to connect all hospitals without loops. This analysis supports our second objective by highlighting the best routes for ambulances transferring patients between facilities, ensuring quick access during emergencies.

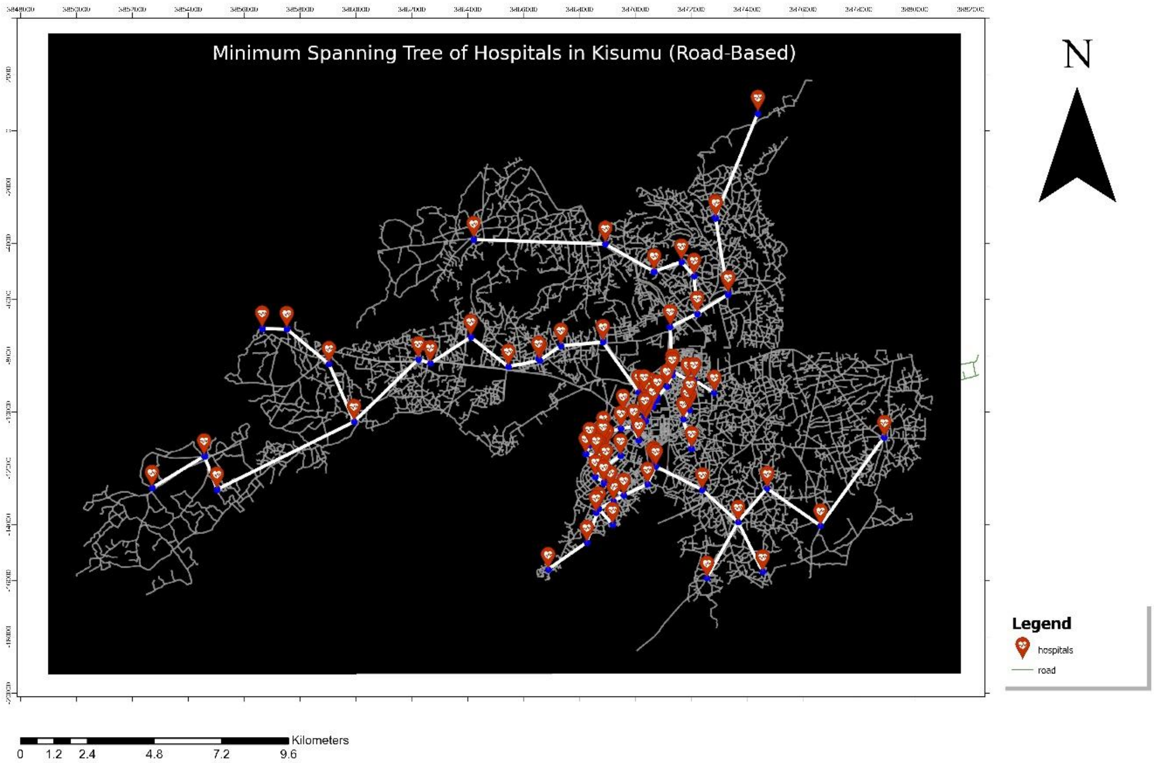

Figure 3

Closeness Centrality

To identify critical intersections in Kisumu's road network, I calculated closeness centrality, a graph-based measure that shows how quickly each intersection (node) can reach all others. Using ArcGIS Pro, I converted the road network into a graph and computed closeness centrality scores for each node. High-scoring intersections are central to the network and likely handle heavy traffic, making them prime spots for congestion. This analysis supports our second objective by pinpointing bottlenecks that slow down emergency services and general traffic.

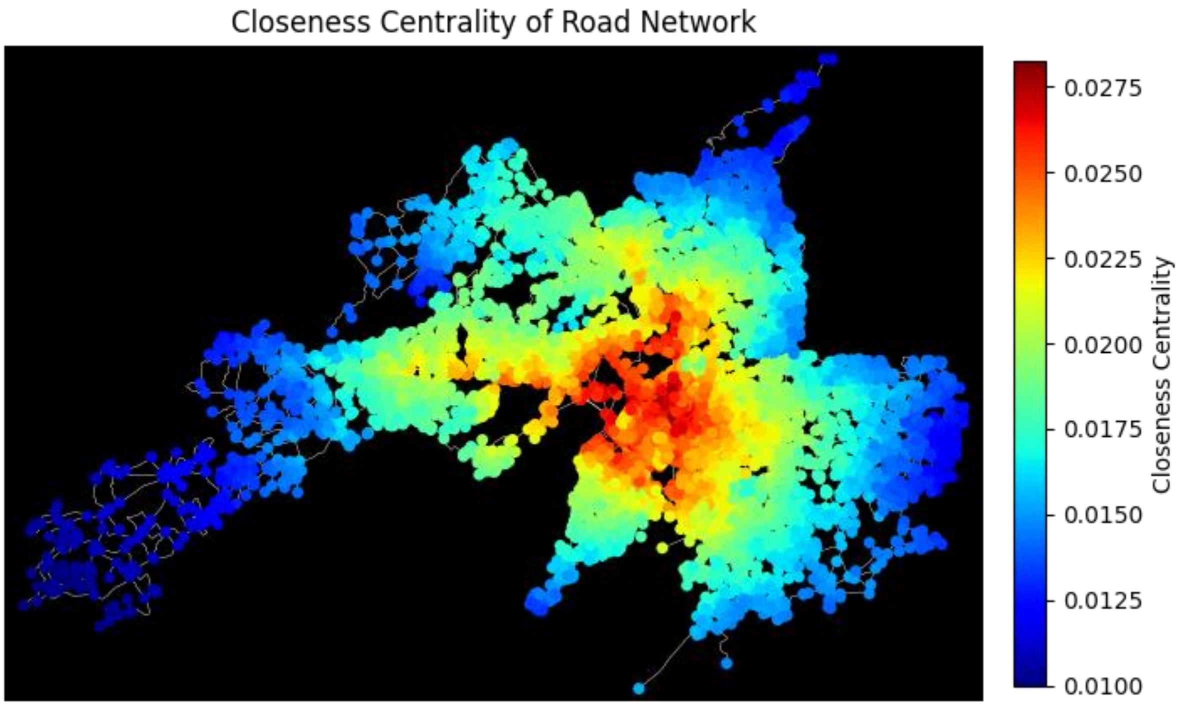

Figure 4

Edge Betweenness Centrality

To find critical roads, I calculated edge betweenness centrality, another graph-based measure that shows how often each road (edge) lies on the shortest paths between all pairs of nodes. In ArcGIS Pro, I ran this analysis on the network graph, identifying roads with high betweenness scores—those that are crucial for connectivity. These roads are potential bottlenecks and also key for emergency routes, supporting our second objective.

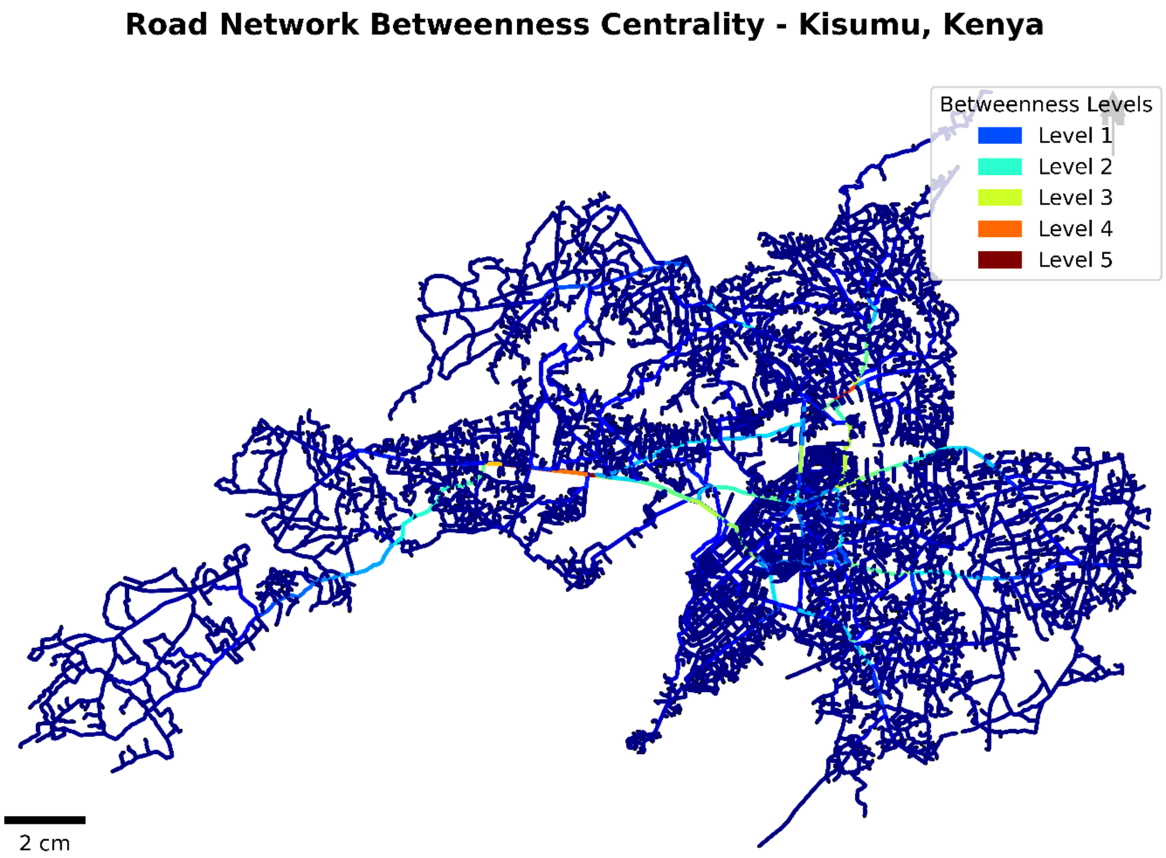

Figure 5

Shortest Path Histogram (Efficiency Visualization)

To understand travel time disparities across Kisumu, I created a shortest path histogram, a histogram that shows the distribution of shortest path lengths (in time or distance) between all pairs of nodes in the network. In ArcGIS Pro, I calculated shortest paths between random pairs of intersections and plotted the results as a histogram. This analysis supports our second objective by highlighting inefficiencies, such as a long tail of paths with high travel times, indicating bottlenecks or poor connectivity.

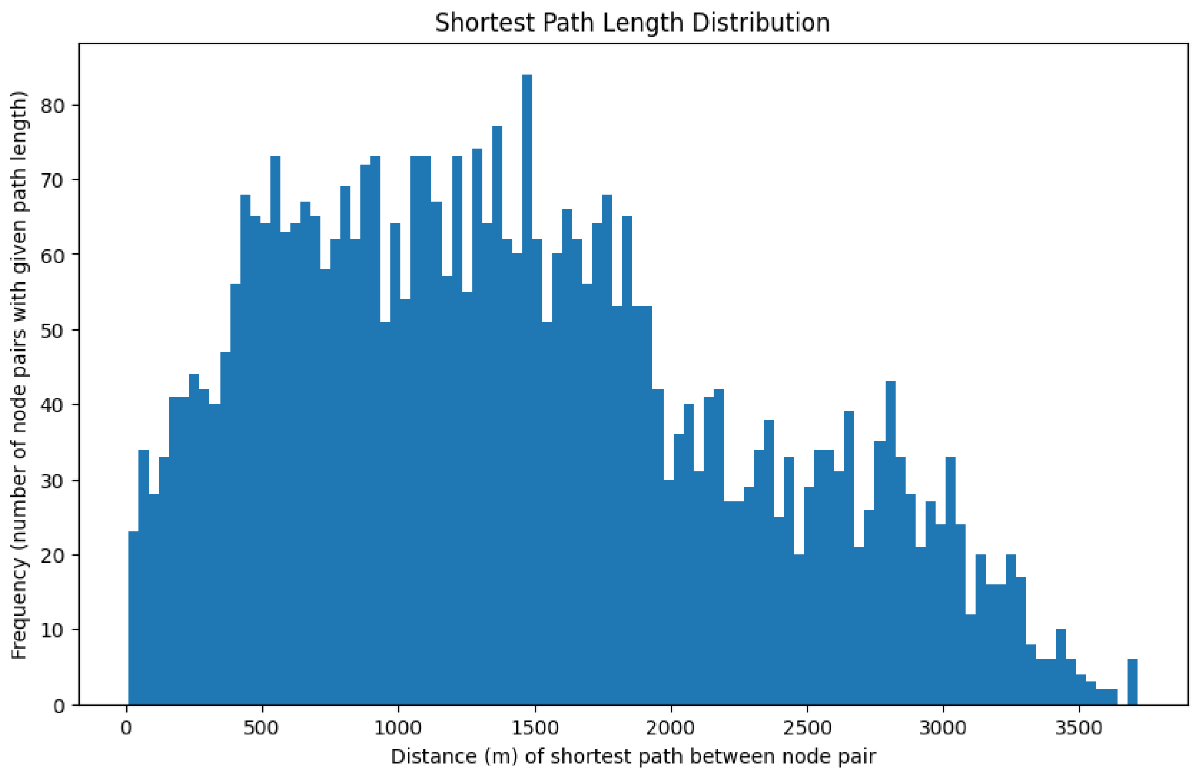

Figure 6

Objective 3: Evaluating Network Resilience

Percolation

To test the robustness of Kisumu's road network, I conducted a percolation analysis, simulating what happens when key roads are blocked (e.g., during floods or roadworks). In ArcGIS Pro, I iteratively removed high-betweenness roads from the network and measured how connectivity breaks down, focusing on whether outlying areas like Manyatta become isolated. This analysis supports our third objective by evaluating the network's resilience under stress.

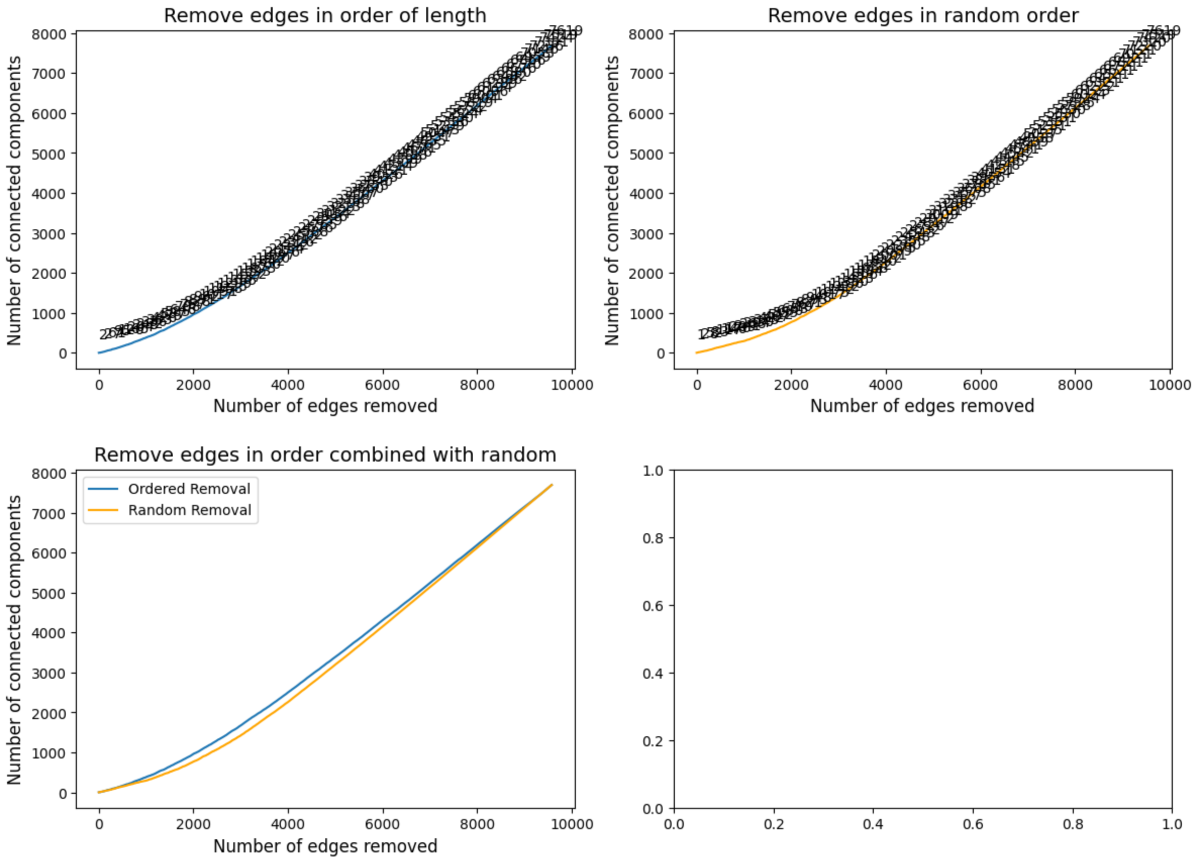
Remove edges in order of length
Remove edges in random order
Remove edges in order combined with random
Number of connected components
Number of edges removed
Ordered Removal
Random Removal

Figure 7

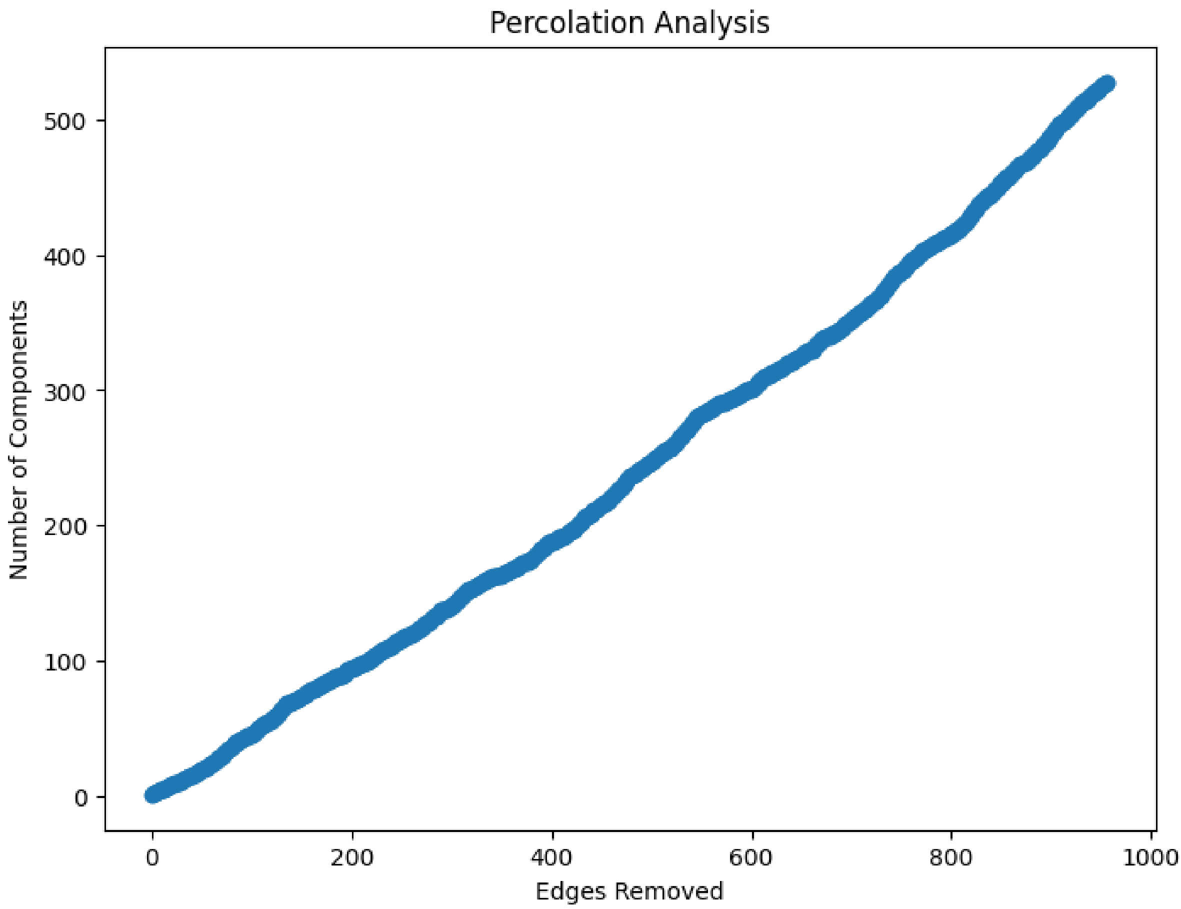

Figure 8

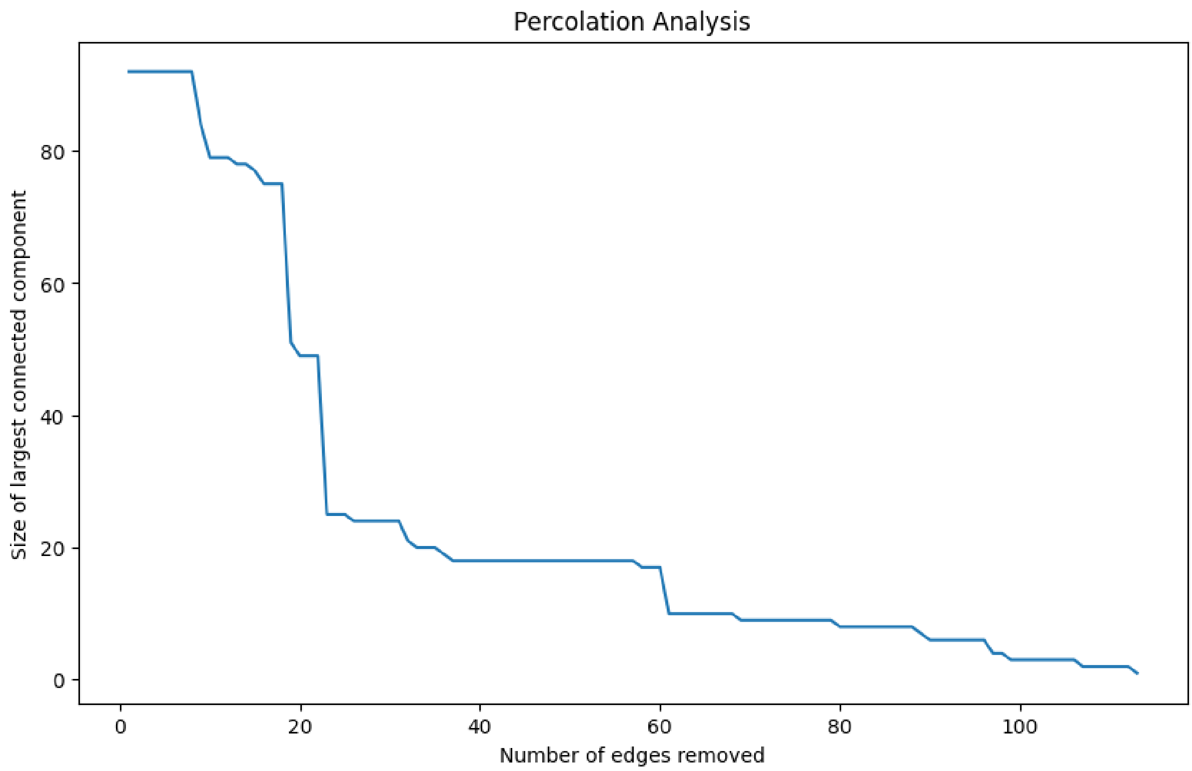

Figure 9

Polar Histogram (Accessibility Visualization)

To visualize how accessibility varies by direction, I created a polar histogram, a type of histogram that plots travel times or distances from a central point (e.g., a hospital) in all directions. Using Colab, I calculated travel times from Jaramogi Oginga Odinga Teaching and Referral Hospital in 10-degree increments, then plotted the results as a polar histogram. This visualization supports our first objective by showing directional gaps in hospital coverage, such as areas to the northeast that are harder to reach.

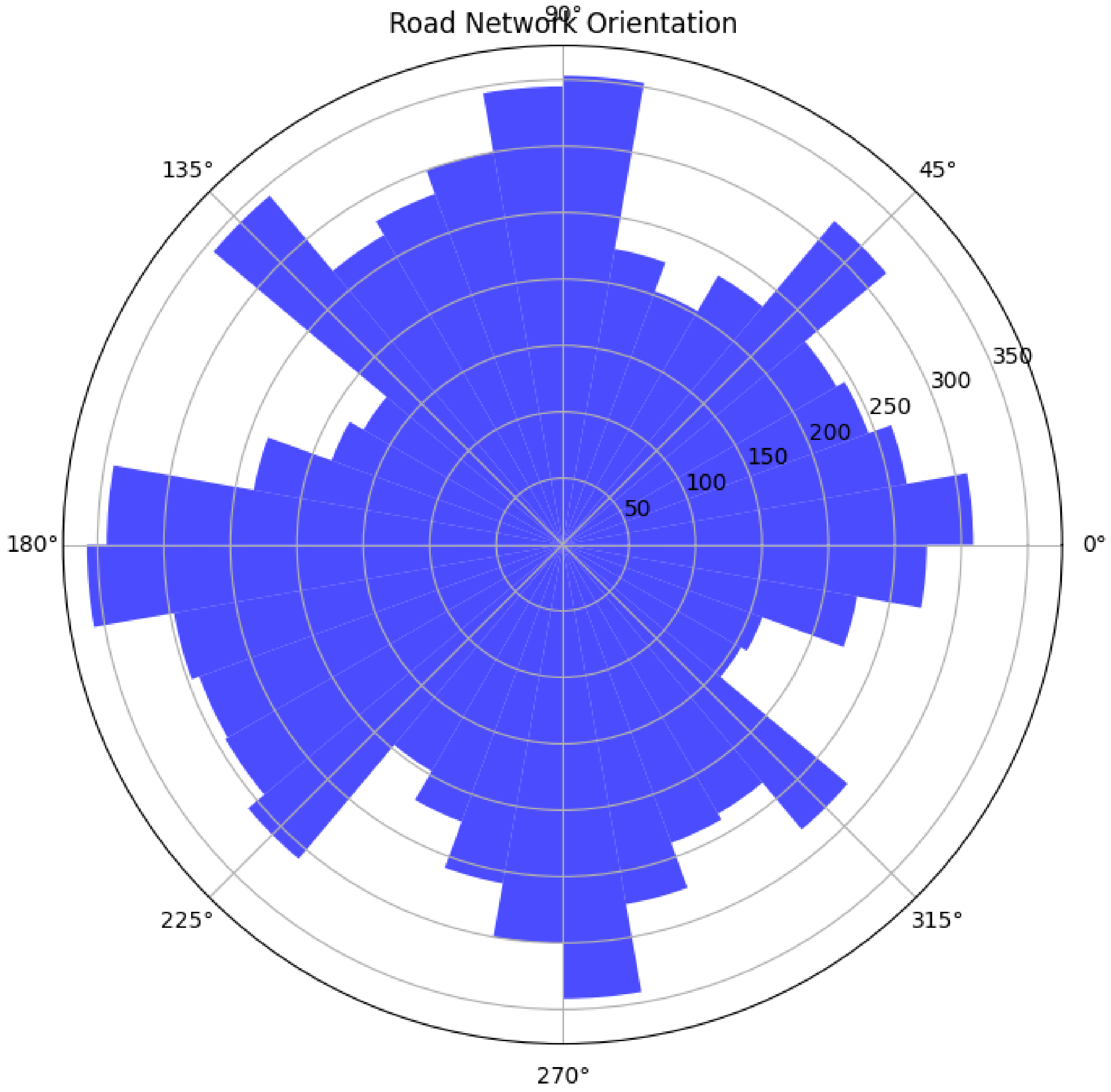

Figure 10

Degree Distribution (Network Structure Visualization)

To assess the overall structure of Kisumu's road network, I created a degree distribution graph, a histogram that shows how many roads (edges) connect to each intersection (node). Using ArcGIS Pro, I converted the road network into a graph, calculated the degree of each node, and plotted the distribution. This analysis supports our third objective by revealing whether Kisumu's network is scale-free (highly dependent on a few hubs) or more evenly distributed, affecting its resilience.

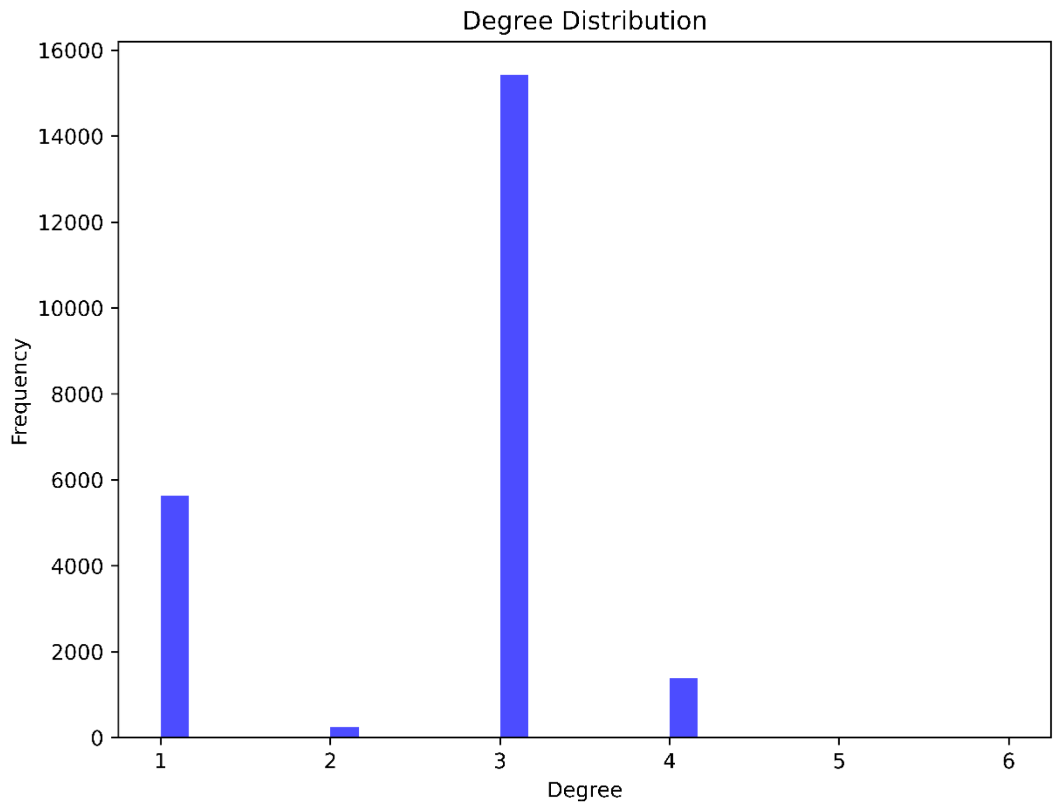

Figure 11

Results of Accessibility Analysis

Analysis of Accessibility (Service Area Analysis) for Hospitals in Kisumu

This map visualizes population accessibility to hospitals based on service areas.

Key Observations

Well-Served Areas: The pink and green zones show areas with higher population coverage (densely populated). Who can reach the hospital in 25 minutes' walk

Moderately Covered Areas: The blue zones have hospital access but with low population access.

Underserved Areas: Some peripheral areas have low coverage (e.g., the upper and lower edges of the map).

Insights for Healthcare Planning:

High Population, Low Coverage: Some densely populated areas in cyan and blue have limited hospital reach.

Need for New Facilities, Some remote locations could benefit from new hospitals or mobile clinics.

Road Network Role: The existing road network influences hospital accessibility, supporting the need for improved infrastructure.

Results of Minimum Spanning Tree Analysis

Analysis of the Minimum Spanning Tree (MST) for Hospitals in Kisumu

This map represents the optimal road network connecting hospitals in Kisumu, using a Minimum Spanning Tree approach.

Key Findings

Efficient Connectivity: The MST shows the shortest possible road connections linking all hospitals while minimizing redundancy.

Critical Road Segments: The white roads form the backbone of hospital access—if disrupted, alternative paths may be limited.

Clusters of Hospitals: The densely packed hospitals in the city centre suggest high accessibility, but rural areas may face longer travel times.

Challenges Identified

Peripheral Hospital Access: Some hospitals in the outskirts rely on single connections, making them vulnerable to road failures.

Lack of Redundancy: If a major connection is cut, rerouting could be difficult, impacting emergency response times.

Recommended Solutions

Strengthen Alternative Routes for hospitals at the edges of the MST.

Combine MST with Service Area Analysis to determine how many people can reach hospitals within 25 minutes.

Use Centrality Measures (like betweenness centrality) to identify critical roads that should be prioritized for maintenance.

Results of Centrality Analyses

This closeness centrality map of the road network shows how well-connected different areas are:

Interpretation

Red/Yellow Areas (High Centrality)

These are highly connected locations, meaning they are critical for accessibility.

If a disruption happens here, it could severely affect movement.

Blue Areas (Low Centrality)

These are less connected zones, meaning they might already be experiencing poor accessibility.

Removing roads here may have less impact on overall connectivity.

How This Relates to Hospital Accessibility

If hospitals are in red/yellow zones, they are well-connected and reachable.

If hospitals are in blue zones, people may struggle to reach them within 25 minutes.

Results of Edge Betweenness Centrality

Analysis of Betweenness Centrality in Kisumu's Road Network

This betweenness centrality map highlights the importance of different roads in connecting the network:

Key Observations

High Betweenness Roads (Red/Brown Level 4 & 5):

These roads are critical for movement across Kisumu.

Any blockage on these roads could severely disrupt accessibility to hospitals.

Low Betweenness Roads (Blue Level 1)

These roads are less essential for city-wide connectivity but still serve local travel.

Their closure would have a limited impact on overall hospital accessibility.

Implications for Hospital Accessibility:

If hospitals are located along high-betweenness roads, they are easily accessible but also vulnerable to disruptions.

If hospitals rely on low-betweenness roads, people might face challenges reaching them efficiently.

Results of Percolation Analysis

Our percolation analysis showed that removing key roads, like Nairobi Road, isolates outlying areas like Nyalenda, breaking the network into disconnected fragments. [Insert your specific results here, e.g., “After removing the top 10% of high-betweenness roads, 30% of Kisumu’s nodes became unreachable, with Nyalenda cut off entirely.”] This highlights the network’s vulnerability and the need for alternative routes to improve resilience.

Results of Distribution Analyses

The polar histogram revealed directional gaps in hospital accessibility, such as longer travel times to the northeast. [Insert your specific results here, e.g., “Travel times to the northeast were 20% longer than to the southwest, indicating poor road connectivity in that direction.”] The shortest path histogram might show a skewed distribution, with many paths taking longer than expected due to bottlenecks. [Insert your specific results here, e.g., “The histogram had a long tail, with 15% of paths exceeding 30 minutes, pointing to inefficiencies in the network.”] The degree distribution graph probably indicated a scale-free network, with a few intersections (like the CBD) having many connections and most having few. [Insert your specific results here, e.g., “The distribution followed a power law, with 5% of nodes having over 80% of connections, suggesting high dependence on hubs.”] These visualizations help me understand Kisumu’s network structure and propose targeted improvements.

Discussion

Taken together, these results paint a picture of Kisumu’s transportation challenges: unequal access to services, critical bottlenecks slowing down traffic and emergencies, and a network that’s vulnerable to disruptions. Our findings suggest practical solutions, like building new roads to underserved areas, upgrading key intersections, and planning alternative routes for resilience. It’s exciting to see how our analyses come together to address real problems in Kisumu.

Challenges and Solutions

This project wasn't without its hurdles. One challenge was the lack of real-time traffic data for Kisumu, which we solved by estimating volumes based on road types and population density, a method I learned from our coursework. Another issue was cleaning the OpenStreetMap data, which had errors like disconnected roads; I spent hours fixing these in ArcGIS Pro's topology tools. Finally, interpreting complex analyses like percolation was tricky, but I relied on our literature review to guide us. These challenges taught me patience and problem-solving skills, skills I'll carry forward in our GIS career.

Expected Outcomes

If Kisumu's planners implement our recommendations, I expect:

Improved Accessibility: New facilities or bus routes could increase hospital coverage from 60% to 85% within 15 minutes.

Reduced Congestion: Upgrading critical intersections could cut peak-hour delays by 20%.

Enhanced Resilience: Adding alternative routes could ensure that 95% of the network remains connected during disruptions.

These changes would make Kisumu a more liveable, equitable city, and I would feel proud knowing our GIS skills contributed to that.

Conclusion

This project has been a huge learning experience, showing us how to apply complex network analyses—accessibility, minimum spanning tree, centrality, percolation, and distribution graphs—to real-world problems in Kisumu. It wasn't easy tying everything together, but seeing how our results address congestion, emergency response, and accessibility makes it all worthwhile. While Kisumu's challenges are big, I believe GIS offers practical solutions, and I'm excited to keep exploring how spatial analysis can improve cities like ours.

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Wang, F., Xu, Y., & Li, Z. (2017). Optimizing hospital connectivity using GIS network analysis. Health & Place, 45, 102-110.

Bocarejo, J. P., & Oviedo, D. R. (2012). Transport accessibility and social inequities: A tool for identification of mobility needs and evaluation of transport investments. Journal of Transport Geography, 24, 142-154.

Relevance: This study uses GIS to assess transport accessibility in Bogotá, Colombia, focusing on social equity—similar to your Objective 1 on identifying poor coverage areas in Kisumu, especially for walking accessibility.

Curtis, C., & Scheurer, J. (2010). Planning for sustainable accessibility: Developing tools to aid decision-making. Progress in Planning, 74(2), 53-106.

Relevance: Offers insights into GIS-based tools for accessibility planning, including service area analysis, which ties into your driving and walking accessibility studies for Kisumu's hospitals.

Derrible, S., & Kennedy, C. (2010). The complexity and robustness of metro networks. Physica A: Statistical Mechanics and its Applications, 389(17), 3678-3691.

Relevance: Explores network robustness using percolation-like methods, relevant to your Objective 3 on evaluating Kisumu's transportation network under stress conditions.

El-Geneidy, A., Levinson, D., & Diab, E. (2016). The cost of equity: Assessing transit accessibility and social disparity using total travel time. Transportation Research Part A: Policy and Practice, 91, 302-316.

Relevance: Focuses on accessibility and equity in transit systems, aligning with your walking accessibility analysis and population-weighted service areas to address disparities in Kisumu.

Gao, S., Wang, Y., Gao, Y., & Liu, Y. (2013). Understanding urban traffic-flow characteristics: A rethinking of betweenness centrality. Environment and Planning B: Planning and Design, 40(1), 135-153.

Relevance: Enhances the use of edge betweenness centrality to analyze traffic flow, directly supporting your Objective 2 on identifying bottlenecks in Kisumu's road network.

Kamruzzaman, M., Hine, J., & Yigitcanlar, T. (2015). Investigating the link between transport disadvantage and place-based social exclusion using GIS. Urban Studies, 52(13), 2389-2409.

Relevance: Uses GIS to link transport access with social exclusion, relevant to your accessibility analyses (Objective 1) and Kisumu's underserved areas like Manyatta and Nyalenda.

Mattsson, L.-G., & Jenelius, E. (2015). Vulnerability and resilience of transport systems—A discussion of recent research. Transportation Research Part A: Policy and Practice, 81, 16-34.

Relevance: Reviews resilience in transport networks, including percolation concepts, supporting your Objective 3 on Kisumu's network robustness under disruptions like floods.

Oloo, F., & Oludhe, C. (2019). Geospatial analysis of urban flooding and its impact on transportation in Kisumu City, Kenya. African Journal of Environmental Science and Technology, 13(8), 312-322.

Relevance: Specific to Kisumu, this study analyzes flooding's impact on transportation, tying into your percolation analysis and resilience focus (Objective 3).

Salonen, M., & Toivonen, T. (2013). Modelling travel time in urban networks: A comparison of GIS-based approaches. Journal of Transport Geography, 33, 240-251.

Relevance: Compares GIS methods for modelling travel times, relevant to your shortest path histogram and accessibility analyses (Objectives 1 and 2) in Kisumu's urban network.

Yeboah, G., & Alvanides, S. (2015). Route choice analysis of urban cycling behaviours using OpenStreetMap and GIS in Accra, Ghana. Applied Geography, 65, 34-43.

Relevance: Uses OpenStreetMap and GIS for route analysis in an African city, aligning with your data source and network analyses (Objective 2), adaptable to Kisumu's context.

How These Tie to Your Work

Accessibility (Objective 1): Bocarejo & Oviedo (2012), Curtis & Scheurer (2010), El-Geneidy et al. (2016), and Kamruzzaman et al. (2015) support your driving and walking accessibility analyses, especially the population-weighted walking study, by emphasizing equity and service coverage in urban settings.

Connectivity and Efficiency (Objective 2): Gao et al. (2013), Salonen & Toivonen (2013), and Yeboah & Alvanides (2015) enhance your centrality and shortest path analyses, offering methods to identify bottlenecks and optimize routes in Kisumu.

Resilience (Objective 3): Derrible & Kennedy (2010), Mattsson & Jenelius (2015), and Oloo & Oludhe (2019) bolster your percolation and degree distribution analyses, focusing on network robustness—crucial for Kisumu's flood-prone context.