



Bridging Urban Mobility Gaps: Integrating Rapid Transit Railways into Lusaka City's Transport Network

¹ MEng. Mwiza Nalomba, ² Prof. Dr. Erastus Misheng'u Mwanaumo, * ³ Dr. Penjani Hopkins Nyimbili, ⁴ Prof. Dr. Wellington Didibhuku Thwala

¹ & ² Department of Civil and Environmental Engineering, School of Engineering, University of Zambia, Zambia

³ Department of Geomatic Engineering, School of Engineering, University of Zambia, Zambia

² Department of Civil Engineering, College of Science, Engineering and Technology, University of South Africa, South Africa

^{3,4} Built Environment and Information Technology, Faculty of Engineering, Walter Sisulu University, South Africa

E-mail ¹: mnalomba09@gmail.com, E-mail ²: erastus.mwanaumo@unza.zm, E-mail ³: penjani.nyimbili@unza.zm,

E-mail ⁴: wthwala@wsu.ac.za

Abstract

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This study explores the feasibility of a rapid transit railway system to address Lusaka City's growing transportation challenges caused by rapid urbanization and population growth. The research proposes the Chongwe-Kafue line through Lusaka to enhance urban mobility. Using Google Earth and QGIS for station identification, mapping and distance analysis, the study delineates a 92.8 km main corridor with 13 branch-off lines spanning 51.6 km, including two direct airport connections, designed to enhance accessibility and efficiency. Travel time analysis, based on Delhi Metro's operational model, estimates a 105.6-minute journey with an average speed of 60 km/h. Additionally, fare structures and construction costs were evaluated. The findings demonstrate the system's viability as an efficient alternative to minibus-dominated transport, offering reduced travel times and improved connectivity, stimulating economic growth and supporting sustainable urban development. This research provides a practical framework for policymakers and urban planners to implement a feasible transit solution in Lusaka.

Keywords: Rapid Transit; Urban Mobility; Railway Network; Transportation Planning; Sustainable Development.

1. Introduction

Urban public transportation systems are a cornerstone of economic activity and social inclusion across various levels of national development. In rapidly urbanising contexts such as Lusaka, Zambia's capital, the demand for efficient, inclusive, and sustainable mobility solutions has intensified (Amen, Afara, and Nia 2023; Aziz Amen 2022; Amen and Nia 2020). Despite being the commercial and administrative hub of the country, Lusaka's current public transport infrastructure—predominantly reliant on informal minibus and taxi services—struggles to accommodate the city's escalating population and urban sprawl. Traffic congestion, environmental degradation, inconsistent transit schedules, and inadequate access for marginalised populations persist as significant urban mobility challenges. Studies have shown that public transportation fosters economic growth, reduces environmental impact, and promotes equitable access to essential services (Salon & Gulyani, 2019; MIT Climate Portal, 2023). In cities like Lusaka, however, the transportation system has evolved with minimal regulation following liberalisation in the 1990s, resulting in fragmented services, spatial inefficiencies, and unsustainable reliance on road-based transit (Addressing Traffic Congestion in Lusaka District, 2024). The failure to incorporate non-motorised and mass transit alternatives into land-use and infrastructure planning has led to radial congestion, particularly within the Central Business District (CBD), undermining productivity and urban liveability.

While the theoretical and practical benefits of rapid transit systems—such as light rail and metro railways—are well documented globally, limited empirical research and planning have been undertaken to assess their contextual applicability, feasibility, and environmental implications in Sub-Saharan African cities. In particular, Lusaka lacks a strategic framework and empirical studies that evaluate how geospatial technologies and sustainable planning principles can be integrated to design a rapid railway transit system tailored to its unique spatial, economic, and infrastructural landscape. Furthermore, the socio-economic impacts of such a system—especially its potential to redistribute economic activity, reduce emissions, and improve accessibility for underserved populations—remain insufficiently explored. Planning a rapid transit railway in Lusaka necessitates a nuanced understanding of local

dynamics, urban growth patterns, stakeholder engagement, and environmental constraints. This gap hinders data-driven policymaking and the advancement of sustainable urban transport initiatives in the region.

In response to these growing challenges, this study investigates the potential integration of a rapid transit railway system into Lusaka's existing transport network, stretching from Chongwe to Kafue and incorporating key intra-city stations. By leveraging geospatial analysis tools such as QGIS and Google Earth, along with environmental assessments and economic feasibility studies, the research aims to develop an integrated framework for route and station planning. The primary research question guiding this study is: *How can a geospatially informed rapid transit railway system contribute to sustainable urban mobility and economic development in Lusaka?* The proposed intervention aims to provide a scalable, sustainable, and efficient urban mobility solution that can accommodate future growth and align with the city's broader development objectives.

The research is guided by the following objectives:

1. To develop and outline a proposed route for the railway line, taking into account Lusaka's urban layout, flooding risks, and projected population and commuter demand;
2. To determine optimal metro station locations by focusing on major economic hubs and existing bus stations for maximum connectivity and accessibility;
3. To examine existing railway systems through case studies to identify a suitable transit model for integration into Lusaka's urban fabric.

By addressing these objectives, the study seeks to contribute to a framework for sustainable urban transit planning in Lusaka. It also aims to offer practical insights for other rapidly urbanising cities across the Global South facing similar transportation challenges. The urgency of this research is underscored by Lusaka's escalating population density. As shown in Table 1, the district of Lusaka alone has a population density of 5,273 persons per square kilometre—substantially higher than surrounding districts such as Chilanga (166 persons/km²), Chongwe (129 persons/km²), and Kafue (49 persons/km²). This spatial disparity further accentuates the concentration of demand within Lusaka's urban core and the critical need for an efficient, high-capacity public transit solution.

Table 1. Population Density of Lusaka (Source: Zambia Statistics Agency (2022)).

District	Area (km ²)	Population (2022)	Population Density (persons/km ²)
Lusaka	418	2,204,059	5,273
Chilanga	1,354	225,276	166
Chongwe	2,431	313,389	129
Kafue	4,471	219,574	49
Luangwa	3,866	35,933	9
Rufunsa	9,446	81,733	9

According to the Zambia Statistics Agency (2022), Lusaka's steadily increasing population density illustrates the growing pressure on its limited transport systems. Table 1 presents the population density trends in Lusaka, illustrating the city's growing pressure on existing transport systems. The data reinforces the necessity of integrating a rapid transit railway into Lusaka's transport network to enhance mobility, reduce congestion, and support sustainable urban development.

This research contributes to the field in several ways. Firstly, it advances the discourse on sustainable transportation planning in emerging African cities by demonstrating the application of modern geospatial techniques in infrastructure development. Secondly, it provides a replicable framework for transit-oriented planning that can inform similar interventions across the continent. Thirdly, it aligns with global climate and equity goals by proposing a mode of transport that reduces emissions, fosters economic inclusion, and enhances resilience in urban systems.

The methodology integrates spatial modelling, urban land-use analysis, and transport planning frameworks to offer practical insights and strategic recommendations. This interdisciplinary approach contributes to the growing body of literature on urban mobility in Africa by providing context-sensitive solutions rooted in geospatial intelligence and sustainability principles.

The remainder of this paper is structured as follows: Section 2 reviews the relevant literature on public transportation planning, rapid transit systems, and spatial transport modelling. Section 3 details the methodology, including the geospatial tools and data sources used. Section 4 presents the results of the spatial analysis, station design, and environmental assessments as well as discusses the policy implications, feasibility, and limitations of the proposed system. Section 5 concludes the paper by summarising the key findings and offering recommendations for future research and implementation.

2. Literature Review

Urban areas across the globe are increasingly adopting rapid transit solutions to address chronic congestion, environmental degradation, and uneven economic development. Research consistently highlights that efficient and reliable public transportation systems can significantly reduce travel times, lower operational costs, improve urban air quality, and foster social inclusion (Yang, Xu, & Sun, 2021). While much of this success has been observed in developed countries, emerging urban centers in developing nations are beginning to replicate these gains through customized implementations.

2.1 Benefits and Global Trends in Urban Rail Transit

Metro systems have been recognized for their high passenger capacity, operational reliability, and environmental benefits. In cities like Tokyo, Paris, and London, urban rail networks have become integral components of daily mobility, helping shape urban form and economic productivity (Shen & Lin, 2019). These systems reduce greenhouse gas emissions by shifting travelers from private vehicles to more efficient rail modes, supporting climate and public health objectives.

Developing cities are also exploring rail-based transit as a mechanism to address rapidly growing populations and strained road networks. For instance, the Addis Ababa Light Rail Transit (LRT) has improved accessibility for thousands of residents in Ethiopia's capital, despite financial and operational challenges. It illustrates how even resource-constrained cities can implement rail systems that support inclusive urban growth (Nallet, 2018). Similarly, the Delhi Metro has significantly reduced commuting times, enhanced productivity, and spurred real estate development along its corridors (Delhi Metro Rail Corporation [DMRC], 2025).

2.2 Transit-Oriented Development and Urban Integration

The integration of transit planning with land use strategies, commonly known as Transit-Oriented Development (TOD), is critical to maximizing the benefits of urban rail investments. TOD emphasizes compact, walkable neighborhoods centered around high-quality public transport, reducing dependency on private vehicles and promoting economic densification (Yang et al., 2021). In cities such as Curitiba, Brazil, and Singapore, TOD has enabled better spatial equity and efficient urban form.

Empirical studies have found that areas around metro stations often experience increased land values, business activity, and housing density, provided there is supportive zoning and institutional coordination (Cervero, 1998; Knowles, 2012). TOD not only enhances the utility of transit systems but also contributes to the long-term financial sustainability of public transport through farebox and non-fare revenues.

2.3 Criteria for Route and Station Optimization

Optimal metro route planning involves a combination of technical, economic, and social considerations. Factors such as population density, employment clusters, land availability, and intermodal connectivity influence both route selection and station placement. Tools such as **Multi-Criteria Decision Analysis (MCDA)** and **Geographic Information Systems (GIS)** have been widely used to assess and simulate various route alternatives (Guihaire & Hao, 2008; Singh & Sarkar, 2020). Key criteria often applied in station optimization models include:

- Proximity to key activity nodes (commercial, educational, residential)
- Accessibility within a reasonable walking distance (400–800m)
- Integration with other modes of transport (buses, BRT, taxis)
- Avoidance of environmentally or culturally sensitive areas

For example, in Delhi, GIS-based planning combined with socio-economic data helped prioritize station sites that offered maximum utility to the commuting public while minimizing displacement or conflict with existing land uses (Singh & Sarkar, 2020).

2.4 Lessons from Global Urban Rail Case Studies

Numerous global metro systems provide instructive lessons for Lusaka:

- **Delhi Metro (India):** A highly integrated network that prioritizes connectivity, punctuality, and urban regeneration through TOD zones (DMRC, 2025).
- **Addis Ababa LRT (Ethiopia):** Demonstrates both the promise and pitfalls of implementing rail in low-income contexts—particularly around maintenance, electrification, and fare affordability (Nallet, 2018).

2.5 Relevance to Lusaka's Transport Challenges

Lusaka's current transport network is characterized by road congestion, limited public transport coverage, and an over-reliance on informal minibuses. Existing infrastructure struggles to meet growing demand, particularly in peri-urban areas. Recent studies indicate a lack of multimodal integration and insufficient investment in structured transport planning (Mulenga & Smid, 2021). Against this backdrop, the introduction of a rapid transit railway system presents a transformative opportunity. However, for such a system to succeed, it must be strategically aligned with land use policies, inclusive access strategies, and fiscal sustainability models. Lessons from TOD, global transit planning, and successful optimization techniques are critical to tailoring a system that addresses Lusaka's unique socio-spatial dynamics.

Urban areas worldwide are increasingly turning to rapid transit solutions to combat congestion and stimulate economic growth. Research has demonstrated that efficient public transport systems not only reduce travel times and operational costs but also improve air quality and contribute to social inclusion (Yang, Xu, & Sun, 2021). The benefits of metro systems have been well documented in developed regions, where their high capacity, reliability, and environmental advantages have transformed urban mobility (Shen & Lin, 2019).

3. Methodology

This study adopted a quantitative research approach to develop a data-driven framework for designing the proposed Lusaka Metro. The methodology was structured around the three research objectives: (1) mapping and proposing the metro route, (2) identifying optimal metro station locations, and (3) evaluating case studies of existing transit

models to inform system design. The methodology is structured into two main components: materials/tools used and methods employed.



Figure 1. Layout for phase one of Lusaka Metro.

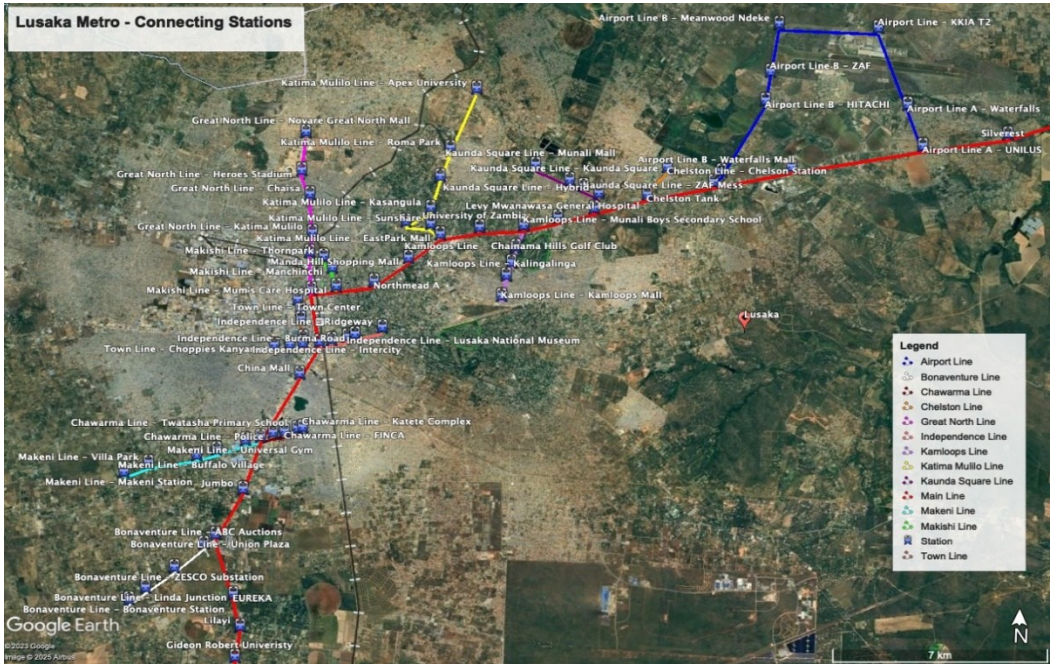


Figure 2. Layout for phase two of Lusaka Metro.

3.1 Materials

3.1.1 Introduction

The materials used in this study supported the development of a proposed metro railway route, the identification of suitable station locations, and the examination of transit models through case studies. Tools included Google Earth for initial mapping, QGIS for refined mapping and distance calculations, and extensive literature on successful metro systems to inform case study analysis.

3.1.2 Development of the Proposed Lusaka Metro Map

Google Earth was selected for the initial mapping of the proposed rapid transit railway owing to its high-resolution satellite imagery and user-friendly interface. This tool provided accurate visualisations of Lusaka’s terrain and existing infrastructure, which facilitated the identification of potential station sites and route alignments. Data extracted from Google Earth were imported into QGIS, where precise distance measurements (using coordinate data in terms of easting and northing) enabled the creation of a detailed metro map. This map comprised the main Chongwe-Kafue line (red), spanning 92.8 km, and 13 branch-off lines, totalling 51.6 km, each assigned a distinct colour for clarity and to enhance navigation.

3.1.3 Case Study Analysis of Existing Railway Systems

Case studies of established metro systems, notably the **Delhi Metro** and **Addis Ababa Light Rail Transit**, were examined to determine a suitable transit model for Lusaka. These systems were evaluated on criteria such as operational efficiency, environmental impact, scalability, and intermodal connectivity. Insights from these cases informed the decision to adopt an electric-powered metro system that utilises a combination of elevated, underground, and at-grade tracks, ensuring alignment with global best practices (DMRC, 2025; Nallet, 2018).

3.2 Methods

3.2.1 Route Selection for the Metro Line

The proposed metro route was determined using Google Earth and refined in QGIS. The route was chosen to maximise connectivity between key economic centres, health facilities, and educational institutions while considering geographical constraints such as flood-prone areas. Optimisation techniques, including shortest path algorithms, were employed to ensure an efficient alignment that minimised construction challenges and land acquisition costs (Delling et al., 2017).

3.2.2 Identification of Metro Stations

Station locations were determined by evaluating factors such as population density, economic activity, and existing transport infrastructure. Data from Google Earth and supplementary maps enabled the precise positioning of stations to serve high-demand areas. This approach ensured that stations were placed in proximity to major transit hubs and commercial centres, thereby promoting high ridership and effective connectivity (Vuchic, 2005).

3.2.3 Distance Measurement and Cost Estimation

Distance measurements between stations were calculated using the Haversine formula to ensure accurate assessments of the total railway length.

The formula is expressed as:

$$= \sqrt{(x_2 - x_1)^2 + (y_2 - y_1)^2}$$

Where:

d is the distance between the two points (in km).

x_2, x_1 are the eastings (longitude coordinates) of the two points.

y_2, y_1 are the northings (latitude coordinates) of the two points (Kumar & Singh, 2016).

Cost estimation was conducted using a bottom-up approach, where unit costs for infrastructure components were derived from global metro projects and adjusted for local conditions in Lusaka. The overall project cost was computed using the formula:

$$C_{total} = \sum_{i=1}^n C_i$$

where C_{total} represents the cost of each component. A contingency of 10% was included to account for unforeseen expenses (Flyvbjerg et al., 2018).

3.2.4 Infrastructure Type Allocation

The distribution of elevated, underground, and at-grade sections was determined by assessing urban density, topographical challenges, and cost considerations. Elevated tracks were favoured in areas with open land and lower population densities, while underground sections were recommended for high-density zones to avoid land acquisition issues. At-grade sections were utilised where feasible to reduce construction costs. This allocation was informed by best practices observed in the Delhi Metro and other global projects (Shen & Lin, 2019).

3.2.5 Integration with Existing Transport Systems

An effective metro system must seamlessly connect with existing transport modes. The study identified key intermodal nodes by mapping existing bus routes, taxi stands, and major roads, ensuring that the proposed metro stations facilitate smooth transfers and improve overall urban mobility (Yang et al., 2021).

4. Results and Discussions

The proposed Lusaka Metro System represents a strategic response to the growing urban transport demands of Zambia's capital. The design features a primary **Chongwe–Kafue corridor** extending approximately **92.8 kilometers**, designated as the **Red Line**, complemented by **13 branch-off lines** totaling **51.6 kilometers**. This integrated rail network aims to serve key residential, commercial, institutional, and industrial zones, providing a backbone for sustainable urban mobility.

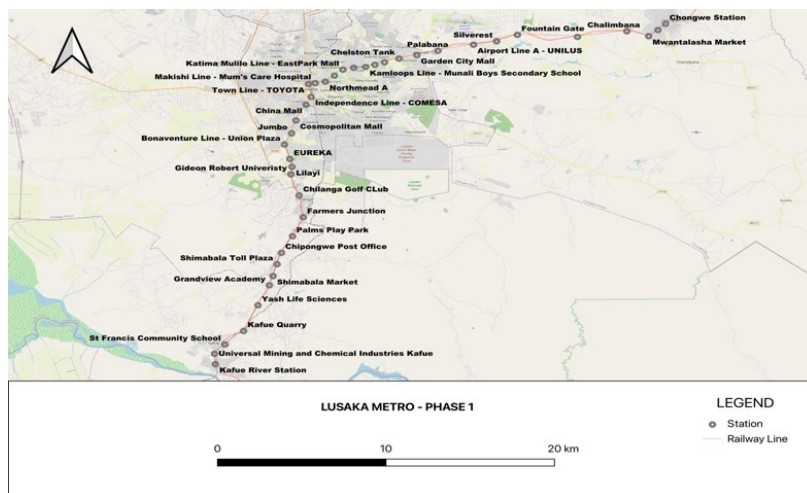


Figure 3. Proposed metro map layout for Lusaka Metro.

A **travel time simulation** was conducted to evaluate journey durations along the proposed routes. Assuming an average operational speed of **60 km/h** and incorporating a **one-minute dwell time** at each station, the estimated travel time from Chongwe (in the east) to Kafue (in the south) was approximately **105 minutes**. This reflects a considerable improvement over current travel times by road, which often exceed 2.5 hours during peak periods due to traffic congestion, poorly maintained roads, and limited public transport options.

In terms of financial planning, **cost estimates** were benchmarked against metro development projects in comparable urban contexts. The analysis suggests that:

- Phase 1 (construction of the main Red Line) would require an investment of approximately USD 5.57 billion;
- Phase 2 (implementation of the branch-off lines) would cost around USD 3.09 billion;
- Additional infrastructure components, including rolling stock, depots, power supply systems, and automated signaling, are projected to bring the total capital outlay to approximately USD 15.14 billion.

While these figures represent a significant financial commitment, the economic and social returns—such as reduced travel times, improved access to jobs and services, environmental benefits, and enhanced urban productivity—are expected to yield long-term value.

The decision to adopt an electric-powered rail system was informed by a comparative case study analysis of the Delhi Metro (India) and the Addis Ababa Light Rail Transit (Ethiopia). Both systems operate on electric propulsion technologies and have demonstrated success in terms of operational efficiency, environmental sustainability, and scalability. Notably, the Delhi Metro's use of regenerative braking and energy-efficient trains, along with Addis Ababa's emphasis on modal integration and affordability, provided valuable insights for the Lusaka context.

The findings from this study suggest that an electric metro system is not only technologically appropriate for Lusaka's environmental and energy landscape but also aligns with Zambia's broader commitments to sustainable development and climate resilience. By reducing reliance on fossil-fuel-powered minibuses and private vehicles, the metro has the potential to significantly cut greenhouse gas emissions, improve air quality, and reduce urban heat island effects.

5. Conclusions

The study set out to determine whether a rapid transit railway system could be viably incorporated into Lusaka's infrastructure, to identify optimal routing and station locations, and to evaluate system design options through comparative analysis. The research successfully answered these questions by using spatial analysis tools (QGIS and Google Earth), transport planning metrics, and global case study benchmarking. The findings affirm the viability of the metro concept in Lusaka, both technically and economically and **potentially transformative** for the city's mobility landscape. Through comprehensive geospatial analysis, travel time modeling, cost estimation, and benchmarking against established systems such as the Delhi Metro and Addis Ababa Light Rail Transit, the research successfully achieved its primary objectives. These included the delineation of an optimal route network, strategic station placement aligned with economic hubs and existing transport nodes, and the selection of an electric-powered metro model tailored to Lusaka's unique urban context. The proposed system, featuring a combination of elevated, underground, and at-grade sections, powered by energy-efficient electric trains, is poised to deliver multiple tangible benefits. Key advantages identified include:

- Substantial reductions in travel times, particularly along the Chongwe–Kafue corridor, enhancing daily commutes and overall productivity;
- Lower operational and maintenance costs relative to conventional bus-based transit modes;
- Improved environmental outcomes through the reduction of greenhouse gas emissions and urban air pollution;
- Strengthened urban connectivity fostering equitable access to employment, education, and healthcare facilities.

While acknowledging critical challenges—such as securing adequate funding, navigating land acquisition complexities, and ensuring community buy-in—the evidence suggests that the Lusaka Metro System can serve as a cornerstone for sustainable urban development and an engine for economic growth in the region. To realize this vision, future research efforts should prioritize the collection of detailed primary data and incorporate

multistakeholder engagement processes to refine route alignments, station siting, and operational frameworks. Additionally, phased implementation strategies, coupled with innovative financing mechanisms including public-private partnerships and international development loans, will be crucial in translating this ambitious infrastructure project from concept to reality.

In conclusion, this study lays a strong foundation for advancing Lusaka's urban transport system into the 21st century, aligning with global trends towards sustainable, efficient, and inclusive public transit solutions.

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Conflict of Interests

The Authors declare that there is no conflict of interest.

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