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Investigating spatial accessibility of public transportation network in Addis Ababa, Ethiopia: The case of Bus stations along Mexico to Hayahulet Road Corridor

By:

Fiyameta Mulugeta

May, 2024

Addis Ababa, ETHIOPIA



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Investigating spatial accessibility of public transportation network in Addis Ababa, Ethiopia: The case of Bus stations along Mexico to Hayahulet Road Corridor

A Thesis Submitted to the School of Graduate Studies of Addis Ababa University, Ethiopian Institute of Architecture, Building Construction and City Development, in Partial Fulfillment of the Requirements for the Award of Master's Degree in Urban Planning

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Declaration

I, Fiyameta Mulugeta G/Tsadik, declare that the research based on "Investigating spatial accessibility of public transportation network in Addis Ababa, Ethiopia: The case of Bus stations along Mexico to Hayahulet Road Corridor" is the result of my personal work and study under the supervision of my research Advisor Dr Dipl- Ing Berhanu Woldetensae, and that all of the study's available materials have been properly recognized. This thesis is my original work and that it has not been submitted partially, or in full, by any other person for an award of a degree in any other university/institution and that all sources of material used for the thesis have been properly acknowledged.

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Confirmation

The thesis can be submitted for examination with my approval as an Institute's advisor.

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This is to certify that the thesis prepared by Fiyameta Mulugeta, entitled: Investigating spatial accessibility of public transportation network in Addis Ababa, Ethiopia: The case of Bus stations along Mexico to Hayahulet Road Corridor, and submitted in partial fulfillment of the requirements for the award of a Master of science in Urban Planning.

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Abstract

This research paper investigates the spatial accessibility of public transportation networks in Addis Ababa, Ethiopia, using Geographic Information Systems (GIS) in the context of time and distance. It highlights the underestimation of nonmotorized travel and the need for accessibility-based planning to address road problems and low transport accessibility in developing countries. This research's main objective is to investigate the public transportation network's spatial accessibility in Addis Ababa, Ethiopia: the case of the Mexico to Hayahulet Route corridor. The methodology is particularly meticulous in terms of measuring the accessibility of bus stops, with a specific focus on walking distances regarded through the average comfortable walking paces and travel time to access different services and activities to be reached within a 15-minute walk. Based on the analysis the first method results illustrate, the existing Bus Stations from Mexico to Hayahulet are accessible to 31300 (62.6 %) individuals settled in 2.79 ha but less than half of the population in that area which is 18700 (37.72 %) individuals settled in 1.68 ha does not have an access to the specified road with a 500m travel distance standard. The accessibility based on time result showed that, around 68.5% of the population can access the bus stations within the standard limit whereas 31.5% of the population will have to walk an extra mile to access the nearest public bus stations. Further research should be conducted in other city areas to create a comprehensive view of public transport accessibility across Addis Ababa.

Keywords: Spatial accessibility; Public transportation network; Geographic Information Systems (GIS); Sustainable transportation system

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Dedication

This study is dedicated to my MOM, **Ananase Abebe**.

I hide my tears when I say your name, but the pain in my heart is still the same.

Although I smile and seem carefree, there is no one who misses you more than me.

Fiyameta Mulugeta

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Acronyms and Abbreviations

A	Area
AA	Addis Ababa
AACTA	Addis Ababa City Transport Authority
AACRA	Addis Ababa City Roads Authority
AAEPA	Addis Ababa Environmental Protection Authority
AAPDC	Addis Ababa Plan Development Commission
AHP	Analytical Hierarchy Process
ARCGIS	Aeronautical Reconnaissance Coverage Geographic Information System
Art.	Articles
CBD	Central Business District
CSA	Central Statistical Agency
DA	Destination Accessibility
FDRE	Federal Democratic Republic of Ethiopia
FR	Frequency Ratio
GIS	Geographic Information Systems
GPS	Global Positioning System
Ha	Hectare
Hr.	Hour
IT	Information Technology
ITMP	Integrated Transport Master Plan
JPEG	Joint Photographic Experts Group
Km	Kilometer
LRT	Light Rail Transit
LUD	Land Use Development
M	Meter
MWUD	Ministry of Works and Urban Development
NHTS	National Household Travel Survey
NTP	National Transport Policy of Ethiopia
OA	Origin Accessibility
PAS	Principal Arterial Street

PT	Public Transit
PTn.	Public Transportation
SNAPTA	Spatial Network Analysis of Public Transport Accessibility
Tiff	Tag Image File Format
TDM	Transportation Demand Management
TOD	Transit Oriented Development
UN	United Nations
WD	Walking Distance
WGS 1984	World Geodetic System 1984

CHAPTER ONE: INTRODUCTION

1.1 Background of study

Cities can be better places to live if the transport system allows them the freedom of movement and enhances the accessibility to essential services (health, education) and to working places (Minister of Transport and Logistics, 2022).

Providing comfortable, safe, dependable, efficient, and equitable transport service for the city of Addis Ababa is a condition to accelerate the development of the city, and make a competent city on regional, continental and international levels. The provision of implementable policy and strategy is a crucial factor to the stated needs (Ethiopia Ministry of transport, 2011).

Accessibility refers to people's ability to reach desired services and activities, which is the ultimate goal of most transport activities. Many factors affect accessibility, including mobility (physical movement), the quality and affordability of transport options, transport system connectivity, mobility substitutes, and land use patterns (Litman, 2022).

Accessibility may be assessed from a variety of angles. It is frequently measured for specific users, modes, activities, locations, times, and scales, such as the number and types of jobs or stores available to low-income non-drivers in a specific neighborhood, or aggregated to measure multiple people's ability to access multiple services and activities in an area (Levinson & Wu, 2020).

Accessibility-based planning justifies more multimodal planning and development policies which create more compact neighborhoods, so any household that wants can find suitable homes in areas where it is easy to get around without driving, often called 15-minute neighborhoods, meaning that commonly-used services and activities can be reached within a 15-minute walk or bike ride. This helps achieve various economic, social and environmental goals (Duany & Steuteville, 2021).

Simmonds & Still, (1998) defined accessibility as “a way of measuring the ease with which a particular category of persons can reach a defined set of destinations, from a given origin (origin accessibility), or the ease with which a particular set of potential individuals can reach a given destination (destination accessibility).

Access is the ultimate goal of most travel activity, so accessibility-based planning tends to reflect best what users want from a transportation system; and offers the broadest range of potential solutions to transport problems. Accessibility-based planning increases support for slower but more affordable and resource-efficient modes, such as walking, bicycling and public transit (Litman, 2022).

Walking is essential mode, both by itself and to provide access to motorized modes, including parked cars and public transit. Walkability indicators are an important but often undervalued accessibility factor ((Pajares, Büttner, Jehle, Nichols, & Wulfhorst, 2021) and (Rowlands, 2020)).

So, public transportation that is effective and easily accessible is essential for urban growth and raising the standard of living for citizens in the modern world. Transportation planners and policymakers use Geographic Information Systems (GIS) to examine the spatial accessibility of public transportation networks in order to accomplish this. The purpose of this research paper is to examine the spatial accessibility of the public transportation network in the case of Mexico to Hayahulet Road segment using GIS; and assess the existing situation of the public transportation road network based on time and distance framework. Evaluating if the study area has adequate spatial accessibility by public transportation system and finally offering viable solutions to Addis Ababa city's concerns.

1.2 Problem statement

Accessibility is affected by the quality of system integration, such as the ease of transferring between modes, the quality of stations and terminals, and parking convenience (Litman, 2022). But due to the increasing urban population and the changing way of life, road transport in most developing countries suffers from many problems like high accident levels, inadequate infrastructures both in capacity and availability, poor quality infrastructure and mismatch between demand and supply. These problems are caused by high urbanization, city growth and lack of proper transport planning and management strategies in the cities of Third world countries. Such cities, especially those found in Africa and mostly capital cities like Addis Ababa (Birhanu, 2016).

As Ethiopia is a developing country, the transport service accessibility is low compared to the developed countries. The mobility rate observed in Addis Ababa is also meager. In the cities of

developed nations average mobility rate per person or trip/day is 2.5. According to the 2005 transport study the Addis Ababa mobility rate or average trip/day/person is 1.08. In this respect the average length of mobility covered by vehicle is 3.3 km and that of 1.5 km by walking on foot (Kassahun, 2007). In developed countries, the average length of walking trips varies from just under 1 km (Great Britain) to 2.8 km (Finland) (European Commission, 2023).

The old, mobility-oriented paradigm recognized the increased access that wider roads and increased parking supply provide to motorists, but it paid little attention to the decrease in walking, bicycling, and public transit access that wider roads, higher traffic speeds, and more dispersed development provide (Litman, 2022).

Traditionally, Transport planning focuses on the public provision and financing of transportation assets, particularly roads and public transit systems. Its emphasis on accommodating private vehicles and improving traffic flow (Rodrigue, Notteboom, & Slack, 2017). However, different scholars describe accessibility-based planning as helping people access essential destinations and services. It focuses on improving the ability of individuals to reach desired locations, regardless of the mode of transportation used. The objective is to reduce public transport travel time and enhance connectivity between residential areas and key destinations such as schools, workplaces, healthcare facilities, shopping centers, and recreational areas (Bos & Lee, 2012; Litman, 2022).

Travel statistics frequently undercount and undervalue nonmotorized travel by disregarding short trips, children's travel, non-commute trips, and non-motorized linkages of motorized travels. Increased vehicle traffic volumes and speeds are recorded, but declines in walkability and land use accessibility are frequently disregarded. Short trips, nonmotorized trips, travel by children, and non-commute trips are often undercounted or ignored in transport surveys, models, and analysis (Litman, 2022).

As the world population increases, life requires competition which requires increased mobility and accessibility. The ability of moving from place to place with comfort, reasonable cost and desired time is one of the major factors affecting the competency of individuals. Human beings use different modes of transport for mobility. The growth of modes of transport varies based on the level of development of countries (Ethiopia Ministry of transport, 2011).

Contrary to the fast growth of the city, the Addis Ababa road network suffers many problems such as narrowness, lack of pedestrian walkways, poor quality of roads, poorly designed road junctions, low accessibility, lack of street parking facilities and over utilization of off-street parking facility, over utilization of road spaced by parked vehicles, substandard terminals for passengers and freight transport and inconvenient bus and taxi ways, lack of segregated bikeways (Birhanu, 2016).

In the rapidly growing urban landscape of Addis Ababa, Ethiopia, the spatial accessibility of public transportation networks has become a critical concern, particularly along the Mexico to Hayahulet Road corridor. The increasing demand for efficient and reliable public transportation is met with challenges related to the distribution and accessibility of bus stations along this route. This study aims to address the inadequacies in the spatial organization of bus stations, analyzing the existing network's effectiveness and identifying potential areas for improvement. As urbanization and population growth continue, ensuring an optimized public transportation system along this corridor becomes imperative for enhancing overall mobility, reducing congestion, and promoting sustainable urban development.

The specific issues to be investigated include the uneven distribution of bus stations, potential gaps in coverage, and the impact of station locations on the accessibility and convenience for the population. This research seeks to provide valuable insights for urban planners, transportation authorities, and policymakers by investigating the spatial dynamics of the current public transportation network. Ultimately, the goal is to propose informed strategies that enhance the spatial accessibility of bus stations, ensuring an efficient and equitable public transportation system that meets the evolving needs of Addis Ababa's residents along the Mexico to Hayahulet Road corridor.

1.3 Research questions

- ✓ What is the existing situation of the public transportation network along the path of Mexico to Hayahulet road?
- ✓ How to analyze the spatial accessibility of the public transportation network along the path of Mexico to Hayahulet road based on distance?
- ✓ How analyze the spatial accessibility of the public transportation network along the path of Mexico to Hayahulet road based on time?

- ✓ How to evaluate if the study area has adequate spatial accessibility by public transportation along the path of Mexico to Hayahulet road path

1.4 Objectives of study

1.4.1 General objective

This research's main objective is to investigate the public transportation network's spatial accessibility in Addis Ababa, Ethiopia: the case of the Mexico to Hayahulet Route corridor

1.4.2 Specific objectives

- Evaluating if the study area has adequate spatial accessibility by public transportation along the path of Mexico to Hayahulet road path
- To examine the existing situation of the public transportation network along the Mexico to Hayahulet road
- To evaluate the connectivity of the path along Mexico to Hayahulet road
- To analyze the time efficiency along the path of Mexico to Hayahulet road
- To provide possible recommendations that enhance the accessibility of bus stops in Addis Ababa

1.5 Scope of the study

Spatial scope

The geographic scope of the research is around Mexico to Hayahulet road that has a distance of 4.9 km. It has a Principal Arterial Street (PAS) with the width of 40m from East to West. The first objective aims to assess whether the study area has sufficient public transportation options and infrastructure to meet the needs of the people using this road. By assessing the availability and quality of public transportation options along the Mexico to Hayahulet road. It would examine factors such as the proximity of bus stops or stations to residential areas, commercial centers, and other important destinations. It could also involve evaluating the coverage and frequency of public transportation services along the road. The second objective focuses on analyzing factors such as the types of transportation modes available, the frequency of service, the locations of bus stops or stations, and any existing challenges or limitations. By gathering data and information about the current state of the public transportation network that serves the Mexico to Hayahulet road. The third objective involves analyzing the connectivity between Mexico to Hayahulet road and other major roads, transit hubs, and important destinations in the study area. This evaluation would consider the ease of accessing the route by walking. The

fourth objective analyze the time efficiency along the path of the Mexico to Hayahulet road for pedestrians, it considers factors such as walking distances, pedestrian infrastructure, and potential obstacles or bottlenecks. By aligning the specific objectives with the defined spatial scope of the Mexico to Hayahulet road, conduct and focus on the analysis that addresses the accessibility, connectivity, time efficiency, and recommendations for improving the public transportation network along this specific route.

Thematic Scope

This research has focused on the spatial accessibility of the public transportation network along the path of Mexico to Hayahulet road. It is found in Kirkos sub-city. To properly achieve the goal of this research, different data collection methods were used like desk review to identify the spatial accessibility of public transportation networks by assessing the existing situation of public transportation networks along the path of Mexico to Hayahulet road using time and distance criteria.

Temporal Scope

The temporal scope of this research study covers a specific timeframe or duration during which the analysis will be conducted. The study will focus on data collected and observations made from [Jan-19-2023] to [Nov-10-2023]. This timeframe allows for a comprehensive assessment of the spatial accessibility, existing public transportation network, connectivity, and time efficiency along the Mexico to Hayahulet road. By setting clear temporal boundaries, the study aims to provide an accurate snapshot of the conditions and dynamics within the specified period. The assessment of the spatial accessibility of public transportation network along the section of Mexico to Hayahulet road was completed in eleven months.

1.6 Significance of the study

The vision of the Transport Policy of Addis Ababa is “To see the transport service accessible to all and play major role for the city’s development”. Addis Ababa, Ethiopia’s administrative and financial capital, is experiencing continuous growth and change. It is genuinely accepted that; change is experienced in all dimensions of the city but different parts grow at different rates. The road network expansion didn't meet the transportation needs, especially for public transport, that did not effectively address the increasing demand for transportation services. The growth in the number of people relying on public transport was not adequately considered during the

expansion, leading to a mismatch between the road capacity and the requirements of the public transportation system.

This study is significant in identifying the spatial accessibility of the public transportation network by assessing the existing situation of the public transportation network along the path of Mexico to Hayahulet road in a time and distance framework. Furthermore, by identifying if it has an adequate spatial accessibility of public transportation system in the area.

The research outcomes consider the followings: -

- ✓ It suggests a direction to reduce the problems and gaps that are found in the spatial accessibility of public transportation network
- ✓ It also enables the Addis Ababa city government to recognize the challenges occurring in spatial accessibility of the public transportation system. It offers viable solutions to the city's problem along the path.
- ✓ It is also an essential input for further research in the gap of GIS-based analysis on spatial accessibility of public transportation system.

1.7 Research limitations

The research is limited in the selected area and was only focused on spatial accessibility of the public transportation network along the path of Mexico to Hayahulet road in a time and distance framework. The Research is limited by the availability of documents and information that was collected through different methods. However extensive literature reviews related to the topic have been covered that include the theoretical framework and conceptual framework that can well describe this research and real-world application of the topic has been explored to build a general insight about the research that was conducted.

1.8 Organization of the research

This research is presented within five main chapters. Chapter one is an introduction part that contains the back ground of the study, the problem statement, objectives, research questions, scope of the study, and the significance. Chapter two reviews literatures that help to guide the research. Chapter three contains the research methodology. Chapter four is the result and discussion section and chapter five is the conclusion and recommendation section.

CHAPTER TWO: LITERATURE REVIEW

A fundamental approach to urban planning is beginning to emerge, one that goes beyond the traditional significance of roads and traffic flow. Accessibility-based planning takes center stage, bringing attention to the areas of walking, bicycling, and public transportation that are frequently disregarded. This paradigm change prioritizes connection for all forms of transportation, with an emphasis on getting to essential destinations, in addition to optimizing traffic. This research explores the significance of accessibility-based planning, how it affects urban growth, and how it may be used to build more sustainable and inclusive cities.

There are three primary sections in this chapter: theoretical, empirical, and conceptual review. Theoretical definitions of concepts are presented, as well as relevant literature that is related to GIS based analysis on Spatial Accessibility of Public Transportation Networks are reviewed in the empirical review section. By identifying the strengths and the weaknesses of the related articles and finding out what was the gap of previous studies. Meanwhile, the conceptual review attempts to identify the existing theories, concepts, and research studies that are relevant to the research question and problem statement. So, it reviewed related literature on investigating spatial accessibility of public transportation networks based on distance and time framework.

2.1 Definition of Key Terms

The following set of definitions is mainly based on use in the context of this study.

Accessibility: it is the design and creation of products, services, environments, and digital content that can be accessed and used by individuals with disabilities or any other diverse needs. It ensures that people with disabilities have equal opportunities to participate in various aspects of society, such as education, transportation, communication, and public spaces (UserTesting, 2023).

Network analysis: in public transportation refers to the study and evaluation of transportation networks, such as bus, train, or subway systems, to understand their efficiency, connectivity, and performance (Dai, Ding, Liu, & Liu, 2022).

Public transportation: refers to a system of transportation available for use by the general public, often operated by government or private entities. It typically includes modes of transportation such as buses, trains, trams, subways, and ferries accessible to anyone and used for

traveling between different locations within a city or region. It aims to provide a convenient, cost-effective, and environmentally friendly alternative to individual car usage, reducing traffic congestion and promoting sustainable mobility (Wikipedia, 2023).

Public transport network: refers to a system of interconnected and publicly accessible transportation services that are designed to carry passengers within a specific region or area. This network typically includes various modes of transportation, such as buses, trains, subways, trams, and other forms of public transit. A public transport network aims to provide efficient, affordable, and convenient transportation options for the general public, facilitating the movement of people within urban, suburban, or rural areas. The network is characterized by organized routes, schedules, and infrastructure to ensure passengers' smooth and reliable flow across different modes of transportation (Rodrigue & Ducruet, 2023).

Spatial accessibility: one is the spatial impedance between demand and supply, and the other is the availability of services (i.e., the amount of supply available to a population group) (Birhanu, 2016).

Travel distance is the distance between demand (Bus Station) and supply (Residential) through walking mode.

2.2 Theoretical Review

Accessibility theory refers to the idea that the ease of reaching a destination is a key determinant of its desirability; it is measured consistently as a product of the travel impedance and the corresponding opportunities reachable (Wu & Levinson, 2020). It helps transportation planners and policymakers to understand how people evaluate the fairness of transportation services and infrastructure. For example, accessibility theory proposes that individuals might perceive transportation services and infrastructure as equitable when they are easily accessible, convenient, and reliable. On the other hand, if transportation services and infrastructure are hard to access, inconvenient, or unreliable, individuals may perceive them as inequitable (Liftango, 2020).

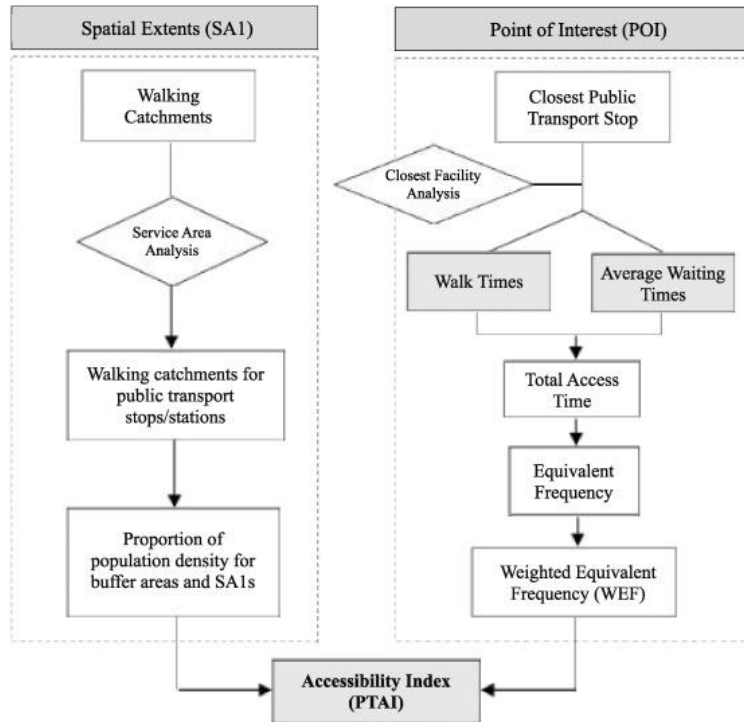


Fig 2. 1 Accessibility Index

Source: - Moridpour, Thompson, & Saghapour (2016)

Furthermore, accessibility theory can be used to evaluate transportation policies and initiatives to improve accessibility for disadvantaged groups, such as people with disabilities, low-income individuals, and older adults. These policies may include providing accessible vehicles, improving transit routes and schedules, and making infrastructure modifications to improve accessibility (Litman, 2022).

Overall, accessibility theory can help transportation planners and policymakers better understand how people evaluate the fairness of transportation services and infrastructure, and design policies and initiatives that improve accessibility for all members of society.

2.2.1 Network Analysis

Transportation Network Analysis is concerned primarily with the spatial, but also the temporal, nature of the movement of people and freight across land, where the movement is channeled onto roads or railways (Michael & Yasunori , 1997). Network analysis in public transportation refers to studying and evaluating of transportation networks, such as bus, train, or subway systems, to understand their efficiency, connectivity, and performance. It involves analyzing transportation networks' structure, flow, and characteristics to optimize their design, operations, and planning.

It can help identify the critical nodes and links in the transit network and analyze the flow of passengers between them (Dai, Ding, Liu, & Liu, 2022).

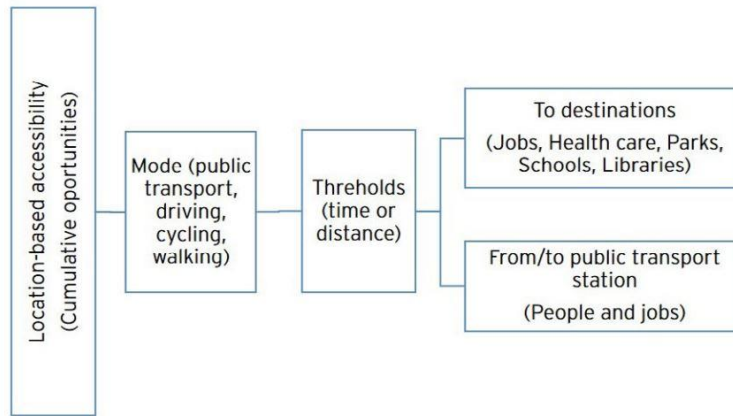


Fig 2. 2 Types of accessibility metrics used in regional land use and transportation plans

Source: - Boisjoly & El-Geneidy (2017)

Network analysis is a useful tool in the planning and administration of public transportation to examine linkages and interactions between various components of the transportation system. It helps with the analysis of traffic flows, congestion, and accessibility as well as the identification of key nodes (like bus stops and train stations) and edges (like transit lines and roads) within the transportation network. One application of network analysis in public transportation is route optimization. By analyzing the transportation network, planners and managers can identify the most efficient routes for buses, trains, and other modes of transportation, and determine the optimal frequency and timing of services. This can help to improve the overall efficiency and effectiveness of the transportation system, while also improving accessibility for users (Rodrigue J. P., 2017).

Additionally, network analysis can reveal vulnerable or disrupted areas in the transportation network, including bottlenecks, high-traffic intersections, and areas with poor road conditions. By identifying these areas, transportation planners and managers can devise strategies to mitigate disruptions and enhance the overall reliability and performance of the transportation system.

Network analysis is a powerful tool for public transportation planning and management, as it allows for the analysis and optimization of complex transportation networks. By using network analysis to improve the efficiency, accessibility, and reliability of public transportation systems,

transportation planners and managers can help to create more sustainable and livable communities.

2.3 Conceptual Review

2.3.1 The concept of Spatial Accessibility

Transportation is the conveyance of “*people, goods and information from one place to another or it is the relocation of people, goods and information over space*”. Therefore, transportation has a direct impact on people’s day-to-day activities, especially in large cities where the distance to be traveled is too far to cover on foot or by bicycle within a reasonable time (Birhanu, 2016, p. 12).

Accessibility refers to people’s ability to reach desired services and activities, which is the ultimate goal of most transport activities. Many factors affect accessibility, including mobility (physical movement), the quality and affordability of transport options, transport system connectivity, mobility substitutes, and land use patterns (Litman, 2022).

Accessibility is one of the critical characteristics of urban transport and it shows the relationship between transport and land use (Liu & Zhu, 2004). Accessibility is used as a key element in the efficiency analysis of transport network and infrastructure planning (Gutiérrez, González, & Gómez, 1996), and to generate the travel demand on public transport (Sullivan, Morrison, & Shearer, 2000).

Accessibility may be assessed from a variety of angles. It is frequently measured for specific users, modes, activities, locations, times, and scales, such as the number and types of jobs or stores available to low-income non-drivers in a specific neighborhood, or aggregated to measure multiple people's ability to access multiple services and activities in an area (Levinson & Wu, 2020).

Accessibility is the main “product” of a transportation system. It determines the locational advantage of an area (a region, a city or a corridor) relative to all areas (ESPON, 2005).

Indicators of accessibility measure the benefits households and firms in an area enjoy from the existence and use of the transportation infrastructure relevant to their area. The critical role of transportation infrastructure for spatial development in its most simplified form implies that

areas with better access to the locations of input materials and markets will be more productive, more competitive and hence more successful than more remote and isolated areas (ESPON, 2005).

Transportation planning is experiencing a paradigm shift, a fundamental change in how problems are defined and solutions are evaluated (Litman, 2013). This involves a change from traffic-based analysis which evaluates transportation system performance based on motor vehicle travel speeds and operating costs, and mobility-oriented analysis which evaluates transport system performance based on persona and freight travel speed and costs, to accessibility-based analysis which evaluates transport system performance based on people and businesses' ability to reach desired services and activities. So, this concept shows that traffic is a subset of mobility, and mobility is a subset of accessibility as illustrated below (Litman, 2022).

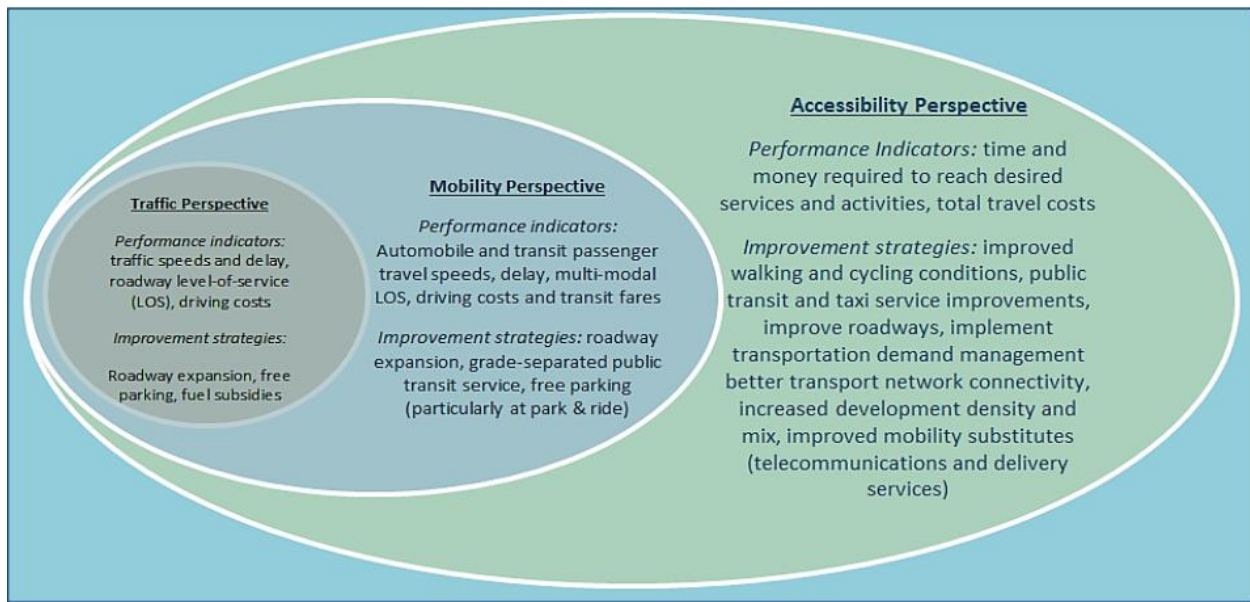


Fig 2. 3 Traffic, Mobility and Accessibility

Source, Litman (2022)

Accessibility-based planning reflects the transportation system user's experience. For example, it evaluates door-to-door travel times, considering all links and connections, and total transportation costs. It expands the range of potential transportation improvement strategies. It recognizes the value provided by non-auto modes and mobility substitutes (walking, bicycling, public transport, telework and delivery services, TDM strategies that increase transport system

efficiency, and Smart Growth development policies that create more compact and mixed communities that provide more excellent proximity (Litman, 2022).

Various scholars like Birhanu (2016), Vulevic (2016), Andualem & Takele (2018), Litman (2022), provide differing definitions of accessibility-based planning as a form of urban planning strategy that concentrates on enhancing access to goods, services, and prospects for individuals, especially those who face marginalization or disadvantages. The aim is to establish more equitable and inclusive communities by guaranteeing that all inhabitants possess equal entry to the resources necessary for their well-being. This approach takes into account numerous considerations, including the availability and quality of public transportation, the location and accessibility of employment opportunities, the presence of community services and facilities, as well as the physical accessibility of public spaces and structures. By evaluating these factors, urban planners can identify areas of a city that are underserved and prioritize investments in infrastructure and services that will improve accessibility for everyone.

Accessibility-based planning defines accessibility as the number of services and jobs people can access within a certain amount of travel time, considering multimodal modes of transport such as walking, biking, driving and the use of public transport. This approach implies a paradigm shift: urban and traffic planners focus on people and their needs instead of the infrastructure system itself. These needs can imply sustainable goals, such as social inclusion, economic urban potential or ecological preservation (Bos & Lee, 2012).

Accessibility and physical barriers in the urban environment, and have a negative impact on the lives of people with disabilities, who are prevented from carrying out daily tasks and from moving freely in attractive and desirable places (Hacini, Bada, & Pihet, 2022). Accessibility-based planning is significant for people with disabilities, older adults, low-income households, and other groups that may face barriers to accessing essential resources. By improving access to transportation, employment, healthcare, and vital services, accessibility-based planning can help to reduce inequality and improve the quality of life for all residents. It boosts the quality of life by enhancing an area's livability and increasing its competitiveness. It also can contribute to better health and wellness within that space (Oberg, 2022).

Accessibility-based planning allows planners to understand interdependencies between transport and land use development. More specifically this implies developing urban regions that offer people and firms the means to reach more opportunities with less mobility (Bos & Lee, 2012).

The concept of accessibility is well-known and extensively researched in the scientific literature. Good transportation accessibility is undoubtedly an essential factor in exploiting spatial potentials. The quality of transportation infrastructure in terms of capacity, travel speed, connectivity etc., determines the quality and advantage of a location relative to other locations, which is usually measured as accessibility (Vulevic, 2016).

The concept generally considers the combination of two elements the location on a surface relative to suitable destinations, and the characteristics of the transport network (Vickerman, 1974).

Some scholars considered how different approaches have been used to measure regional spillover effects and proposed a new methodology based on GIS and accessibility indicators to measure spatial spillovers of transport infrastructure investment (Gutiérrez, Condeço, & Martín, 2010).

But some outlined the concept and methodology of a Spatial Network Analysis of Public Transport Accessibility (SNAPTA) model for measuring the accessibility by public transport to different urban services and activities, and presented the findings related to this pilot study with a focus on changes in potential accessibility to jobs between four different public transport network scenarios (Karaou & Hull, 2014).

SNAPTA is GIS-based accessibility instrument that defines accessibility as “whether or not people can get to services and activities at a reasonable cost, in reasonable time and with reasonable ease”. Three measures or indicators of accessibility are used: Time access to the city center by public transport from each zone during the morning peak hour travel to the Central Business District (CBD). A contour measure that calculates the total number of economic activities or destinations within a maximum travel time by public transport for different trip purposes (Hull & Karou, 2012).

The SNAPTA model influences advanced network analysis techniques to calculate the travel durations and distances connecting transit stops and various destinations, including employment

centers, residential areas, and commercial districts. By considering factors such as the frequency of transit services, the location and capacity of transit stops, the urban environment's physical and social attributes, it accurately determines the most efficient routes for commuters. This comprehensive approach ensures that the model provides precise information to help individuals navigate their journeys effectively, considering the specific features of the transit network and the surrounding urban landscape.

The SNAPTA model is useful for policymakers and urban planners to estimate the potential impact of infrastructure developments on accessibility patterns. This approach provides valuable insights for decision-makers in making informed choices that enhance transportation systems and promote efficient urban development. It can also be used to evaluate the impacts of changes in transit service, such as route modifications, changes in service frequency, or the introduction of new transit modes (Karaou & Hull, 2014). Overall, the SNAPTA model is critical in improving the efficiency and accessibility of public transportation networks, which benefits the entire community (Karaou & Hull, 2014).

Liu & Zhu (2004) define accessibility as the individual's possibility to take advantage of resources with fixed location in space that requires presence. It is evident that the possibility of distance restricts access to resources. It is evaluated based on the time, money, discomfort and risk required to reach opportunities. Maximizing accessibility, along with minimizing travel, revitalizing central centers, minimizing environmental impacts and reducing social inequities, has become an important agenda in urban transportation planning.

In measuring the performance, quality and level of provision of urban services, accessibility has been employed in different forms as an indicator of the guiding principles of equity, efficiency (Hodgart (1987) and effectiveness (Sheriff, 2005)). Planners and politicians use accessibility indices to bolster their everyday propositions (Baradaran & Ramjerdi, 2001).

Accessibility is strongly affected by the design of infrastructure such as public transportation routes and stops, road network, and the availability of various LUDs (Land Use Development) in a close proximity. It is also influenced by problems such as the legibility of a timetable and the perception of safety (Tyler, 1999).

Bertolini, Clercq, & Kapoen; (2005) argue that accessibility can be directly related to both the qualities of the transport system (e.g.travel speed), and the qualities of the land use system (e.g., densities and mixes). At the same time, it can also be directly related to economic goals (access to workers, customers, suppliers), social goals (access to employment, goods, services, social contacts), and environmental goals (resource efficiency of activity/mobility patterns).

2.3.2 Empirical Review

2.3.2.1 Previous Research Studies

It is empirically proven that public transport makes cities more inclusive, safe and sustainable. Effective and low-cost transportation is critical for reducing urban poverty and inequalities and enhancing economic development because it provides access to jobs, health care, education and other public goods (UN-Habitat, 2018).

Analysis of GIS-based accessibility to destinations using public transport research paper focuses on the importance of accessibility to destinations, as it affects the daily lives of individuals, especially in urban areas. It aims to develop a methodology that can measure accessibility to destinations using public transport. It can also be used to inform urban planning decisions and improve public transportation systems. It uses different variables such as travel time, distance, and mode of transport. It also presents a case study of applying the methodology in the city of Pilsen, Czech Republic. The results of the study showed that the methodology can effectively measure accessibility to destinations using public transport (Hussein & Asmael, 2021)

Another paper written by Cyril, Mulangi, & George, (2019) discusses developing a composite public transport accessibility index using (GIS) as a case study of an Indian city, Trivandrum. The index measures the accessibility of different areas based on their proximity to bus stops and land-use destinations. The study finds that the city's central area has higher accessibility values, indicating a greater availability of opportunities compared to the periphery. This is because of a higher concentration of population, more bus stops, and a denser road network in the central area. The visual representation of the index helps identify areas with limited accessibility, which can aid in route planning, adding new buses in high-density zones, connecting missing links in the network, and increasing accessibility in the city outskirts.

The GIS-based accessibility index can serve as a valuable decision support tool for transit operators and planners due to its ease for planners to evaluate and ensure moderate accessibility

(Cyril, Mulangi, & George, 2019). This study is an excellent illustration of how to do this type of investigation in our city of Addis Ababa to produce findings that will help urban planners make better decisions.

The article written by Andualem and Takele, (2018) discusses the analysis of spatial accessibility, user population, and coverage of the Light Rail Transit (LRT) system in Addis Ababa. The study integrates spatial and statistical analysis methods to identify the factors affecting accessibility to LRT stations. The findings reveal that stations are the least accessible due to various factors such as land use and road network characteristics. These factors include large government and social institutions, low road network density, open spaces without road networks, natural barriers like water courses, and large public squares. The study also identifies stations with overlapping service areas and neighborhoods not covered by the current service areas. Therefore, considerable service area overlap is considered wasteful and does not contribute to increasing the number of users.

In conclusion, the study highlights the importance of spatial accessibility analysis in transportation systems, particularly GIS technology. It provides insights into the challenges faced by LRT stations in Addis Ababa. It offers recommendations for improving accessibility by addressing road network density and considering various factors influencing user numbers (Andualem & Takele, 2018).

As cited in Cyril, Mulangi, & George, (2019) from Bhat C., et al., (2000), the paper explores the different measures of accessibility that determine the relationship between land use and transport. These measures are classified into five categories: spatial separation, cumulative opportunity, gravity, Logsum or utility, and time and space models. The spatial separation measure is the simplest, considering only distance as a variable. The cumulative opportunity measure takes considers both distance and the purpose of the trip, using accessibility based on the number of potential activities within that distance or time. The gravity measure considers both attraction and separation factors, considering the attractive force and the impedance of intervening space. The utility measure focuses on the perceived utility of the traveler. Time and space models determine accessibility based on spatiotemporal constraints, considering both spatial and temporal aspects.

2.3.3 Legal framework of spatial accessibility of public transportation in transport policy of Addis Ababa

Minister of Transport and Logistics, (2022) stated that the key role played by the transport sector in ensuring economic and social growth for the whole country is widely recognized by the National Transport Policy of Ethiopia (NTP) which states that its mission is:

“To benefit our society equally and create linkage and economic integration among people; support and speed up the economic development; attain accessible, integrated, efficient, effective, reliable and transparent system that considers paying ability and is supported by Information technology”.
(*Minister of Transport and Logistics, 2022*)

The Minister of Transport and Logistics in Ethiopia oversees and coordinates all aspects of the country's transportation system, including roads, railways, airports, and ports. One of their key responsibilities is to ensure that the transportation system is efficient, safe, and accessible to all citizens, including those in rural and remote areas. In terms of public transportation, the Minister would be responsible for ensuring adequate infrastructure and services to meet the population's needs. This would include the spatial accessibility of public transportation; or the degree to which people in different parts of the country can access public transportation services (International Trade Administration, U.S. Department of Commerce, 2022).

Transportation must be equal and accessible to all. By making sure that the transport sector competently contributes to enhancing the overall economic development and social interaction; Start making the transport sector convenient, efficient, safe and accident-free, by supporting it with Information Technology (IT), constructing reliable and accessible transportation network system; and also ensuring our country's strategic, economic, and social benefits has a secure a fair and effective transportation infrastructure and service operation (Minister of Transport and Logistics, 2022).

The administration of the transport sector is based on the constitutional principles of the FDRE. The primary principle states (Articles 51.9 and 55.2.c) that responsibilities assigned at the Federal level (Federal Government and House of Representatives) concerns the development, administration and regulation of air, rail, waterways and sea transport and major roads linking two or more Regional States. Below the Federal level, the Regional States are responsible for

construction, maintaining, and managing of roads that start and end in their boundary. Moreover, the Federal Government may delegate the Regional States to exercise its powers (Art. 50.9), though no such delegation has been made for transport matters (Ethiopia Ministry of transport, 2011).

In Addis Ababa, Ethiopia, a transport policy that has been developed to enhance the spatial accessibility of public transportation within the city. This policy is established primarily through the Addis Ababa City Government Transport Program Regulation No. 197/2011, which sets forth the fundamental principles and guidelines for the city's transport initiatives (Ethiopia Ministry of transport, 2011).

The regulation aims to achieve several key objectives, including the improving of safety and efficiency within the transport system, the promoting sustainable modes of transportation, and assuring equal access to the transport network for all residents, regardless of their location or socioeconomic status. The policy focuses on expanding the transport network, encouraging the use of non-motorized modes of transport, and ensuring that public transportation services are affordable and of high quality (Ethiopia Ministry of transport, 2011).

According to Ethiopia Ministry of transport (2011), by implementing these measures, the city of Addis Ababa seeks to create a transportation system that prioritizes the well-being and safety of its residents and contributes to a sustainable and accessible urban environment for everyone. The regulation establishes several key provisions for the city's transport policy, including:

1. Development of a comprehensive transport strategy that considers all stakeholders' the needs and preferences.
2. Establishment of a Transport Management Agency to oversee the implementation of the transport program.
3. Promotion of sustainable modes of transport, such as walking, cycling, and public transport, to reduce the reliance on private vehicles.
4. Expansion of the public transport network to ensure that all areas of the city are well-connected and accessible to residents.
5. Improvement of the quality and safety of public transport services through the regulation of operators and the establishment of minimum service standards.

6. Promotion of non-motorized transport modes, such as walking and cycling, through developing pedestrian-friendly streets and sidewalks and the constructing dedicated cycling infrastructure.
7. Encouragement of the use of environmentally friendly vehicles and fuels to reduce the impact of transport on the environment.

In addition to the Transport Program Regulation, the city has also developed many other legal frameworks and guidelines to improve the spatial accessibility of public transportation. These include guidelines for the construction of pedestrian-friendly streets and sidewalks, regulations for the operation of public transport services, and standards for the design and construction of transport infrastructure (Ethiopia Ministry of transport, 2011).

The legal framework for spatial accessibility of public transportation in, Addis Ababa, Ethiopia's transport policy primarily revolves around several key laws and regulations. Here are some of the essential aspects related to this:

1. Ethiopian Constitution: The country's fundamental law ensures that all citizens have the right to access public services, including transportation, without discrimination.
2. Federal Transport Policy (2013): The national-level policy ensures equitable and sustainable transport services for all citizens. It emphasizes the need to improve access to public transportation, especially for vulnerable groups.
3. Addis Ababa City Government Proclamation No. 361/2000 establishes the legal framework for urban transport in Addis Ababa. It empowers the city government to plan, regulate, and administer transportation systems, including public transport services.
4. Integrated Transport Master Plan (ITMP): This long-term plan for Addis Ababa's transport system emphasizes spatial accessibility in public transportation. The ITMP focuses on improving connectivity, reducing travel distances, and enhancing access to public transport by developing an integrated network of routes and services.
5. Addis Ababa City Government Proclamation No. 329/2002: This proclamation sets the legal basis for establishing and operating of the Addis Ababa City Transport Authority. AACTA is

responsible for planning, regulating, and overseeing public transport services in the city, aiming to enhance access for all residents.

6. City Roads Authority's Regulations, Directives, and Standards: The Addis Ababa City Roads Authority (AACRA) sets regulations, directives, and standards to guide the planning, design, and construction of road infrastructure, including public transport facilities.

7. Transport Services Regulation (2009): This regulation, issued by the Ministry of Transport, governs the operation and management of transport services, including public transport. It covers licensing, safety standards, and fare regulations to ensure accessibility and accountability.

These legal frameworks collectively emphasize the improvement of spatial accessibility of public transportation in Addis Ababa by focusing on integration, efficiency, and inclusivity. However, it is essential to note that policies and legal frameworks can evolve, and it is always recommended to refer to the latest laws and regulations for accurate and up-to-date information.

Overall, the legal framework for spatial accessibility of public transportation in Addis Ababa's transport policy is aimed at ensuring that all residents have access to safe, affordable, and efficient public transportation services, regardless of their location or socioeconomic status.

2.3.4 Existing situation of the public transportation network

Public transportation networks vary significantly from city to city and country to country. They typically consist of various modes of transportation such as buses, trains, trams, subways, ferries, and light rail systems. These networks are designed to provide affordable and accessible transportation options for the general public, aiming to reduce traffic congestion, lower carbon emissions, and improve overall mobility (Conserve Energy Future, 2023).

Accessibility is the quality of travel at the community and individual levels through access management techniques to provide access to different land uses. It is primarily concerned with travel cost, travel time, travel options, ease and risk must all be considered when responding to the requirements of everyone in the community (Community Planning and Zoning, 2019). Accessibility and mobility are considered to be the "Ying and yang" of transportation. The aim is to improve the transport system's overall capability while maintaining efficiency and ease of access.

Accessibility in the transportation domain is a wide and very fluid concept; as a result, it can be confusing and complicated at times. For simplicity, it could be described primarily from two viewpoints: individual (origin) and service provider (destination). Defined accessibility as “a way of measuring the simplicity with which a particular category of persons can reach a defined set of destinations, from a given origin (origin accessibility), or the ease with which a particular set of potential individuals can reach a given destination accessibility” Similarly presented it as: “The ability of people being able to get to key services at reasonable cost, in reasonable time and with reasonable ease” different modes have different speeds and different scales of accessibility (Andualem & Takele, 2018).

2.3.4.1 Modes of transportation Network based on accessibility

Automobiles generally provide good accessibility, but many services and activities are challenging to reach by other modes. This is a problem because most communities contain a significant portion of people who cannot or should not drive because they lack a driver’s license, have a disability, cannot afford a car, are impaired by alcohol or drugs, or prefer to use alternative modes in order to save money, reduce stress, or exercise more. In addition, many communities want to minimize motor vehicle travel to reduce traffic congestion, parking facility costs, accidents and pollution emissions. It is therefore helpful to identify ways to create multi-modal communities where residents do not need a personal car and can reduce their vehicle travel (Litman, 2022, p. 32)

An efficient multi-modal transportation system must integrate these facilities and services. For example, most public transit trips include walking and cycling links. Hence, the feasibility of public transit travel depends on neighborhood walking conditions, and users need accurate information use new travel options. Multi-modal planning involves identifying and filling system gaps. Not everybody wants to live in a multi-modal area some people enjoy driving or value living in an isolate location but because automobile travel is expensive and imposes high external costs, everybody can benefit if any household that wants, including those with low incomes and special needs, can find suitable housing in the area that offer high-quality non-automobile accessibility (Litman, 2022).

Public transport focuses on improvements in sustainability, and improving access to public transit (PT) can be considered as an effective way to reduce the external cost and negative impacts of motorized vehicles (Moridpour, Thompson, & Saghapour, 2016). Better access will

encourage people to use more environment-friendly transportation modes, including walking and cycling. These features that promote various forms of physical activity (such as walking) can be referred to as 'neighborhood walkability' and they often consider destinations such as retail stores and parks, and community design features such as street connectivity and sidewalk access (Duncan, Aldstadt, Whalen, Melly, & Gortmaker, 2011).

Walking distance refers to the distance from home to work place to a nearby transit or bus stop. It is an indicator of service coverage area and is one of the critical important factors that affects or influences people's decision to use public transport. A walking distance in the range of a 300-500m radius is considered as comfortable walking distance. In low-density areas, a walking distance over 500m is acceptable but the maximum should not exceed 1000m. A place of good accessibility has good street design and shorter destinations trips (Abreha, 2007).

Walkability deserves particular attention in accessibility analysis because it is essential itself and supports other modes. For example, improved walking conditions increases the range of parking facilities that serve a destination, which improves automobile access, and most transit trips include walking links, so that walkability improvements can improve transit accessibility (Litman, 2022, p. 35).

Walkability is crucial in accessibility analysis, particularly in urban planning and transportation studies. It refers to the ease and convenience of walking within a given area, typically a neighborhood, city, or region. Walkability analysis assesses how pedestrian-friendly an area is and examines the various elements that influence the walkability of a place (Moura , Cambra, & Gon, 2016). When evaluating the walkability of an area, several crucial factors come into play:

1. **Pedestrian Infrastructure:** To create a safe and comfortable walking environment, the presence and quality of sidewalks, crosswalks, pedestrian signals, footpaths, and pedestrian bridges or tunnels are considered.
2. **Connectivity:** Walkability analysis assesses how well different parts of an area are connected through pedestrian routes. A well-connected network of streets and pathways promotes walking as a viable mode of transportation.
3. **Accessibility to Destinations:** Encouraging walking depends on the proximity and accessibility of critical destinations such as schools, parks, workplaces, retail areas, public transit stations, and community services. Walkability analysis evaluates how easily pedestrians can reach these destinations on foot.

4. **Safety:** Safety measures play a significant role in walkability analysis. Low traffic speeds, proper lighting, crime prevention strategies, and traffic calming measures contribute to creating a safe walking environment.
5. **Comfort and Amenities:** Assessing walkability considers amenities that enhance the comfort and enjoyment of pedestrians. These may include benches, shade trees, public restrooms, drinking fountains, public art, and other features contributing to a pleasant walking experience.
6. **Land Use and Density:** Walkability is influenced by the mix of land uses and population density. Higher-density areas with a combination of residential, commercial, and institutional uses tend to be more walkable as they offer shorter distances between destinations.
7. **Design and Aesthetics:** The design and aesthetics of the pedestrian environment, including building facades, street furniture, landscaping, and overall urban design, can significantly impact the desirability and attractiveness of walking.

By conducting a walkability analysis, urban planners, transportation professionals, and policymakers can identify areas for improvement and develop strategies to enhance the walkability of a place. This endeavor contributes to creating healthier, more sustainable, and livable communities by encouraging active transportation, reducing cars dependence, and fostering social interactions within neighborhoods.

As the author of *Evaluating Accessibility for Transport Planning* (Litman, 2022) states that “No single analysis method can evaluate all accessibility factors since different methods reflect different impacts, scales and perspectives”. A particular planning decision may require use of multiple methods. For example, pedestrian accessibility evaluation requires local scale analysis that considers factors such as sidewalk and crosswalk quality, roadway traffic speed and volume, and inclines, plus surveys of users and potential users to identify perceived barriers and problems. Walking is significant for specific demographic groups (children, low-income households, tourists) and in geographic locations (downtowns, schools, and parks), so walkability analysis is essential for evaluating accessibility for these groups and areas (Litman, 2022).

2.3.5 Analyzing the spatial accessibility of public transportation network based on time

Accessibility-based planning justifies more multimodal planning and development policies which create more compact neighborhoods, so any household that wants can find suitable homes in areas where it is easy to get around without driving, often called 15-minute neighborhoods, meaning that commonly-used services and activities can be reached within a 15-minute walk or bike ride. This helps achieve various economic, social and environmental goals (Duany & Steuteville, 2021).

However, there are no universally acknowledged definitions of accessibility and various indicators have been used to quantify it. Birhanu (2016) as cited (Abreha, 2007) highlights that, accessibility is a much broader concept than mobility that can describe travel patterns entirely and defines it as “mobility for opportunities”. Accessibility measures include a density of opportunities enabled by transportation services. For example, the number of households within a 30-minute drive of key regional centers or employment opportunities within a 10-minute walk of transit stops or facility’s ability to serve a particular user group. Availability of mode and modal choice is also treated as an accessibility measure (NCHRP, 1997).

Wu, et al (2021) evaluated 30-minute access to jobs by four modes in 117 cities from 16 countries. They find that sprawled America cities provide modest automobile access and relatively poor transit and walking access; Australian and Canadian cities have lower automobile access, but better transit access; while Chinese and European cities tend to have the best overall accessibility due to their combination of compact development and intensive transport network. This indicates that access requires optimal combinations of density and mobility (Litman, 2022)

2.3.6 Analyzing the spatial accessibility of public transportation network based on distance

As transport officers approves, one of the goals of the transport system is to increase mobility and access to facilities. Even though the definition of accessibility varies depending on its application (Curl, Nelson, & Anable, 2011), based on this context, it can be generally defined as the ease with which specific destinations can be reached from a particular origin using the specified mode of transport (Sullivan, Morrison, & Shearer, 2000). It can be measured by the mobility that the transport network provides and the density of opportunities that can be accessed within a particular time or distance. It depends on the spatial distribution of activities, the origins of demand and the transport system connecting the origin and destinations (Birhanu, 2016).

To assess accessibility, several methodologies and methods have been created like infrastructure-based measures that consider the network's performance and entailing parameters such as capacity, frequency or reliability (Church, Frost, & Sullivan, 2000). It also analyzes by taking the physical distance between infrastructure elements as input and is helpful in for analyzing nodes and network topologies (Bhat C. , et al., 2000). The method measures travel impediment or resistance between origin and destination between nodes and employed impediment measures viz., physical distance, network distance, travel time, travel cost, and service quality. It is facilitated to implement and demand minimal easy-to-obtain data input (Baradaran & Ramjerdi, 2001).

Information on destinations such as whether a store offering a particular good is within convenient walking distance can also affect accessibility. There are many ways to provide transportation information, including maps, brochures, websites, social media and telephones systems. New communications systems can significantly improve transportation user information, including in-vehicle navigation systems for motorists, websites with detailed transit route and schedule information, real-time information on transit vehicle location and arrival websites accessible by mobile telephone, and monitors at transit stops, can indicate the number of minutes until a particular bus or train will arrive at a particular location, and various scale maps and guides for pedestrians and cyclists. The effectiveness of such information depends on how well potential users are aware of, can access, and apply this information (Litman, 2022).

Simmonds & Still (1998) defined accessibility as “a way of measuring the ease with which a particular category of persons can reach a defined set of destinations, from a given origin (origin accessibility), or the ease with which particular set of potential individuals can reach a given destination”.

The average mobility rate per person or trip per day can vary greatly depending on the location, age group, and other factors. However, according to data from the National Household Travel Survey (NHTS) conducted in the United States in 2017, the average number of daily trips per person was 3.1. Additionally, the NHTS found that the average daily travel time per person was about 51 minutes. Remember that this is just an average, and travel patterns can vary significantly based on individual circumstances and factors such as transportation infrastructure, urban vs. rural living, and more (NHTS, 2017).

As Ethiopia is a developing country, the transport service accessibility is low compared to the developed countries. The mobility rate observed in Addis Ababa is also meager. In the cities of developed nations average mobility rate per person or trip/day is 2.5. According to the 2005 transport study the Addis Ababa mobility rate or average trip/day/person is 1.08. In this respect, the average length of mobility covered by vehicle is 3.3 km, and that of 1.5km by walking on foot. In developed countries the length of mobility by walking is not more than 500m (Ethiopia Ministry of transport, 2011).

2.3.7 Evaluating if the study area has an adequate spatial accessibility to public transportation
Adequate accessibility analysis can be generally described as a four-step process: concept formulation, measure selection and specification, accessibility measurement, and interpretation and evaluation (Suxia & Xuan, 2004).

The first step of concept formulation involves defining the purpose of accessibility analysis, understanding the planning context within which the accessibility analysis is to be conducted, and formulating the concept of accessibility. The concept of accessibility should be defined according to the purpose of the analysis, the nature of the planning issues, and the relevance to particular groups of planners, policy makers or residents who will use the concept and relevant measures to examine and evaluate the need for or the effectiveness of particular transportation and land use policies (Suxia & Xuan, 2004).

The second step measure selection and specification involve selecting or developing an appropriate type of accessibility measures, and specifying the selected or developed measures. In transportation planning, as stated in (Liu & Zhu, 2004) and referenced in Morris et al. (1979), Jones (1981), Miller (1999), an accessibility measure is usually formulated in terms of a set of destinations representing activity sites and a set of origins representing potential users of the facilities at the activity sites. Most accessibility measures assume that the accessibility between origins and destinations is directly proportional to the associated demand and attraction, and inversely proportional to the distance, time or cost for traveling between them.

The specification of an adequate accessibility measure may include seven aspects: the definition of a spatial unit for analysis, the definition of socio-economic groups, the type of opportunities, the mode of travel, the definition of origins and destinations, and the measurement of attractiveness and travel impedance (Suxia & Xuan, 2004).

The next step is accessibility measurement. It involves calculating travel impedance, measuring accessibility based on the specifications defined in the second step and calibrating the accessibility measures by changing parameter values and using travel survey data. The final step of accessibility analysis focuses on the presentation, interpretation and evaluation of the results of accessibility measurement. It aims to interpret the results and translate them into useful information for policy making (Suxia & Xuan, 2004).

2.3.8 Factors affecting Accessibility

The quality of information can affect the functional availability and desirability of mobility and accessibility options. For example, motorists need accurate and convenient information on travel routes, roadway conditions such as when congestion, construction and accidents delay traffic, vehicle services, and parking availability and price. Potential transit users need information on transit routes, schedules, fares, and comfort factors such as whether vehicles will have seats or stations will have washrooms, and access to destinations. Walkers and cyclists need information on recommended routes, and cyclists need information on parking options (Litman, 2022).

Economically, transport is an essential element of city development that, in turn, is a significant source of national economic growth. Simply stated, poor transport inhibits growth. Furthermore, socially, transport is the means of accessibility to jobs, health education and social services essential to the welfare of the city residents. Deteriorating transport conditions affect all city residents; they impact particularly the poor through a decline in public transport service levels, increased length of the journey to work and other essential services and the negative impacts on the environment, safety and security that the poor are least able to mitigate (The World Bank, 2011).

2.3.9 Application of GIS for identifying the spatial accessibility of public transportation network

The ArcGIS Application section explores the use of ArcGIS, a geographic information system, to analyze the spatial accessibility of public transportation networks. This involves using ArcGIS tools and techniques to collect, process, and analyze data related to public transportation. The section covers various aspects of the application, including data collection and analysis using ArcGIS. The ArcGIS Application section provides a comprehensive overview of how this technology can be utilized to assess network density, service coverage, and connectivity of public transportation systems. Additionally, it discusses the factors that affect accessibility, such

as distance to transit stops, population density, and land use patterns. Overall, this section highlights the importance of using ArcGIS in evaluating and improving the spatial accessibility of public transportation networks.

The current GIS-based accessibility analyses typically build specific accessibility measures for particular applications into stand-alone modeling programs with direct or indirect access to the GIS database. Although some leading generic GIS software packages such as ArcView's Network Analyst have embedded certain network analysis functions that can be used to support accessibility measurement, accessibility analysis has not been fully integrated with GIS or become a standard GIS function. There is also a lack of a general framework for the integrated use of GIS, travel impedance measurement and accessibility measures for accessibility analysis (Suxia & Xuan, 2004).

A GIS-based ensemble of Frequency Ratio (FR) and the Analytical Hierarchy Process (AHP) model was established. To analyze the characteristics of locations accessed in relation to eight environmental factors including slope, elevation, land use, population density, travel time, building density, intersection density, and public transport service area (Khatun, Mohammed, & Ashraf, 2020).

2.4 Research gap

The research gap regarding GIS-based analysis on spatial accessibility of the public transportation network in the context of Ethiopia can be identified in several areas. These research gaps represent areas where further investigation and studies are needed to increase our understanding. For example, we can list some areas that can help to investigate for future studies like data availability and quality, network analysis techniques, multi-modal analysis, and sustainable transport planning.

To elaborate these lists further when we say data availability and quality most of the time research is determined by availability and quality of data related to public transportation networks in Ethiopia. The accuracy and completeness of data on bus routes, schedules, stops, and other relevant information may vary across different regions and cities. Conducting research to improve data collection methods, data integration, and data quality assurance would be beneficial.

Regarding Ethiopia's transportation network, we need cutting-edge research that focuses on developing and applying advanced network analysis techniques. These powerful tools have the potential to evaluate the spatial accessibility of public transportation services, identify critical gaps in the network, and propose efficient improvement solutions. It's like giving the transportation system a high-tech GPS to navigate through the challenges it faces.

Imagine busy Ethiopian cities with various of transportation options, from buses and minibuses to light rail and informal transportation networks. It's like a movement masterpiece! We need detailed models that take their interactions into account to properly understand the effects of these different approaches on spatial accessibility. We can build a full picture of accessibility and offer precise assessments by including multi-modal analysis into GIS-based research.

Assessing the spatial accessibility of Ethiopia's public transportation network is a crucial step toward achieving sustainable transport goals. But there is more work to be done. We need further research to investigate how accessibility analysis can inform decision-making processes related to infrastructure development, route planning, and service optimization. By understanding the implications of accessibility improvements, we can grow towards a greener and more sustainable future.

Addressing these research gaps can provide valuable insights into the spatial accessibility of Ethiopia's public transportation network. The findings can guide policymakers, urban planners, and transportation authorities in making informed decisions to enhance accessibility, promote sustainable mobility, and improve the overall transportation system in the country.

However, the above studies have a gap of focusing on the spatial accessibility of public transportation network as they are not effectively using GIS instruments for the analysis. The consequences of neglecting GIS-based analysis in evaluating the spatial accessibility of public transportation networks are far-reaching. Suppose it is appropriately applied on the ground. In that case, it can reduce inefficient accessibility routes, wasted resources, disproportionate access, environmental consequences like (increased fuel consumption, higher emissions, and contribute to air pollution), and increased quality of life. As we progress, prioritizing data-driven solutions will lead to more efficient, sustainable, and inclusive public transportation systems. So, this study takes account in identifying the spatial accessibility of the public transportation network by assessing the existing situation of the public transportation network along the path of Mexico to Hayahulet road in a time and distance framework to promote equitable access to public

transportation networks, reducing travel time, easy access of services and improving quality of life.

CHAPTER THREE: RESEARCH METHODS AND MATERIALS

This chapter briefly describes the research approach methodology that was used in the study. It describes the study area, research design, methods of data collection, methods of data analysis, sample methods and data types, data collection instruments, and data analysis method.

3.1 Research Design

The research design is the research road map the researcher must follow to conduct the study. Preparing research design highly contributes by showing all highlights of methods and helps visualize the whole image of the work towards achieving specific objectives.

This study was undertaken to investigate the spatial accessibility of public transportation networks in the case of bus stations along Mexico to Hayahulet Road, Addis Ababa, Ethiopia. The spatial accessibility of the public transportation network was done by considering the 10th Addis Ababa structural plan endorsed in 2017 and the Ethiopian Ministry of Works and Urban Development MUDW (2017) Public Transportation Network manual.

Mainly, the process of this study needs spatial and non-spatial data collection of the road path of the selected road network, bus stations on both sides of the road, the surrounding area services and land use map, analysis of spatial distribution pattern, the adequacy of the accessibility of the existing physical condition and public transportation network of the Mexico to Hayahulet road, the standard of road network based on time and distance.

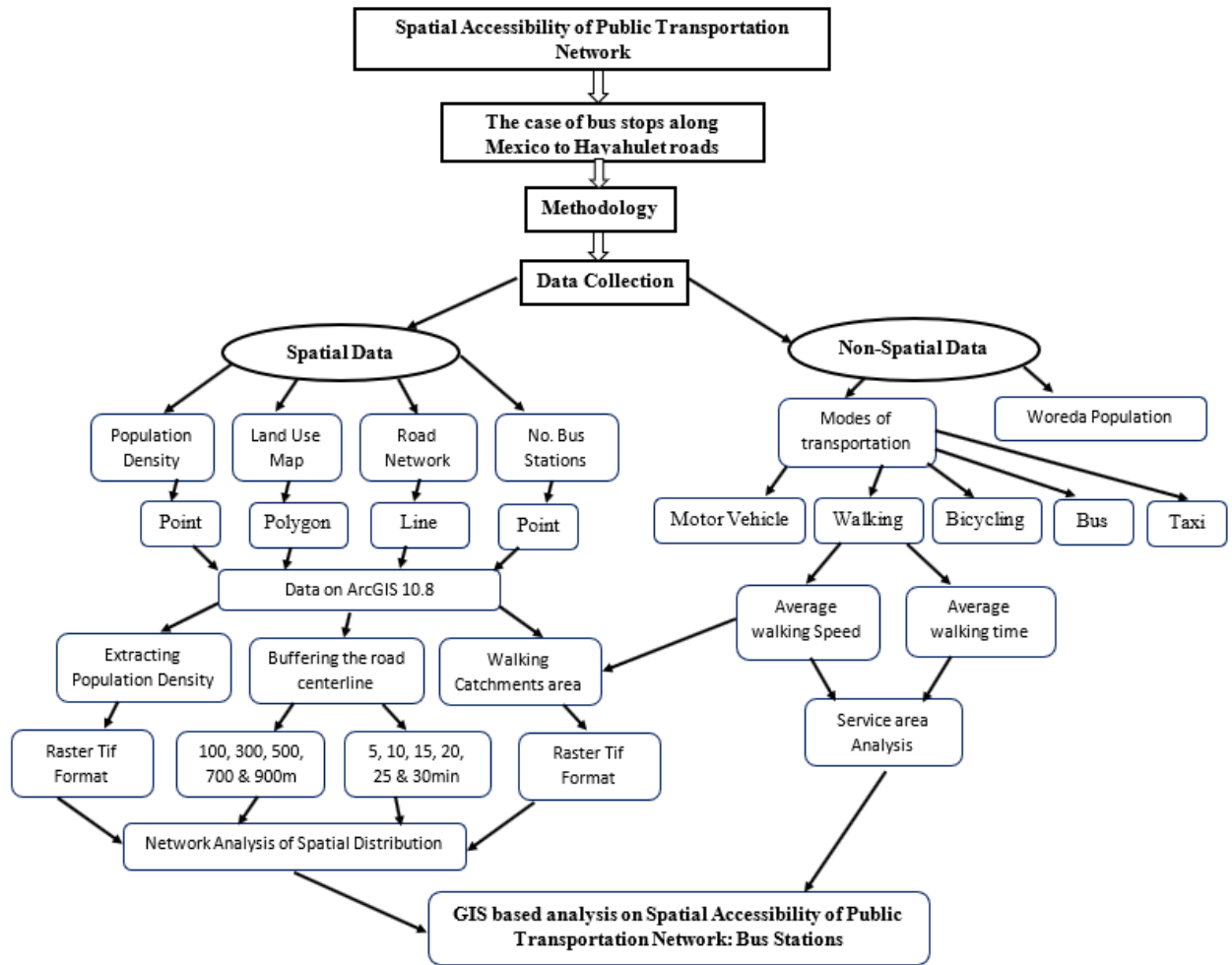


Fig 3. 1 Research methodology for the objective one

Source: Authors computation, 2023

3.2 Site Selection Criteria

Spatial accessibility in public transportation is a critical factor influencing urban mobility and the well-being of communities. The choice of transportation routes plays a pivotal role in shaping accessibility outcomes. This paper focuses on the research route from Mexico to Hayahulet in Addis Ababa, Ethiopia, exploring why this route holds promise for improving spatial accessibility in public transportation compared to alternative routes. The study aims to contribute valuable insights to urban planning and transportation strategies.

Geographical Significance:

The Mexico to Hayahulet route stands out due to its strategic location within Addis Ababa. This route connects the bustling neighborhood of Mexico to the rapidly growing area of Hayahulet, facilitating improved access to key amenities, employment centers, and educational institutions.

Analyzing the spatial distribution of population and services along this route provides a foundation for understanding how it influences accessibility.

Population Density and Demand:

One of the primary factors influencing spatial accessibility is population density. The Mexico to Hayahulet route traverses areas with a significant population concentration. This high density underscores the potential demand for public transportation services, making it an attractive route for enhancing accessibility and meeting the mobility needs of many residents.

Economic Dynamics:

Examining the economic dynamics along the route reveals opportunities for increased spatial accessibility. The route passes through commercial and business districts, fostering economic activities and job opportunities. Enhanced public transportation along this route can benefit commuters and businesses, contributing to economic growth and creating a positive feedback loop supporting sustainable urban development.

Infrastructure Development:

The Mexico to Hayahulet route is marked by ongoing and planned infrastructure developments, including road expansions and public transportation projects. These developments help to improve connectivity and reduce travel times, further enhancing spatial accessibility. Integrating modern transportation infrastructure aligns with the goal of creating a well-connected and accessible urban environment.

Social Inclusion:

Spatial accessibility is not only about physical distance but also about fostering social inclusion. The route in question serves diverse communities, and an inclusive public transportation system can bridge social gaps by providing equal opportunities for all residents. By prioritizing accessibility along this route, urban planners and policymakers can contribute to a more inclusive and equitable cityscape.

Environmental Sustainability:

Promoting spatial accessibility through public transportation aligns with environmental sustainability goals. The Mexico to Hayahulet route, when optimized for efficient public transportation, has the potential to reduce individual car usage, mitigate traffic congestion, and minimize environmental impacts. A sustainable transportation system contributes to a healthier urban environment and enhances residents' overall quality of life.

In conclusion, selecting Mexico to Hayahulet route in Addis Ababa for research on spatial accessibility in public transportation holds significant promise. The route's geographical significance, population density, economic dynamics, infrastructure development, social inclusion aspects, and environmental sustainability considerations collectively make it a compelling case for study. Understanding how improvements in public transportation along this route can positively impact spatial accessibility provides a foundation for informed urban planning decisions that prioritize the well-being and mobility of city residents. This research contributes to the ongoing discourse on sustainable and inclusive urban development, emphasizing the role of well-designed transportation routes in shaping the accessibility landscape.

3.3 Description of the Study Area

Addis Ababa is a vibrant and bustling city located in the central part of Ethiopia. It is the country's political, cultural, and economic center, and serves as the headquarters for the African Union and the United Nations Economic Commission for Africa. The city is mostly linked with the surrounding towns and beyond by single-legged roads, except for the southern (a new toll road) and western corridors.

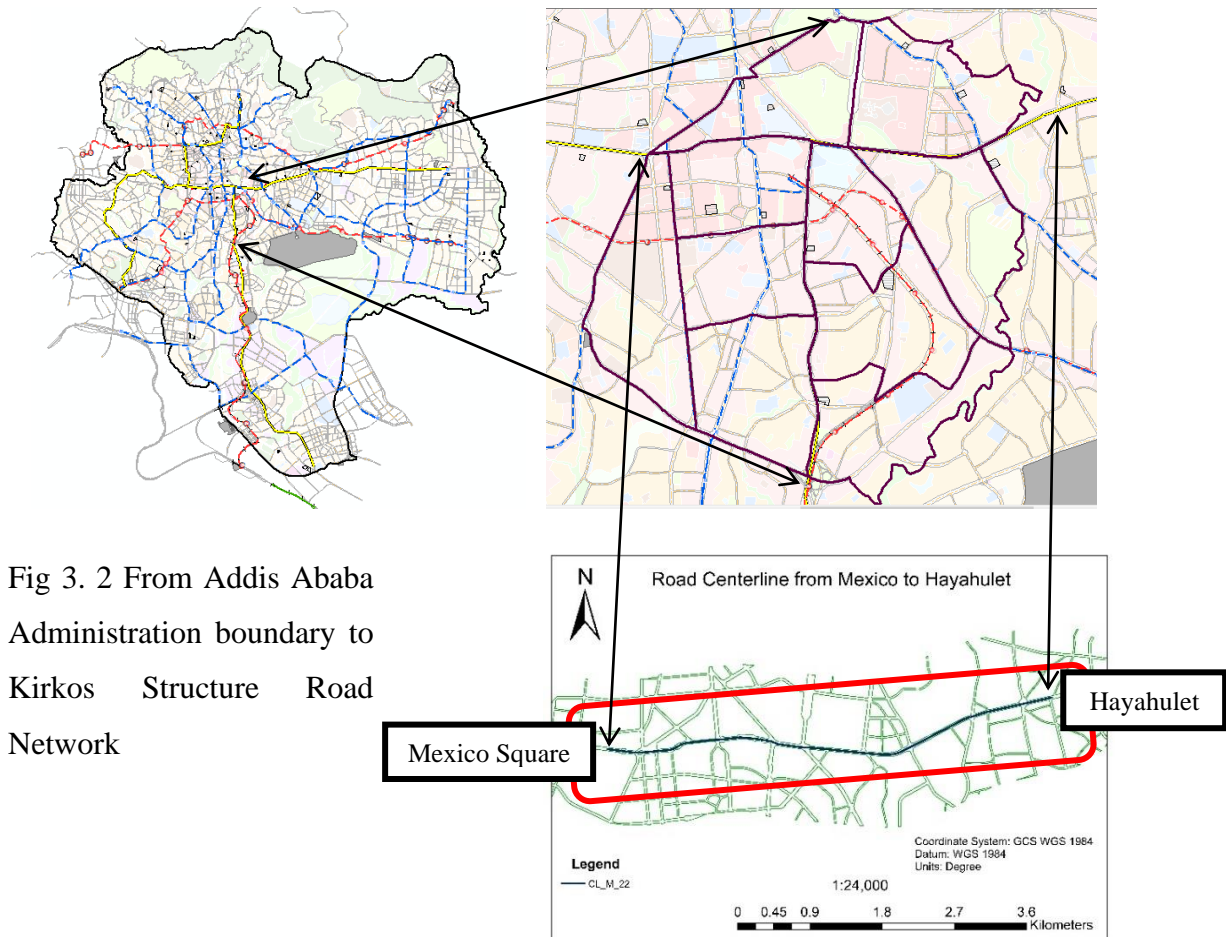


Fig 3. 2 From Addis Ababa Administration boundary to Kirkos Structure Road Network

Source: Addis Ababa Plan Development Commission (AACPPO, 2017)

The transportation system in Addis Ababa, Ethiopia connects various areas of the city, including the route from Mexico to Hayahulet Road. Addis Ababa has an extensive network of public buses operated by the Addis Ababa City Administration. These buses serve different routes throughout the city, including the Mexico to Hayahulet Road route. Anebesa and Sheger buses are a popular mode of transportation and offer an affordable option for getting around. The city also provides a modern light rail system called the Addis Ababa Light Rail Transit. It covers two lines: the Blue Line and the Green Line. The light rail system is directly on the Mexico to Hayahulet Road route, people can utilize the rail network to reach nearby areas and then take a bus or taxi to their destination.

Addis Ababa’s transportation system consists of streets, highways, and railroads in its boundary. Addis Ababa has 11 sub-cities and the selected road passes through Kirkos Sub-city and Lideta Sub-city. It is a Principal Arterial Street (PAS) with a width of 40m from East to West. It is

covered in asphalt pavement. The route in the study has a coordinate of Starting and ending point of (471823.7, 995801.38) and (476541.42, 996401.33) respectively. It has a distance of 4.89km.

To travel from Mexico to Hayahulet Road in Addis Ababa, Ethiopia, you can follow a route that takes you through various neighborhoods and main roads. Here's a general description of the route: Begin your journey at Mexico Square, a noticeable landmark in Addis Ababa. Mexico Square is located in the central part of the city and serves as a major transportation hub. From Mexico Square, take Ras Mekonen Avenue in the east direction. This road will lead you through the bustling streets of Addis Ababa, passing commercial areas, residential neighborhoods, different public sectors and various landmarks. As you proceed on the Street, you will eventually reach Legare as one of Addis Ababa's transportation hubs and when you pass through that you will find Addis Ababa Stadium. Continue on Ras Mekonen Avenue passing through Meskel Square, Saint Estifanos Church. Then you reach Jomo Kenyatta Street and find Bambis supermarket. As you go along the path, you will find Saint Urael Church. After passing that you will be on Haile Gebre Silase Street and find different commercial centers and residential neighborhoods. Keep following the road until you reach the intersection with Hayahulet Road.

3.4 Data Types

Any kind of research needs data to be successful. Spatial data in Vector and Raster formats from the Structural plan of Road Network Dataset ArcGIS in geographic format and non-spatial data are essential to achieving the pre-established goals of the research. This research uses a quantitative and qualitative data collection method. The data collection method takes the first step followed by data analysis.

Quantitative data refers to numerical information that can be measured and analyzed statistically. This data type is often obtained through structured surveys, experiments, or existing datasets. So, for this research the researcher has used different kinds of data like the Road Network Dataset from Mexico to the Hayahulet center line, the location of the bus stations on both sides, Satellite images of the surrounding area, and also by buffering the road center line we can extract population density map of 2020. The elements for spatial, and non-spatial data types needed for this research are as follows.

- ◆ **Land use:** the September, 2022 land use survey is the most critical data needed for this study. It shows all land use categories, including both built and non-built environments and what the service area is used for.
- ◆ **Road network:** From the structure plan of the road network, we can take the Road center line and buffer it with 100, 300, 500, 700, and 900m intervals and see whether the stations are easily accessible to the community around them.
- ◆ **Bus stations:** The researcher has identified the location of the bus stations using hand-held GPS or Satellite images like google earth software.
- ◆ **Population Density:** In the year of 2021, the forecasted Population Density of Addis Ababa was used to analyze the spatial accessibility of Mexico to Hayahulet Road path. The points were converted to Tiff file on ArcGIS software and analyzed.

Qualitative data is non-numerical information that is collected through methods such as interviews, observations, focus groups, or open-ended survey questions. This data type provides in-depth insights into people's experiences, beliefs, attitudes, and behaviors.

- ✧ **Site observation** – Field observation was gathered to identify the problems that have occurring to obtain the current practices and challenges about spatial accessibility of the public transportation network and its surrounding neighborhoods. This was related to the existing transportation condition in Mexico to Hayahulet road activities, the nature of the road path and its accessibility to major road accesses and utilization of the public community.
- ✧ **Desk review** – Information was assessed from different relevant documents like policy, regulations, and related studies and archives, reports, and site analysis reviews done by different sectors and sub-city spatial data bases. Archival sources help to reconstruct the occurrences of events, feelings and emotions of peoples in the past. Thus, a review of existing published and unpublished materials and proclamations that can explain the spatial accessibility of public transportation networks of various countries, such as manuals, journals, office reports, guides and regulations, books, research and working papers will be analyzed and literature review will be conducted.

Mixed: Mixed methods research combines quantitative and qualitative data in a single study. It collects and analyzes numerical and non-numerical data to gain a more comprehensive

understanding of the research topic. This approach allows for triangulation, where data from different sources and methods are compared and integrated to provide a richer and more robust analysis. So, this research will use both quantitative and qualitative data type.

3.4 Source of Data

In this research, the researcher used both primary and secondary data types from primary and secondary sources.

Primary data sources were gathered

- Field observation was conducted to observe and analyze the existing physical condition and accessibility of the public transportation network of the selected path.

Secondary data sources were conducted from desk study various documents such as:

- Updated data from AA city road network, the Transport map and Structural Plan, Google Earth and other satellite images.
- Books, related articles, reports, and published and unpublished documents are helpful for this analysis.
- Data from various institutions was used as input for the research.
- With the help of ArcGIS using satellite images, the researcher identified the shape, area, size, width, and length of the Principal Arterial Street (PAS) road.
- A checklist was prepared and filed for analysis on the site.

Table 3. 1 Summary of data type and source

Data	Sources	Data format	Purpose	Year
Addis Ababa city Land use	AAPDC	AutoCAD/GIS	To define the study area boundary	September, 2022
Population density map of Addis Ababa	CSA	JPG/GIS /AutoCAD	Know subject population	July, 2022
Road network base map	AAPDC	AutoCAD/GIS	To build network dataset and to know the service area coverage	September, 2022
Aerial photo	Google Earth	AutoCAD/ GIS/ JPG	To updating development changes (Road network, Land use)	June, 2023

Bus Stations	Field survey	Point with X & Y coordinate	To know the spatial location	June, 2023
Master plan report	Document	AAPDC	To consider the standards as explicitly indicated in the manuals	2017
Norms & standards	Document	MWUD	To consider the accessibility and services standards	2017

Source: Authors Computation, 2023

3.5 Methods of Data Collection

Both primary and secondary data collection techniques were used for this research. These are field observation and reviewing documents. On the primary data collection techniques, the researcher identified the location of the bus stations by using hand-held GPS on field surveying time. In comparison the secondary data collection techniques were conducted from different governmental institutions such as the Addis Ababa Plan and Development Commission, Addis Ababa City Roads Authority, and Addis Ababa Road and Transport Bureau. The data was used as input for the research such as Land use map, Road Network and Transport Map, Population Density and the geographical location of the bus stations. The latest satellite image of the area from Mexico to Hayahulet Road Network and Transport map was downloaded from the 2023 Google Earth image which helps to trace developmental changes such as road network and the service area of the land use.

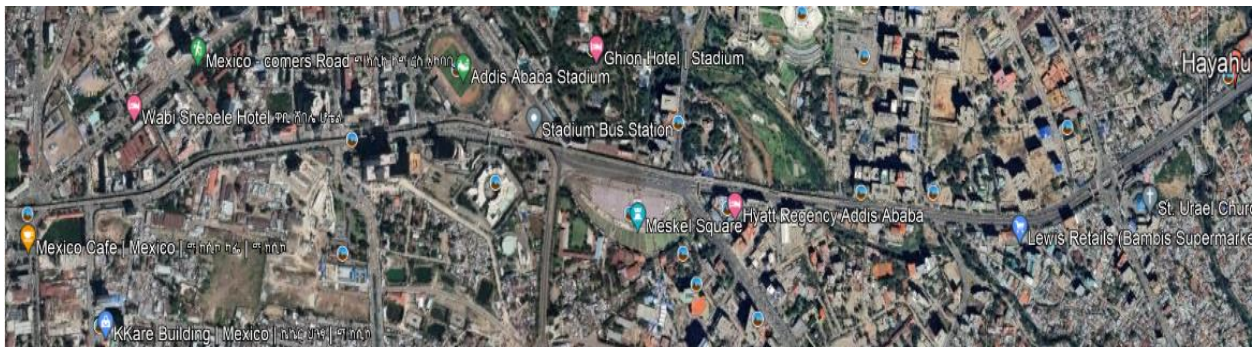


Fig 3. 3 Satellite image 2023

Source: Authors computation, 2023

3.6 Data analysis methods

During this stage, all of the collected data, information, ideas, opinions, and comments were precisely arranged and analyzed, then it was interpreted based on the literature view which was carried out.

Data analysis – Analyzing the spatial accessibility of the public transportation network by assessing the existing situation of the public transportation network along the section from Mexico to Hayahulet road in a time and distance framework. It was attempted to come up with whether the study area has adequate spatial accessibility of a public transportation system. Geographic Information Systems (GIS), maps, and other tools, such as Google Earth, have provided the means to quantify and describe the spatial accessibility of public transportation networks.

3.6.1 Existing situation of public transportation network from Mexico to Hayahulet route

Collecting public bus stations on the road path of Mexico to Hayahulet is essential for the research to be conducted. It identified the location of the bus stations using hand-held GPS and Satellite images with google earth software and found around 24 locations on each side of the roads. And analyze the distance between the two buses stations if it is located based on the standard.

3.6.2 The spatial accessibility of public transportation analysis methods from Mexico to Hayahulet based on time

Based on the literatures reviewed the standard spatial accessibility to public transportation is 15-minute neighborhoods, meaning that commonly-used services and activities can be reached within a 15-minute walk or bike ride. So, to measure that we can convert the growth population density to the road path, we will analyze and buffer the road centerline with (5, 10, 15, 20, 25 and 30 min) walking time on ArcGIS Software. Calculation of percentages, proportions, ratios, and comparison of figures in comparison with urban plan standards was used as an approach to interpret the research findings.

Analyzing the spatial accessibility of public transportation networks based on time involves assessing the ease with which people can reach different locations within the network, taking into account travel time and connectivity of the areas with the bus stations in the neighborhood areas. Here are some steps to analyze spatial accessibility using time.

The first is by defining the study area and then identifying different kinds of transportation modes such as Anbesa or Sheger buses, and light rail transits by identifying their stations along the path from Mexico to the Hayahulet road network. And then gather the population density of the specific path by buffering the road center line on the transportation network. Then, by collecting or taking the average walking speed of humans such as children, adult, older people and disabled people to estimate travel times between different stations within the study area. This can be done by considering the distance between the study area, average speeds of walking, and factors such as comfortable pathway and adequate infrastructures.

Then create a network graph using the transportation data, where each stop can be represented as a node, and the connections between stops are represented as edges. Assign travel times as weights to the edges. Then select specific origin and destination points within the study area that you want to assess for accessibility. These points could be essential landmarks, residential areas, or employment centers.

Apply accessibility metrics to evaluate the ease of reaching destinations from different origins based on travel time. One standard metric is the cumulative opportunity measure, which calculates the total accessibility of destinations within a given time threshold. Then present the results of the accessibility analysis using maps, graphs, or other visualizations. This helps to identify areas with high or low accessibility and understanding the spatial patterns within the transportation network. Based on the analysis results, identify areas with low accessibility and potential bottlenecks in the transportation network. Transportation planners and policymakers can use this information to make informed decisions regarding infrastructure improvements, service adjustments, or new route designs. Following these steps, you can conduct a spatial accessibility analysis of public transportation networks based on time. This analysis can provide valuable insights into the efficiency and effectiveness of the transportation system and contribute to improving overall accessibility for residents and visitors.

3.6.3 The spatial accessibility of public transportation analysis methods from Mexico to Hayahulet based on distance

In the cities of developed nations average mobility rate per person or trip/day is 2.5. According to the 2005 transport study the Addis Ababa mobility rate or average trip/day/person is 1.08 (Ethiopia Ministry of transport, 2011, p. 5). The average walking speed can differ based on various factors, including age, fitness level, terrain, and purpose. However, as a general

guideline, a healthy adult typically maintains an average walking speed of approximately 4.8 to 6.4 kilometers per hour. This speed represents a comfortable walking pace allowing a steady stride without excessive exertion. It is important to note that individual walking speeds can vary, with some individuals naturally walking faster or slower than the average (Cronkleton, 2019).

The overall spatial accessibility metric for bus stops and the percentage of the population served by bus service, calculated by measuring the service area of the road center lines for example we can take these intervals to buffer the road center line (100, 300, 500, 700 and 900 meters) and with these buffer zones we are gone divided it by the total population of the influenced zones. Based on the 500m accessibility distance standard, five accessibility travel break value scenarios have been tested in this study. These are 100m for the first, 300m for the second, 500m for the third, 700m for the fourth, and 900m for the fifth. Break values are selected to generate the results.

Using network analysis, we can determine the service area and all available routes within a certain walking distance can fall inside the buffered area. It helps in assessing how accessible the Network Analyst tool's results are. Concentric service areas demonstrate how accessibility changes with walking distance. They determine the number of individuals, amount of land, or quantities of other entities within a neighborhood or region. Distance-based service areas are also helpful for predicting travel distances from demand points to bus stations. In this study, the service area was generated from bus stations, which were used as service points based on distance.

Road network dataset analysis preparation

To build a road network dataset using a Network Analyst tool

Step 1: Creating a personal database.

Step 2: Built a network dataset from the road network for creating a service area analysis using Network Analyst.

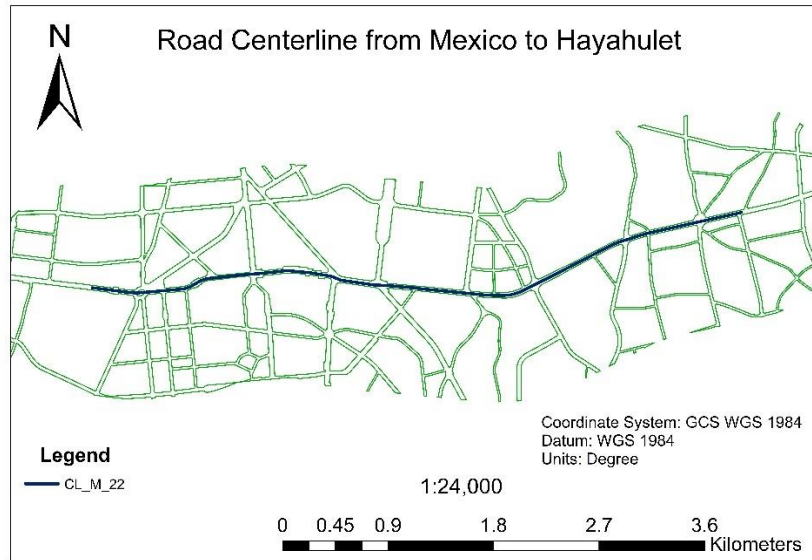


Fig 3. 4 Road Centerline from Mexico to Hayahulet

Step 3: Create the service area layer that contains (the service area and polygons).

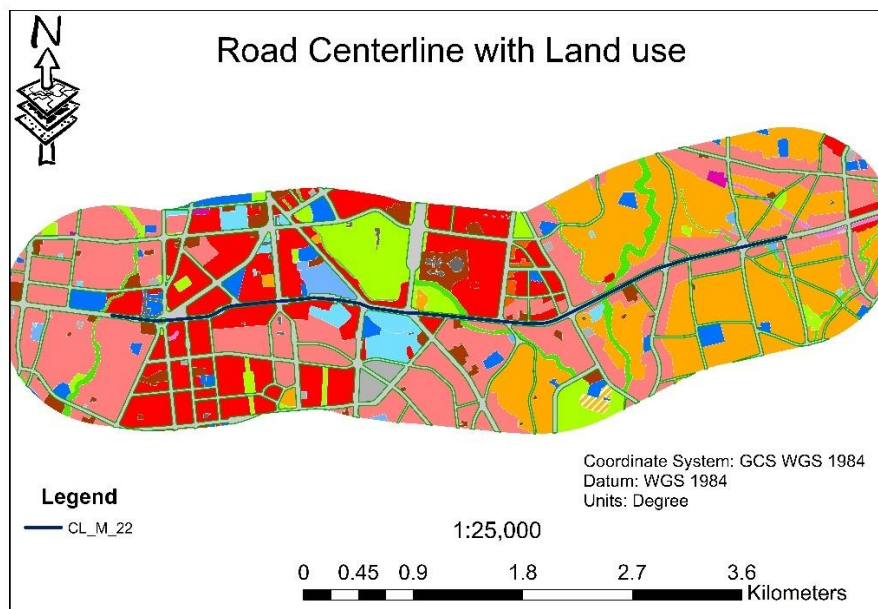


Fig 3. 5 Road Centerline with Land use

Step 4: Loading the bus stations location in to the service area layer as destination points to the population density.

Step 5: Insert access to travel distance standard.

Step 6: Then generate service area polygons to identify spatial accessibility in terms of distance. To identify the coverage amount, the distance and attribute were evaluated in five different magnitudes of intervals bench marking the accessibility standard 500m distance breaks values. Five travel distance break values are assigned in the distance variables (100, 300, 500, 700 and 900 meters).

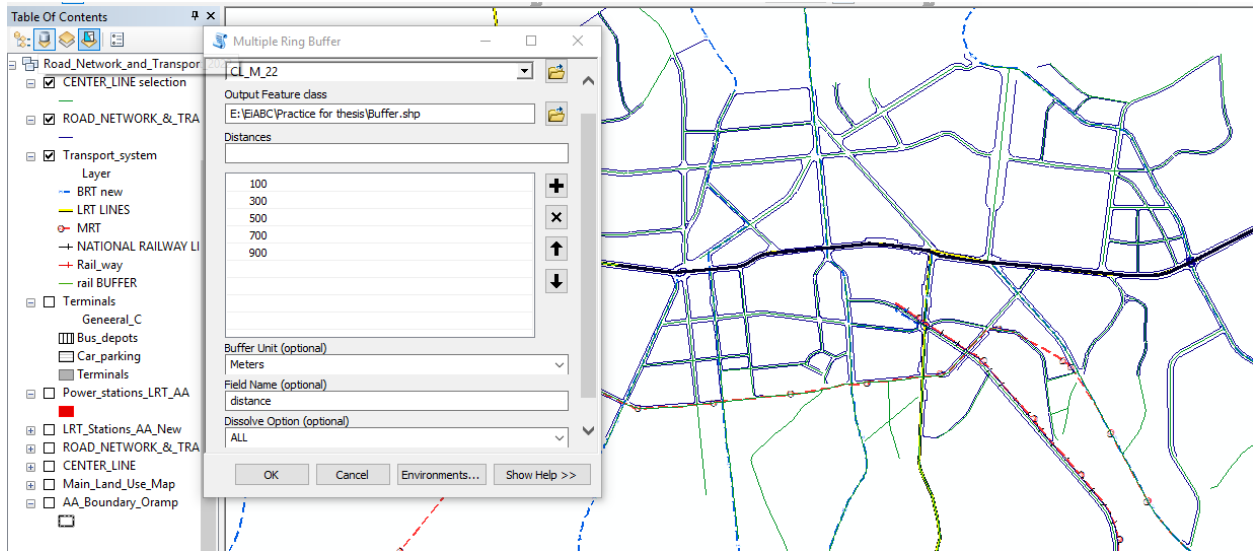


Fig 3. 6 Buffering the Road center line with the intervals of (100, 300, 500, 700 & 900 meters)

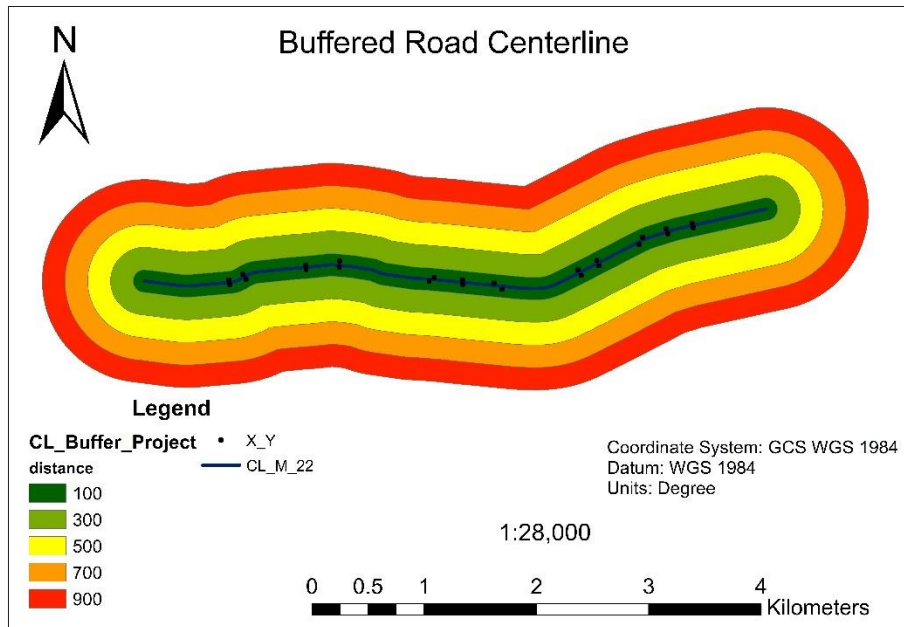


Fig 3. 7 Road Centerline buffered in 100, 300, 500, 700, 900 m

Step 7: Lastly, generating service area polygons, calculating the coverage area by population by clipping each residential area by polygons, and this step answers this objective of the spatial accessibility of public transportation analysis methods from Mexico to Hayahulet based on distance.

Finally, the quantitative method was used to compute and analyze data collected from the road path from Mexico to Hayahulet that is found in Addis Ababa. The descriptive method was used to evaluate and explain the results of the analyzed data that were going to be collected during the research.

3.7 Methods of Data Presentation

There are different types of data analysis presentation techniques. Accordingly, each objective analysis result was presented separately. Firstly, the land use map, road network, population density and the bus station location were collected and presented using different data presentation techniques such as tables, figures, maps, graphs and text narrations. Finally, the services area accessibility analysis was presented in maps, tables, figures and percentages. Generally, this study's data analysis results were presented using different data presentation techniques such as tables, figures, maps, graphs and text narrations.

3.8 Ethical considerations

Ethical considerations in research are principles that guide your research designs and practices. These principles include voluntary participation, informed consent, anonymity, confidentiality, potential for harm, and results communication (Scribbr, 2021). The fundamental principles of research ethics are informing participants about the nature of the research and the potential risks and benefits before they agree to participate. Dedication to the researcher and respect for the participant's viewpoint were reflected in this research. When conducting research, data integrity is one of the significant concerns, so the researchers must handle data responsibly, ensuring its accuracy, security, and appropriate storage. Data should be used only for the purposes outlined in the research plan. The data collected were analyzed without bias and interpreted for research purposes only.

Table 3. 2 Summary of research methods applied in the study

No.	Research Question	Data Types	Methods of Data Collection	Methods of Analysis	Expected Outcomes
1.	How can we examine the existing situation of the public transportation network along the path of Mexico to Hayahulet road?	Primary	With the help of Hand-held GPS identifying the (X, Y) coordinate system location of the bus stations	1. Identified the location of the bus stations using hand-held GPS and Satellite images with google earth software and identified around 24 locations on each side of the roads. 2. Computing population density using the ratio of demographic data and net built-up area.	Fig 3.2, 3.3, 3.4, 4.1, 4.2, 4.3 Tables 4.1, 4.2, 4.3, 4.4 and 4.5
		Secondary	2023 Google Earth image Addis Ababa city Land use map Road network base map Aerial photo Bus Stations		
2.	How do we analyze the spatial accessibility of the public transportation network along the path of Mexico to Hayahulet road based on distance?	Primary	With the help of Hand-held GPS identifying the (X, Y) coordinate system location of the bus stations	Creating a personal database. Built network dataset from the road network Creating the service area layer Loading the bus stations X&Y coordinates Buffering Road center line with intervals of (100, 300, 500, 700 and 900 m) Then calculate the coverage area of the population by clipping each	Fig 3.5, 3.6, 4.4, 4.5 4.6, 4.11, 4.12, and 4.13 Tables 4.6 and 4.8
		Secondary	2023 Google Earth image Addis Ababa city Land use map Population density map of Addis Ababa Road network base map Bus Stations		

				residential area with polygons	
3.	How do we analyze the spatial accessibility of the public transportation network along the path of Mexico to Hayahulet road based on time?	Primary	With the help of Hand-held GPS identifying the (X, Y) coordinate system location of the bus stations	Creating a personal database. Built network dataset from the road network	Fig 4.7, 4.8, 4.9 and 4.10 Table 4.7
		Secondary	2023 Google Earth image Addis Ababa city Land use map Population density map of Addis Ababa Road network base map Bus Stations	Creating the service area layer Loading the bus stations X&Y coordinate Buffering Road center line with intervals of (5, 10, 15, 20, 25, and 30 min).	
4.	How can we evaluate, if the study area has an adequate spatial accessibility in public transportation along the path of Mexico to Hayahulet road path?	Primary	-	By analyzing the study area has adequate spatial accessibility in public transportation along the path of Mexico to Hayahulet road path	Fig 4.4, 4.5 and 4.6 Table 4.6
		Secondary	2023 Google Earth image Addis Ababa city Land use map Population density map of Addis Ababa Road network base map		

Source: Authors Computation, 2023

CHAPTER FOUR: RESULT AND DISCUSSION

In order to find relevant insights to address the research questions, this chapter briefly describes the data analysis which is examining, transforming, analyzing, and interpreting data. On the other hand, presentation involves conveying these insights clearly and engagingly. A critical challenge for researchers, transportation authorities, and urban planners is to use GIS (Geographic Information Systems) to analyze the spatial accessibility of a public transportation network. This analysis assesses how well different areas within the selected road path are connected to public transportation services. So, the analysis was basically done by using the interactive software of ArcGIS 10.8.

4.1 Existing situation of public transportation network from Mexico to Hayahulet route

In the road path of Mexico to Hayahulet, there is a well-developed public transportation system; bus stops are often located every few blocks, with an average distance of around 160 to 320 meters between stops. By plotting X & Y coordinate system into ArcGIS 10.8 Software, then measure the distance between each of the public transportation stops (Bus Stations).

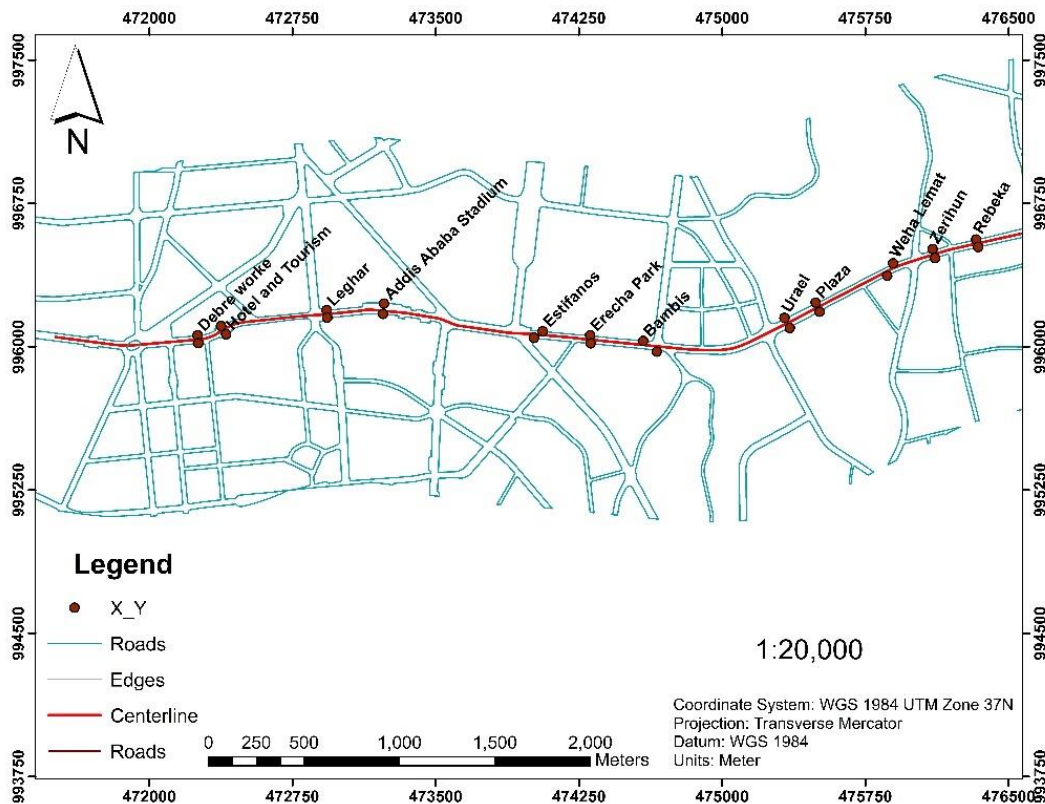


Fig 4. 1 Location of Bus stations from Mexico to Hayahulet

Table 4. 1 Bus Stations X, Y coordinate system

No.	Name of the Place for Bus stations	X-Coordinate	Y-Coordinate	Distance between Bus Stations (m)
1	Debre worke Right Side	472256.85	996018.2	152.6
2	Hotel and Tourism Right Side	472402.16	996064.83	536.7
3	Leghar Right Side	472931.8	996151.68	292.8
4	Addis Ababa Stadium Right Side	473223.91	996171.53	800.5
5	Estifanos Right Side	474014.48	996046.12	298.3
6	Kirkos Sub-city Right Side	474311.34	996017.54	348.8
7	Bambis Right Side	474657.42	995973.88	707.8
8	Urael Right Side	475354.33	996097.47	178.1
9	Plaza Right Side	475510.7	996182.4	400.3
10	Weha Lemat Right Side	475864.19	996370.25	267.74
11	Zerihun Right Side	476115.01	996463.92	232.8
12	Rebeka Right Side	476340.7	996521.19	-

No.	Name of the Place for Bus stations	X-Coordinate	Y-Coordinate	Distance between Bus Stations (m)
1	Debre worke Left Side	472253.15	996058.95	132.5
2	Hotel and Tourism Left Side	472375.98	996108.58	558.7
3	Leghar Left Side	472928.65	996190.47	302.1
4	Addis Ababa Stadium Left Side	473228.67	996225.5	844.5
5	Estifanos Left Side	474060.52	996080.24	249.3
6	Erecha Park Left Side	474308.96	996059.6	279.4
7	Bambis Left Side	474586.78	996029.44	749.5
8	Urael Left Side	475326.55	996149.85	182.1
9	Plaza Left side	475490.07	996230.02	454.5
10	Weha Lemat Left Side	475895.14	996436.13	220.2
11	Zerihun Left Side	476102.31	996510.75	233.5
12	Rebeka Left Side	476330.43	996560.74	-

Source: Authors Computation, 2023

Based on Table 4.1, the maximum distance from station to station is 800.5m from Addis Ababa Stadium to Estifanos in right side and 844.5m from Ababa Stadium to Estifanos left side when measured between station to stations. While the minimum is found to be 152.6m and it is measured from Debre worke to Hotel and Tourism in right side stations. And 132.5m and it is measured from Debre worke to Hotel and Tourism in right side stations.

The table further show that the average distance between the stations in the left side is 382.39 m and it is 383.31m in the right side.

Traveling out from Mexico toward Hayahulet, most of the bus station distance has an average distance from one station to another but five bus stations on the right side and four on the left side are not based on the standard. When we come to suitable bus stations for user it has a waiting area to shield passengers from weather like suns and rain. It has comfortable seating benches with shade and it somehow maintain cleanliness and proper waste management to create a pleasant environment in the surroundings. It is well integrated with nearby train stations that pass through the same direction.



Photo 1.1 Different bus stations along Mexico to Hayahulet and dustbins

Based on the above, public bus stations X and Y coordinate locations and the spatial distribution and service area accessibility were analyzed and discussion have been presented step by step following pre-described study objectives based on time and distance.

4.1.1 Service area on public transport stops

In order to calculate the service area accessibility towards the public bus stations we need to have the total area of the land use and total population in the area based on the existing road network. The analysis subsequently demarcates catchment area and population around each public bus stations travel distance. The served population for each public bus stations travel distance impedances has been calculated from the catchment residential area portions multiplied by population net density.

Table 4. 2 Service area accessibility analysis result at different travel distance

Accessibility (m)	Served residential area (ha)	Served population	
		Number	Percentage
100	119.92	12900	8.70
300	379.21	42100	28.39
500	664.37	74500	50.24
700	975.33	110200	74.31
900	1312.16	148300	100.00

Table 4.2 illustrates that it covers 119.92 ha in 100m distance and serves 12900 people, 379.21 ha in 300m distance and serves 42100 people, 664.37 ha in 500m distance and serves 74500 people, 975.33 ha in 700m distance and serve 110200 people, and 1312.16 ha in 900m distance and serve 148300 people being the most prominent coverage area. These indicate that when the distance increases, it will cover a larger area.

4.2 Spatial accessibility of public transportation along the path of Mexico to Hayahulet road

4.2.1 Computing Population Density

Computing population density is the primary task for accessibility analysis. The point data for population density is acquired from CSA 2021 and must be converted to a raster image using a conversion tool. Subsequently, each population point is intersected with the centerline buffered area at different distances (100, 300, 500, 700, and 900 meters).

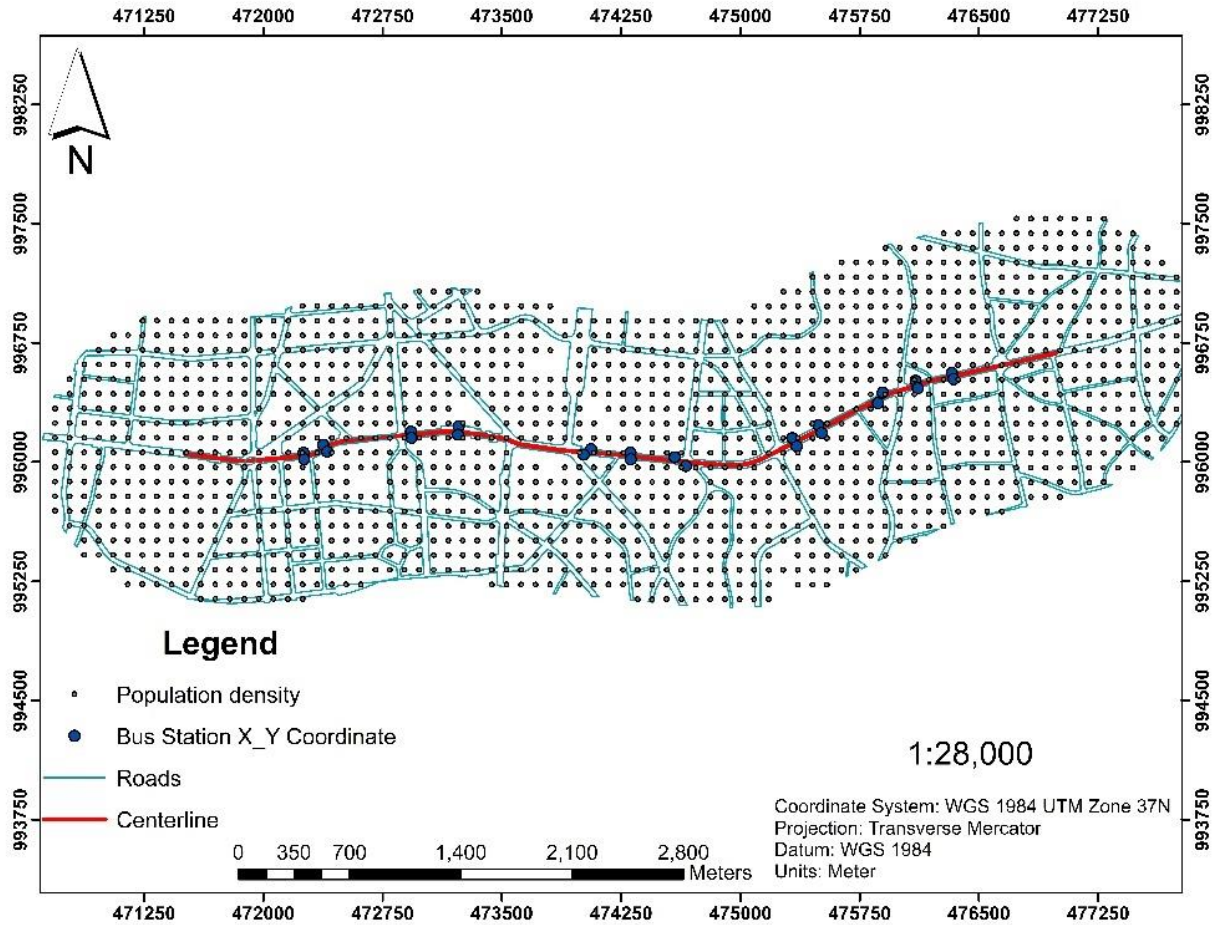


Fig 4. 2 Point data in population density

In this analysis, each population point represents 100 individuals. This conversion factor is crucial for precise calculations. Thus, multiplying the total number of point data by one hundred gave us the overall population in the area. To determine population density, dividing the total population by the land area is necessary. Finally, population density (number of populations per hectare) has been computed using the ratio of demographic data and net built-up area.

Table 4. 3 Population Density of the Buffered Areas

Centerline Buffered (m)	100	300	500	700	900
Area (m ²)	1199221	3792116	6643700	9753345	13121632
Area (ha)	119.9221	379.2116	664.37	975.3345	1312.163
Population	12900	42100	74500	110200	148300
Population Density (m ²)	0.010757	0.011102	0.011214	0.011299	0.011302
Population Density (ha)	107.5698	111.0198	112.1363	112.9869	113.0195

The number of people living in a given land area is measured as population density. So, the above table 4.3 is computed to identify the population density of each buffered areas. It shows that the population density increases as the area increases.

4.2.2 Service Area Accessibility Analysis

The research delineates the population and catchment area surrounding each bus stop based on the 500m accessibility distance standards. The population net density multiplied by the catchment residential area sections has been used to calculate the serviced population for each bus station location. By calculating Ava.net population density in (ha).

Population density = Area /population

Table 4. 4 Calculation of Population Density in Land Use

ID	Layer	Area Hectares	Population	Population density
1	Administrative Services	38.555	3400	88.18
2	Commerce	209.588	24300	115.94
3	Environmental protection	106.198	12200	114.87
4	Historical Construction and Site	5.379	400	74.36
5	Infrastructure Service	7.042	700	99.40
6	Mixed Residence	622.313	73200	117.62
7	Mixed Environmental protection Residence	0.019	0	0
8	Municipal Service	26.499	3200	120.76
9	Social Service	50.238	6000	119.43
10	Special Project	3.350	200	59.70
	Total	1069.18	123600	<u>115.6</u>

To calculate accessibility percentages and disadvantaged population, the following formulas are applied:

1. Accessibility Percentage Formula:

Accessibility Percentage = (Total Population ÷ Accessible Population) ×100

Example: Accessibility Percentage = (31300 ÷ 50000) ×100=62.6%

2. Disadvantaged Population Formula:

Disadvantaged Population = Total Population – Accessible Population

Example: Disadvantaged Population = 50000–31300 =18700

3. Extended Travel Formula:

Extended Travel = Travel Distance to Public Bus Stations – Standard Travel Distance

Example: Extended Travel = Actual Travel Distance – 500m

This detailed analysis provides insights into the accessibility of existing bus stations, emphasizing the challenges faced by a significant portion of the population in reaching public transportation facilities. The formulas presented offer a quantitative understanding of the accessibility dynamics, allowing for targeted interventions to improve overall service area accessibility.

Table 4. 5 Service area analysis result at 500m travel impedance

Travel impedance (m)	Residential Area				Population			
	Served		Unserved		Served		Unserved	
	ha	%	ha	%	Number	%	Number	%
500	2.79	62.27	1.68	37.72	31300	62.6	18700	37.4

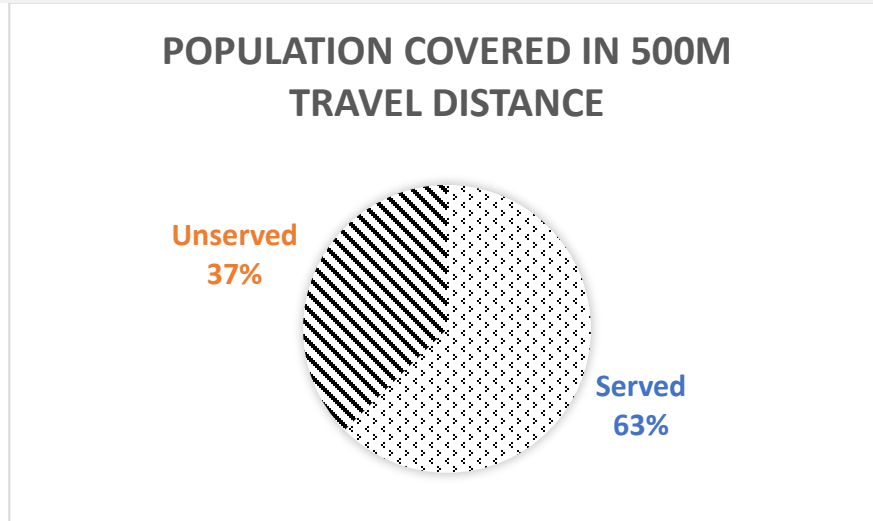


Fig 4. 3 Population that can access 500m travel distance from the Bus Stations

The overall service area accessibility result indicates that, the existing Bus Stations from Mexico to Hayahulet are accessible to 31300 (62.6 %) individuals settled in 2.79 ha with a 500m travel distance standard. But less than half of the population in that area which are 18700 (37.72 %) individuals settled in 1.68 ha don't have access based on the standard 500m to the specified road.

4.2.3 Duplicate Coverage Area

In accessibility-based planning compact neighborhoods, services and activities can be reached within a 15-minute walk. The service area accessibility results at 500m traveling distance have been considered as a base for this spatial accessibility analysis and are presented in figure 4.4. The area where multiple stops are located within a predetermined walking distance is known as the duplicate coverage area. As shown in the figure 4.4 below most of the public bus stations are less apart from the standard and some are very far apart.

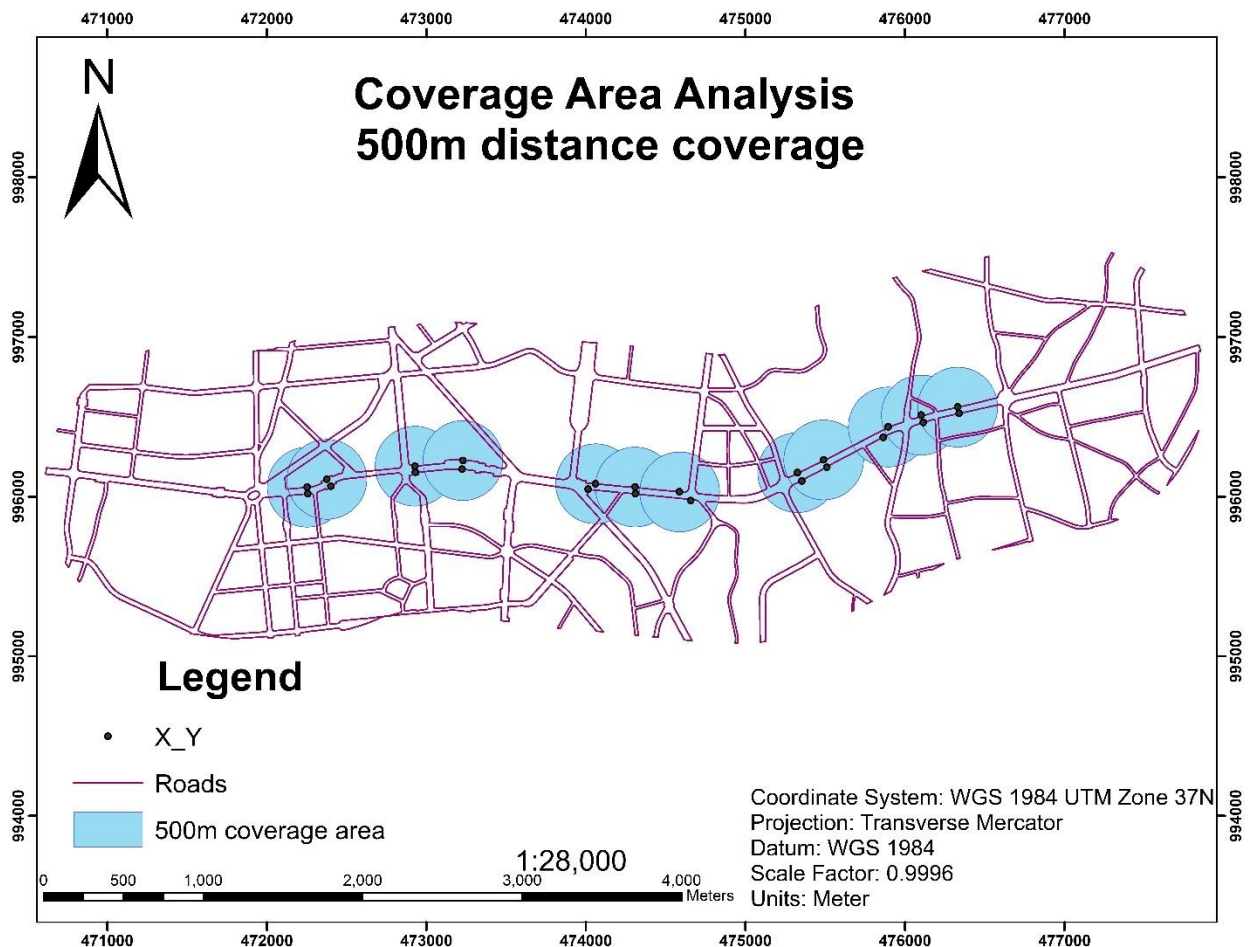


Fig 4. 4 Coverage Area Analysis based on the standard 500m radius walking distance

According to figure 4.4 the coverage area analysis focuses on assessing the accessibility of the existing Bus Stations from Mexico to Hayahulet within a standard 500m walking distance. Suppose a passenger have a map of Mexico to Hayahulet road path. A circle was drawn around each bus station from Mexico to Hayahulet with a radius of 500 meters. It shows how much of the area between Mexico and Hayahulet is covered by these circles. If many circles overlap or

close together, it means there are many bus stations to walk easily. But if there are significant gaps between the circles, there might not be many bus stations nearby. So, understanding the coverage area analysis helps people plan where to put new bus stations or improve existing ones to make it easier for people to travel.

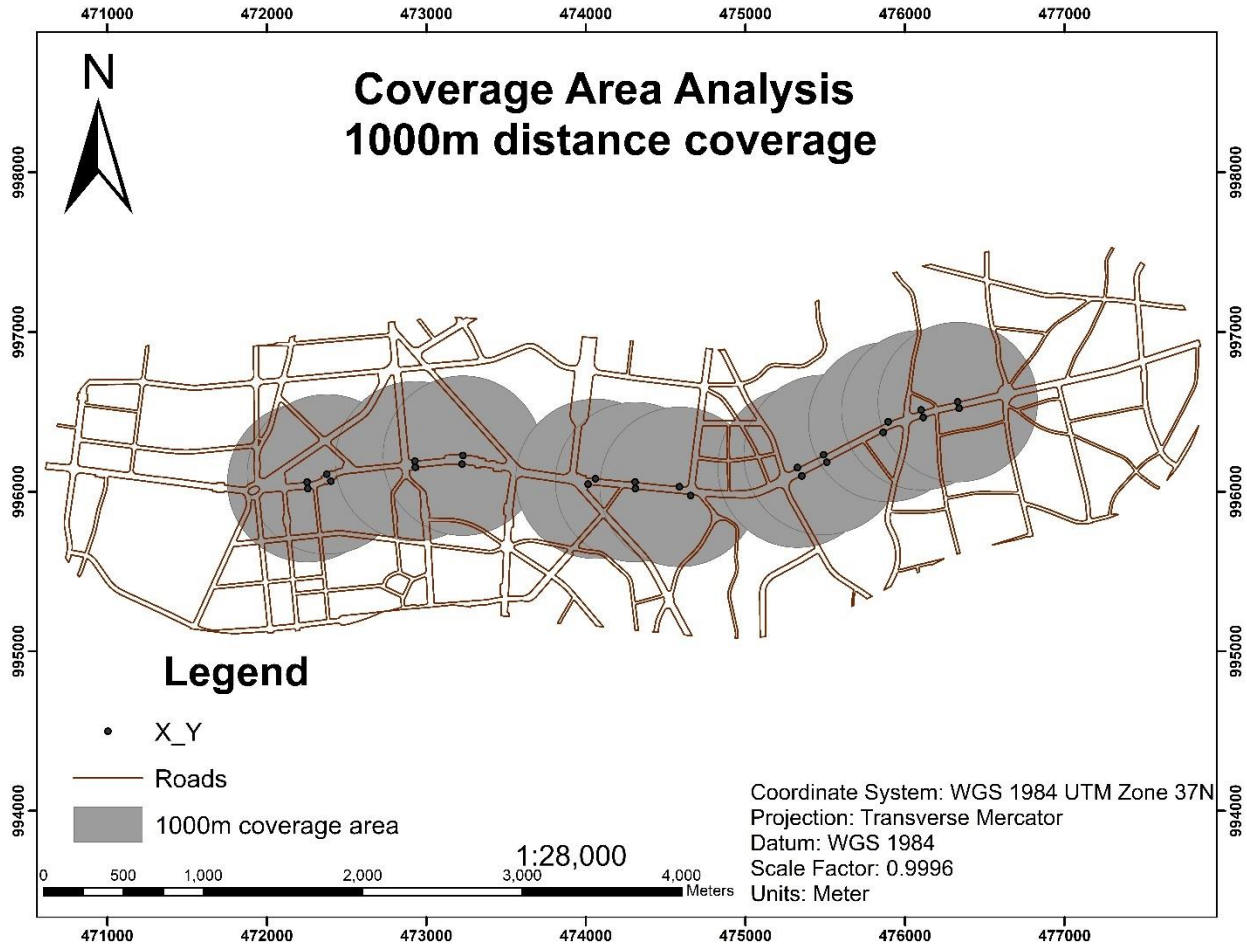


Fig 4. 5 Coverage Area Analysis based on 1000m radius walking distance

Using a 1000-meter walking distance (WD), the duplicate service area analysis output revealed an overlap area between the service area coverages of two consecutive stations. As we can observe from the above figure 4.5, most of the public bus stations are overlapped and the residents that live in that area can access two or more bus stations while walking less than one km.

Table 4. 6 Distance between consecutive stations and overlap areas between respective service areas

No	Name	Distance (m)	Overlap area (m ²) in 500 m Walking Distance
1	Debre worke - Hotel and Tourism	132.5	653307.27
2	Hotel and Tourism - Leghar	558.7	257300.56
3	Leghar - Addis Ababa Stadium	302.1	487996.49
4	Addis Ababa Stadium - Estifanos	844.5	56477.02
5	Estifanos - Erecha Park	249.3	538707.06
6	Erecha Park - Bambis	279.4	509625.12
7	Bambis - Urael	749.5	113654.37
8	Urael - Plaza	182.1	604292.94
9	Plaza - Weha Lemat	454.5	347076.05
10	Weha Lemat - Zerihun	220.2	566990.47
11	Zerihun - Rebeka	233.5	554003.80

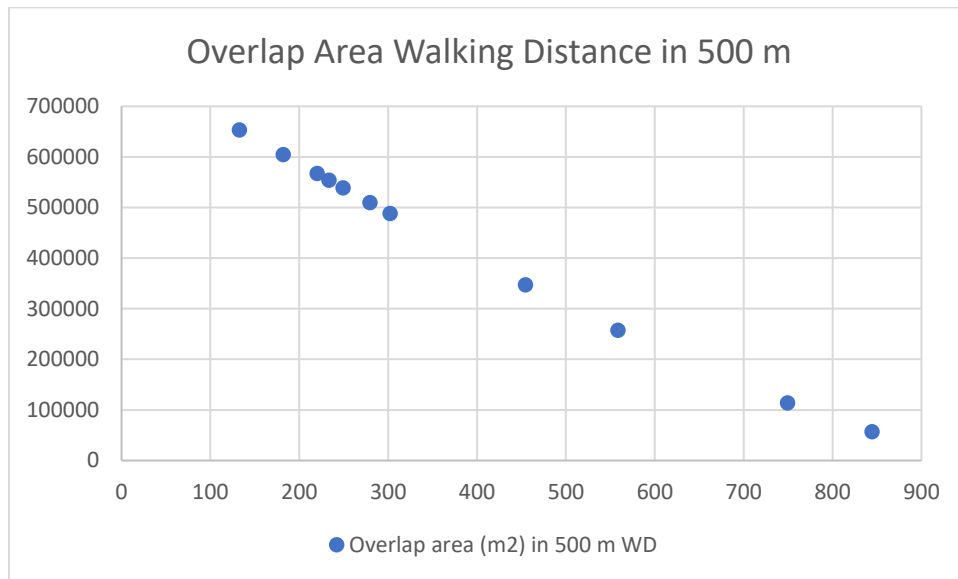


Fig 4. 6 Scatter plot of overlap area versus distance between stations

The correlation coefficient between the distance from stations to stations and the overlap areas using 500m walking distance is -0.998 , indicating the finding that as the distance between stations increases, overlap between subsequent service areas decreases; or the shorter the distance between stations, the more considerable the overlap between service areas of stations.

4.2.4 Spatial accessibility of the bus stations based on time

To analyze the time, it takes from different kinds of land uses to the nearest bus stations can be conducted by using Network Dataset Analysis. So, to measure that we can convert the growth population density to the road path, we will analyze and buffer the road centerline with (5, 10, 15, 20, 25 and 30 min) walking time on ArcGIS 10.8 Software.

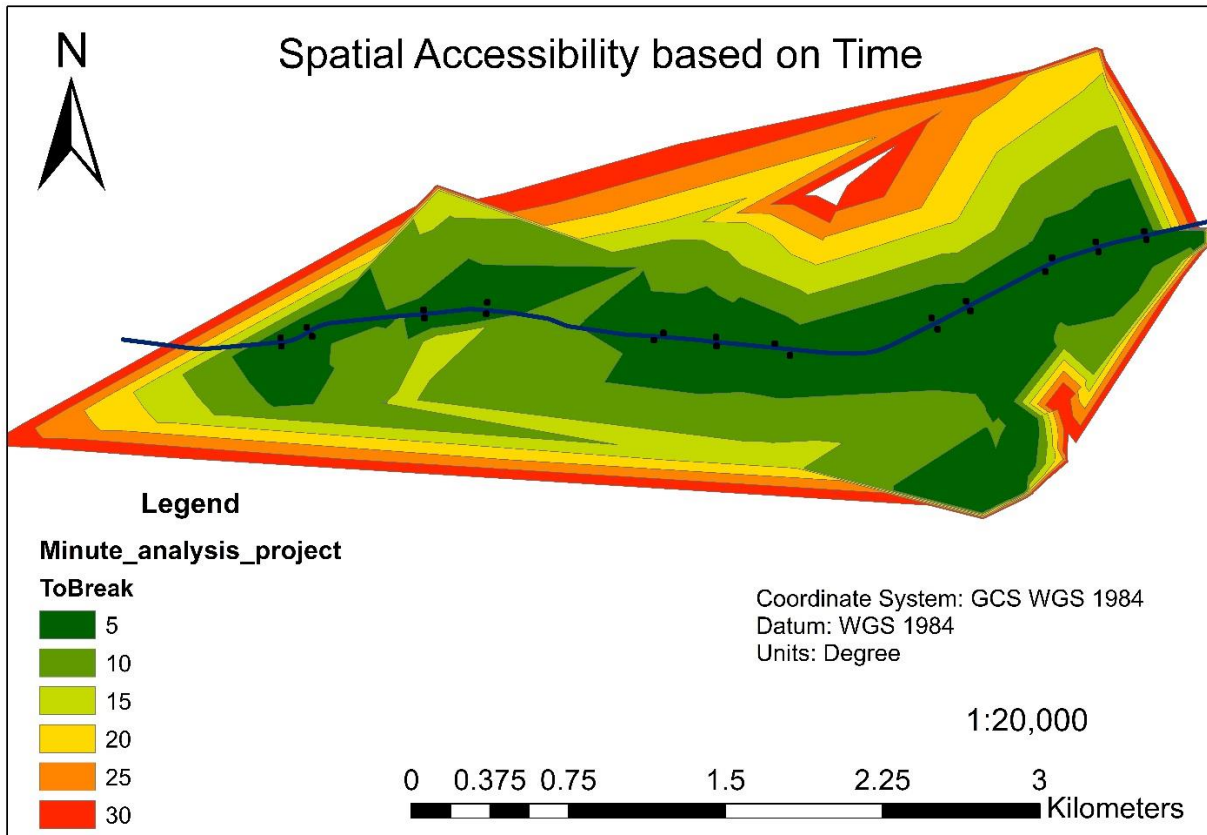


Fig 4. 7 Spatial Accessibility based on time

Table 4. 7 Spatial Accessibility that is covered in time

Time Analysis						
Time (min)	5'	10'	15'	20'	25'	30'
Area (m)	1970755	4074050	5104461	5931060	6749531	7451412
Area (km)	2	4	5	6	7	7
Perimeter(m)	14256.56	15761.56	13291.45	14872.58	15604	14637.14
Population	20700	45300	56900	66200	74300	81200
Population Density	1.050	1.112	1.115	1.116	1.101	1.090

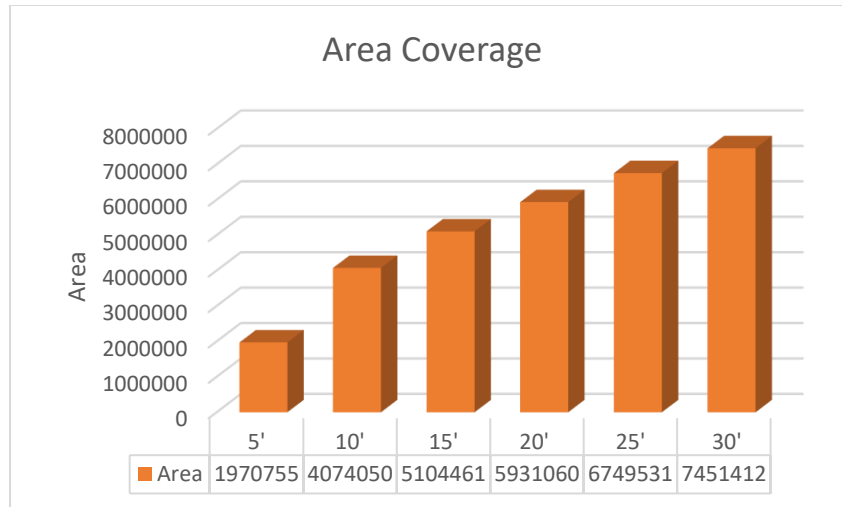


Fig 4. 8 Area Coverage based on time

Figure 4.8 shows that the area that will be covered in the interval of the time (5, 10, 15, 20, 25, and 30 minutes). Thus, it illustrates and covers 1,970,755 m² in 5 minutes, 4074050 m² in 10 Minutes, 5104461 m² in 15 Minutes, 5931060 m² in 20 Minutes, 6749531 m² in 25 Minutes, and with 7,451,412 m² in 30 Minutes being the largest coverage area. These indicate that it will cover a larger area when the amount of time increases. But the standard spatial accessibility to public transportation is 15-minute neighborhoods, so, as we can see from the fig 4.1 around 68.5% of the population can access the bus stations within the standard limit whereas 31.5% of the population will have to walk an extra mile in order to access the nearest public bus stations.

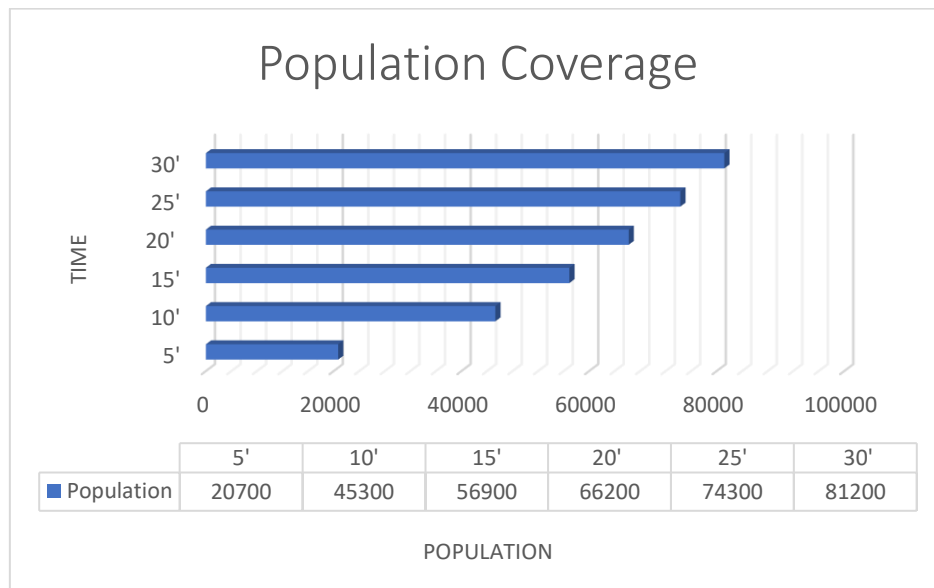


Fig 4. 9 Population Coverage based on time

Figure 4.9 shows, in 5 minutes 20700 individuals will access it, in 10 Minutes 45300 individuals will access it, in 15 Minutes 56900 individuals will access it, in 20 Minutes 66200 individuals will access it, in 25 Minutes 74300 individuals will access it, and in 30 Minutes 81200 individuals will access it. Based on the standard of spatial accessibility to public transportation it is 15-minute neighborhoods, meaning that commonly used services and activities can be reached within a 15-minute walk or bike ride. So, from the analysis 56900 individuals will access it is 70.07% will have a standard walking time from there residents.

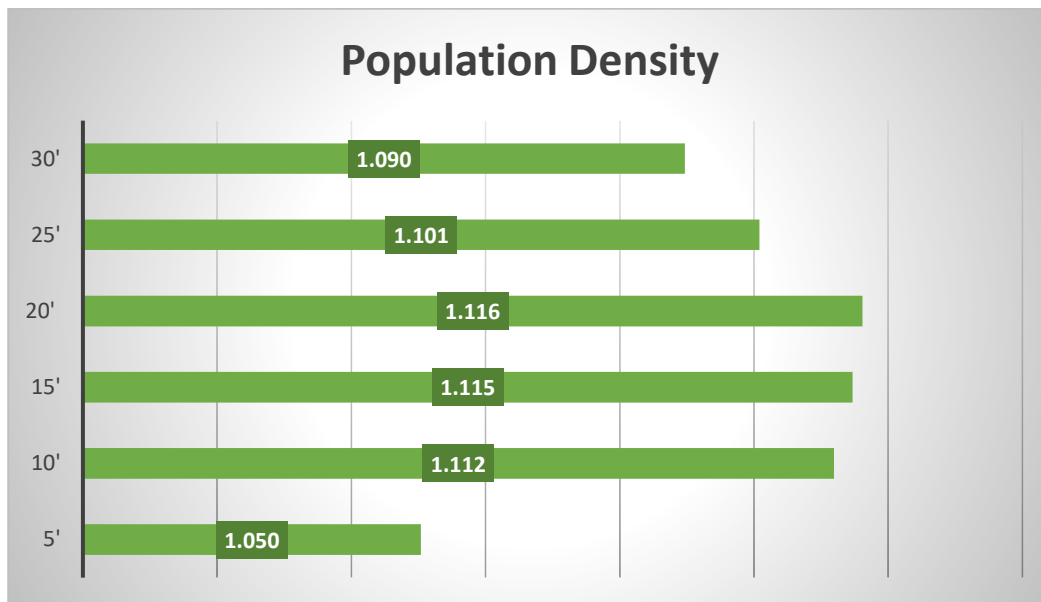


Fig 4. 10 Population Density based on Time

These Fig 4.10 Shows that the population density on the road path From Mexico to Hayahulet Road based on time. An additional method of calculating the duration of the travel it takes is by adding field for the road network that is length in Km form, its average speed can be 5 km/hr. and we can calculate the time it takes by dividing length with speed and multiple it by 60 to get the minute it takes to travel on that road.

4.2.5 Spatial accessibility of the bus stations based on distance

To analyze the spatial accessibility of public transportation according to distance, determine the area of interest and the public transportation system to be analyzed, then calculate the distance between each public transportation stop and the road network. This can be done using GIS software and spatial distance measures such as Euclidean distance or network distance. After that analyze the accessibility of the public transportation system by calculating the travel distance

from each location in the study area to the nearest public transportation stop. Finally, the spatial accessibility of public transportation can be conducted by taking point data from different land uses to the nearest bus stations using Network Dataset Analysis.

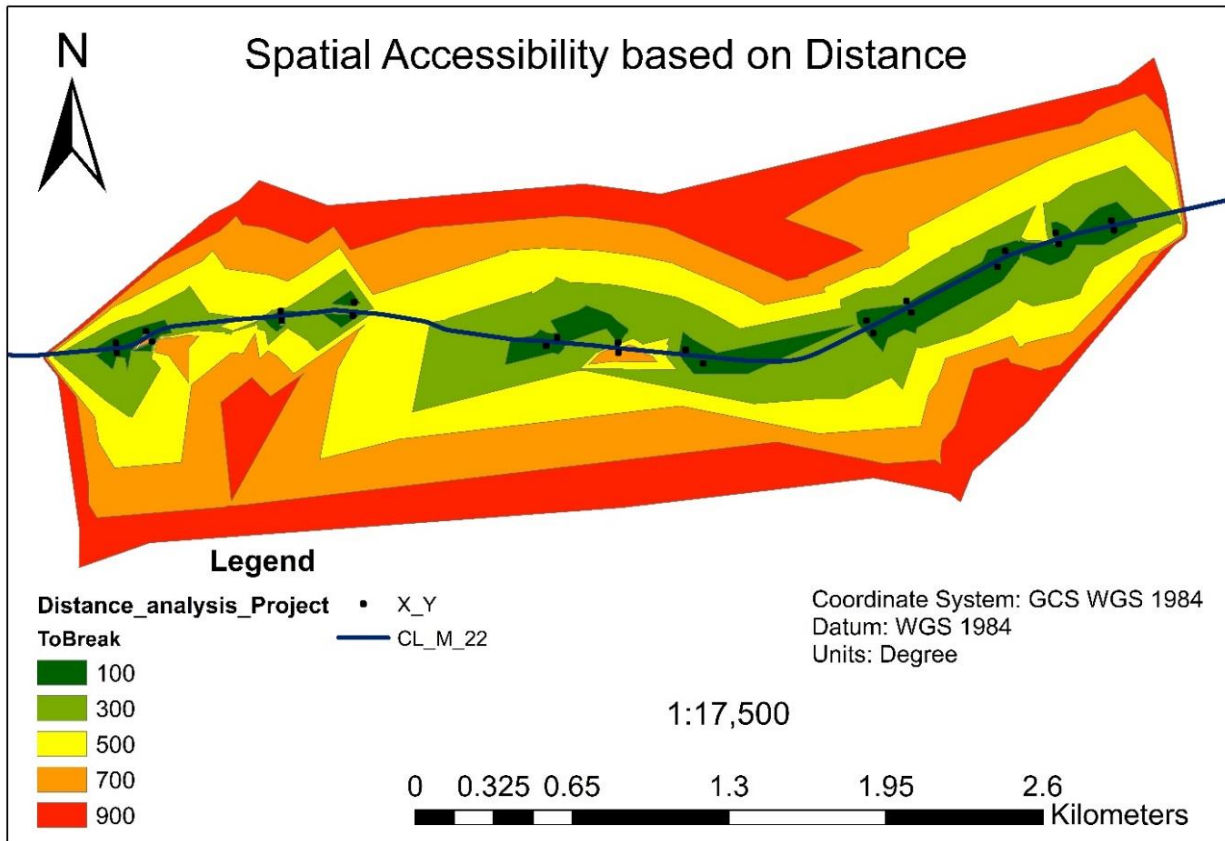


Fig 4. 11 Spatial Accessibility based on distance

When we talk about "spatial accessibility of the bus stations based on distance," it means we're looking at how easy or difficult it is for people to reach the bus stations depending on how far away they are. Imagine you're standing somewhere, and you want to catch a bus. The distance between where you are and the bus station matters because you might not want to walk that far if it's too far. So, spatial accessibility looks at how many bus stations are nearby and how far away they are. If there are many bus stations nearby, that's good for accessibility because you have options nearby. But it might not be so convenient if they're all far away.

Table 4. 8 Spatial Accessibility based on distance

Distance Analysis					
Distance (m)	100	300	500	700	900
Area (m²)	286875.7	1322400	2793753	4474144	6005700
Area (Km²)	0.29	1.32	2.79	4.47	6.0
Perimeter (m)	8407.549	12991.07	13969.25	13716.06	11845.08
Population	3500	14500	31300	50000	67300
Population Density	1.220	1.096	1.120	1.118	1.121

As we can see in the Table 4.8, in 100m 3500 individuals will access it, in 300m 14500 individuals will access it, in 500m 31300 individuals will access it, in 700m 50000 individuals will access it, and in 900m 67300 individuals will access it. Based on the standard of spatial accessibility for public transportation, it is 500m, meaning that commonly used services and activities can be reached within a 500m walking distance. So, from the analysis 31300 individuals will access it that is 46.5% will have a standard walking distance from there residents.

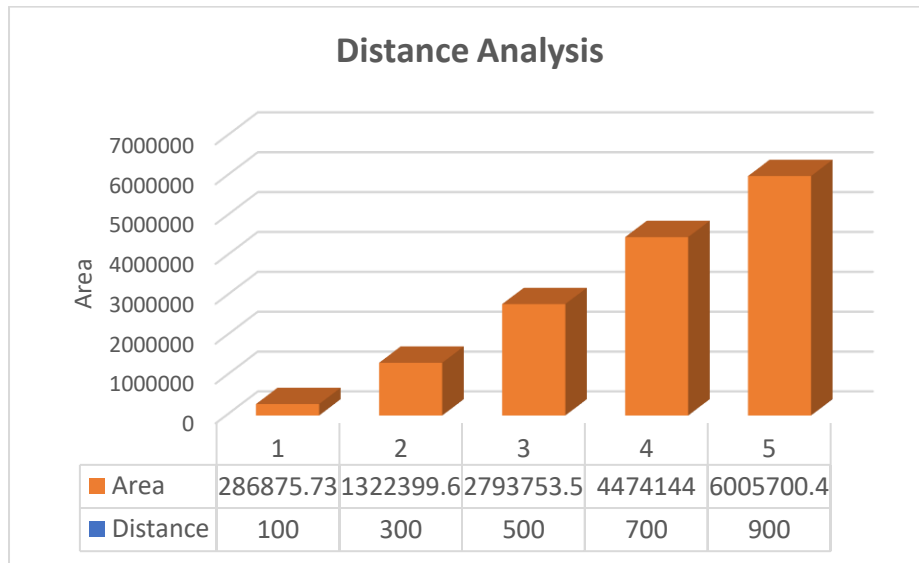


Fig 4. 12 Area Coverage based on Distance

The above figure 4.12 shows that the area that will be covered in the interval of the distance which are (100, 300, 500, 700, and 900m). It illustrates that it covers 286875.7 m² in 100m distance, 1322400 m² in 300m distance, 2793753 m² in 500m distance, 4474144 m² in 700m distance, and 6005700 m² in 900m distance being the largest coverage area. These indicate that when the amount of distance increases, it will cover a larger area.

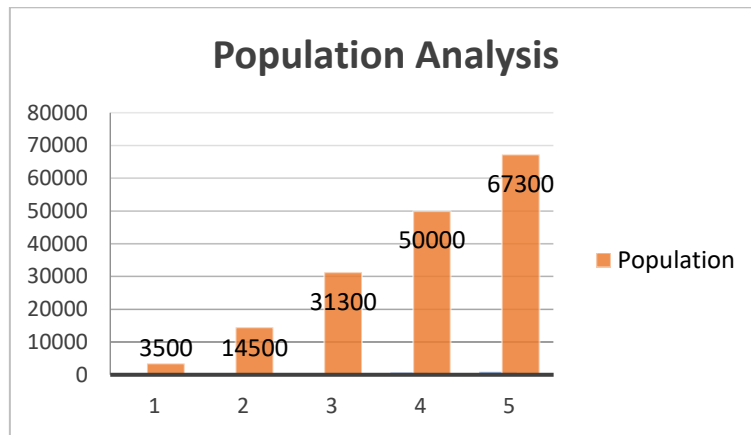


Fig 4. 13 Population Analysis based on Distance

With a maximum boundary spacing of 900 meters from the centerline, the researcher attempted to clip the total population density data for Addis Ababa to selected location road path from Mexico to Hayahulet. The point data is then converted to raster utilizing the arc tool box's point to raster (feature to raster) conversion features.

Network Dataset Analysis can be used to determine the distances between various land uses and the closest bus stops. It needs road networks in shape-line style to accomplish the work. The researcher then uses the road networks to identify the nodes and junctions of the chosen road network, which is the road path from Mexico to Hayahulet.

After doing that the researcher attempts to enter the locations of the bus stops as point data in the facilities, set the analysis impedance length with the interval of 100, 300, 500, 700 and 900m, and then execute the analysis, and obtained the figure below.

When we talk about accessibility the most important land use types to be considered in this research work are the existing road network. A road is a transportation route that determines the degree of importance of land use types by increasing the accessibility of that area. There are five

major categories of roads that are arterial, sub arterial, collector, local and access roads. The road coverage accounts for about 189.39 ha from the whole land use.

4.3 Discussion

This section is an essential part where the findings are interpreted, analyzed, and contextualized based on findings against previous studies conducted across the globe. Specifically in investigating spatial accessibility of public transportation network: The case of Bus stations along Mexico to Hayahulet Road, Addis Ababa, Ethiopia. The paper is divided into several sections:

According to the result above, there are nine bus stations with distances above standards, two with distances below the standard, and the remaining have an average of between 160 and 320 meters between bus stations. Which indicates the presence of uneven stations accessibility.

Normally, bus stations are like evenly spaced dots on a road. Making each dot (bus station) is an interval of 160 - 320 meters away from the next one, making it easy and predictable to access. But when irregular stations occur in the road path like the five stations on the right side and four on the left side. This implies that for passengers and the bus driver, it might make the journey a bit confusing or different than usual and they will travel longer distance from their location.

Passengers may encounter unpredictable variations in travel times, as buses can experience both longer and shorter durations between stations. This variability makes it more challenging to accurately predict arrival times, thereby impacting the convenience for passengers. In particular, individuals residing in less accessible areas may need to travel greater distances to reach a bus stop, exacerbating the issue. Moreover, buses may experience imbalances in passenger loads, with certain stops becoming overcrowded while others remain underutilized. These disparities in demand allocation can result in inefficiencies in resource utilization and potential delays.

Additionally, the irregular spacing of bus stops can have implications for fuel consumption and bus maintenance. The frequent stops and starts associated with unevenly spaced stops impose greater strain on the vehicles compared to a more evenly distributed route. Consequently, planning and optimizing routes become more complex, necessitating the utilization of advanced algorithms and planning tools to uphold service efficiency and cater to passenger requirements.

The irregular placement of bus stops also has implications for traffic flow, particularly within urban areas. Stops that are positioned too closely together can lead to congestion, while stops that are spaced too far apart can encourage higher speeds, potentially compromising safety. Moreover, ensuring equitable access to public transportation becomes more challenging when stops are irregularly spaced. Certain areas may become underserved, resulting in disparities in transportation accessibility.

To address these challenges, transit authorities often conduct comprehensive studies and employ sophisticated planning tools to design routes and schedules that strike a balance between these factors. The aim is to provide efficient and reliable service while accommodating the diverse needs of passengers (Itani & Liu, 2017).

While the majority of bus terminals are designed with the well-being of users in mind, providing a safe and comfortable waiting space, these bus stations also offer various features to enhance the overall passenger experience. For instance, they often provide sheltered waiting space to shield passengers from bad weather conditions. This thoughtful provision ensures that individuals waiting for buses are protected from rain, sun, or extreme heat.

Moreover, these terminals are equipped with shaded seating arrangements to ensure that passengers can comfortably wait for their buses. This consideration for passenger comfort is essential, especially during hot or sunny weather, as it allows individuals to rest and wait for their buses without being exposed to direct sunlight.

In addition to prioritizing passenger comfort, bus terminals also maintain high standards of cleanliness and waste management. This practice helps create a pleasant environment for passengers and ensures that the surrounding area remains tidy and well-maintained. By effectively managing waste disposal and maintaining cleanliness, bus terminals contribute to a positive and hygienic atmosphere for passengers and the surrounding community.

Furthermore, the strategic location of bus terminals in close proximity to adjacent train stations that operate in the same direction is an added advantage. This seamless connectivity provides passengers with convenient transfer options between different modes of transportation, facilitating their journeys and improving overall travel efficiency.

To summarize, bus terminals are not only designed to provide a waiting space that protects passengers from adverse weather conditions but also offer shaded seating, maintain cleanliness, and facilitate smooth connections with nearby train stations. These efforts collectively contribute to enhancing the overall experience of passengers using public transportation facilities (Zhang, 2018)

Upon evaluating the overall service area accessibility from Mexico to Hayahulet, it was determined that the coverage of existing bus stations played a crucial role. The analysis revealed that within a 500-meter travel distance standard, approximately 31,300 individuals, accounting for 62.6% of the population, settled in an area spanning 2.79 hectares, granting them convenient access to bus stations.

On the other hand, the analysis also unveiled that approximately 18,700 individuals, constituting 37.72% of the population, settled in a smaller area of 1.68 hectares, lacking access to the specified road within the 500-meter standard. Consequently, these inner-city residents face a significant disadvantage as they are unable to access public bus stations situated in the city center.

As a consequence of this limited accessibility, the affected population of approximately 18,700 individuals will have to travel longer distances to reach public bus stations, resulting in increased inconvenience. The lack of proximity to bus stations poses challenges for these individuals in terms of commuting efficiency and accessibility to essential services. It is very important to consider alternative transportation options that are accessible in their vicinity. This may include other modes of public transportation, such as minibuses or taxis, or even non-motorized options such as walking or cycling. By considering these alternatives, individuals can still access the necessary transportation services despite the additional travel distance required.

This disparity in accessibility highlights the importance of addressing the transportation needs of inner-city residents who are currently underserved. Efforts must be made to improve the accessibility and connectivity of public transportation, ensuring a more equitable and efficient system that caters to the needs of all residents. It is imperative to implement measures that enhance the accessibility of public bus stations for the affected population, thereby mitigating the inconvenience they face due to limited proximity. By doing so, the overall transportation

experience can be improved for all residents, fostering a more inclusive and accessible urban environment (Mekonnen & Brouwer, 2017).

The standard distance between public bus stations in Addis Ababa is not uniform throughout the city but varies based on factors such as location and population density. In urban areas where there is a higher demand for public transportation, bus stations are typically situated within a range of 1 to 2 kilometers apart. This closer proximity ensures convenient access to bus services and reduces the walking distance for passengers, enhancing the overall efficiency of the transportation system.

But when we come to suburban or rural areas it is characterized by lower population density, the spacing between bus stations tends to be more substantial. In such areas, the distance between stations can range from 5 to 10 kilometers or even more. The wider spacing takes into account the lower demand for public transport in these areas and the need to cover larger geographical areas with limited resources.

It is crucial to recognize that these distances are not fixed and can vary depending on various factors. Local regulations, geographical conditions, and transportation planning strategies implemented by local authorities all contribute to determining the optimal spacing between bus stations. Flexibility is key in adapting the spacing to meet the specific needs and characteristics of each area within Addis Ababa.

By carefully considering these factors and implementing appropriate spacing strategies, transportation planners and authorities can ensure a balanced distribution of bus stations that effectively serves the diverse needs of the city's residents. This approach aims to optimize accessibility, convenience, and efficiency within the public transportation network (Zewdu & De Roo , 2020).

According to the literature cited above, a walking distance within the range of 300-500 meters is generally regarded as a comfortable walking distance for most individuals. Within this radius, pedestrians can conveniently access nearby destinations, including public bus stations, without significant physical exertion.

In low-density areas where population density is lower, it is generally accepted that walking distances may exceed 500 meters due to the need to cover larger geographical areas. However, it

is important to note that even in these areas, the maximum walking distance should ideally not exceed 1000 meters. This upper limit ensures that individuals residing in such areas can still access essential services and transportation options with reasonable ease.

By adhering to these guidelines, urban planners and transportation authorities can ensure that pedestrian infrastructure is designed to prioritize the comfort and convenience of residents. By keeping walking distances within a reasonable range, the accessibility and usability of public bus stations can be enhanced, promoting sustainable transportation options and accommodating the diverse needs of the population (Rupi & Irawati, 2019).

It is important to remember that these guidelines are based on literature and best practices, and they may be subject to local variations and context-specific considerations. Local authorities should take into account factors such as local regulations, topography, and the specific needs of the population when determining appropriate walking distances for different areas within Addis Ababa.

When we come to the coverage area analysis it focuses on assessing the accessibility of the existing Bus Stations from Mexico to Hayahulet within a standard 500m walking distance. This criterion is crucial for understanding the reach and effectiveness of the public transportation system.

In Addis Ababa, the standard distance between public bus stations can vary based on the specific location and population density. This variation takes into account the unique characteristics and dynamics of different areas within the city. Urban planning considerations, population distribution, and the intricacies of the transportation network all contribute to determining the optimal placement and spacing of bus stations.

The factors that determine the duplication of bus station coverage area can be:

1. High urban density may lead to the establishment of multiple bus stations in close proximity, resulting in coverage area duplication.
2. Presence of transportation hubs or interchanges can contribute to duplication as multiple bus routes converge, necessitating multiple stations.
3. Uneven population distribution may prompt the establishment of multiple stations to cater to densely populated areas, causing overlap.

4. City planning decisions, such as zoning regulations or development incentives, can influence the clustering of bus stations, leading to coverage duplication.
5. Bus stations may be strategically placed near economic centers, and if multiple centers exist, it can result in overlapping coverage areas.
6. Variations in demand at different times or days might lead to the establishment of additional stations to manage peak periods, causing coverage duplication.

Avoiding unnecessary duplication of bus station coverage areas is a multifaceted process that requires a comprehensive understanding of these factors. By considering urban planning principles, demographic trends, and the intricacies of the transportation network, authorities can optimize the placement of bus stations. This optimization ensures efficient coverage of the city without unnecessary overlap or duplication.

By strategically locating bus stations and assessing their coverage areas, urban planners and transportation authorities can enhance the accessibility and usability of the public transportation system. This approach facilitates efficient mobility for residents, reduces travel distances, and promotes sustainable transportation options within Addis Ababa.

It is essential to continually evaluate and refine the placement of bus stations to accommodate the evolving needs of the population, changes in urban dynamics, and advancements in transportation planning strategies. This ongoing assessment allows for the optimization of bus station coverage areas, ensuring an effective and well-integrated public transportation network (Tulu & Oka, 2019).

The concept of accessibility, encompassing both time and distance, holds immense significance across various domains such as urban planning, transportation, and infrastructure development. It pertains to the level of ease and convenience with which individuals can reach their intended destinations within a reasonable timeframe and distance.

In the context of urban planning, accessibility plays a vital role in shaping the design and layout of cities. It involves creating an environment that enables residents to access essential services, amenities, and opportunities without encountering significant barriers. By considering factors such as the location of transportation hubs, the distribution of public facilities, and the connectivity of transportation networks, urban planners strive to optimize accessibility and enhance the overall quality of life for residents.

Within the realm of transportation, accessibility is a key consideration in designing efficient and sustainable transportation systems. It involves providing adequate connectivity between different modes of transportation, such as buses, trains, and pedestrian pathways, to facilitate seamless movement. By reducing travel times and distances, transportation planners aim to improve mobility, reduce congestion, and promote the use of public transportation.

In the domain of infrastructure development, accessibility serves as a guiding principle in determining the location and design of critical facilities. This includes schools, hospitals, workplaces, and recreational areas. By ensuring that these facilities are easily accessible to the population, planners strive to enhance social inclusion, promote equal opportunities, and foster a sense of community cohesion.

Overall, the concept of accessibility acknowledges the importance of minimizing physical and temporal barriers that individuals may face in reaching their desired destinations. By prioritizing accessibility in various domains, stakeholders can create more inclusive, sustainable, and livable environments that cater to the diverse needs of the population.

In order to assess time-based accessibility, the analysis focuses on evaluating the walking time required to reach the nearest bus stations within specific intervals. This includes assessing walking times at intervals of 5, 10, 15, 20, 25, and 30 minutes. By examining these intervals, the analysis aims to identify the areas that can be reached within these timeframes, providing insights into the population with access to public transportation within each interval.

Additionally, the spatial accessibility of public transportation is further explored based on distance. This involves calculating the distances between different land uses and nearby bus stops, considering intervals such as 100, 300, 500, 700, and 900 meters. By analyzing these distances, the study reveals the areas that can be reached within specific distance thresholds, shedding light on the population that has access to public transportation within these limits.

By conducting these time and distance-based accessibility analyses, researchers have a comprehensive understanding of the extent to which the public transportation system effectively serves various areas within the study area. The above results provide valuable insights into the areas that are well-connected and easily accessible, as well as areas that may require further attention in terms of enhancing accessibility.

These analyses contribute to evidence-based decision-making processes in urban planning, transportation, and infrastructure development. They inform policymakers and stakeholders about the areas where transportation improvements may be needed, allowing for targeted interventions to enhance accessibility and improve the overall transportation experience for the population.

The standard spatial accessibility to public transportation is based on the concept of 15-minute neighborhoods, where approximately 68.5% of the population can access the nearest bus stations within this standard limit. These individuals enjoy the convenience of having public transportation options available within a reasonable walking distance from their locations.

However, it is important to acknowledge that around 31.5% of the population falls outside this standard limit. They are required to walk an additional distance in order to access the nearest public bus stations. These individuals may face challenges in terms of travel time and convenience, as they have to cover a longer distance to reach the transportation services they require.

To address the needs of this 31.5% of the population, urban planners and transportation authorities should consider strategies to improve accessibility. This could involve expanding the coverage of bus stations to encompass a wider area, implementing shuttle services or feeder routes, or exploring alternative transportation options to bridge the gap between these individuals and public transportation services.

By recognizing and addressing the spatial accessibility disparities, urban planners can strive towards creating a more equitable transportation system. This ensures that a larger portion of the population has convenient access to public transportation within the standard limits, ultimately promoting sustainable mobility, reducing reliance on private vehicles, and enhancing overall connectivity within the community.

Time-based accessibility analysis can indeed be likened to planning a treasure hunt. Each time interval serves as a clue, guiding individuals to discover hidden treasures in the form of bus stations. The shorter the time interval, the closer one is to the treasure, indicating better accessibility. Just as finding a treasure quickly brings a sense of accomplishment, shorter travel times to bus stations reflect improved accessibility for individuals.

Similarly, distance-based accessibility analysis can be compared to mapping out the proximity of favorite places to one's home. The shorter the distance, the easier it is to reach these places, signifying better accessibility. Just as having favorite places close to home brings convenience and ease, shorter distances to bus stations reflect enhanced accessibility.

In this analogy, different areas can be seen as distinct service areas, each offering its own set of treasures or favorite places. Some areas may have bus stations located nearby, providing excellent accessibility, while others may require individuals to travel greater distances to access these transportation services.

By employing this treasure hunt analogy, the time and distance-based accessibility analyses become more relatable and understandable. It highlights the importance of shorter travel times and distances in ensuring better accessibility to public transportation, ultimately contributing to improved mobility and convenience for individuals in different service areas.

Each time interval represents a new level of accessibility, ensuring everyone has a chance to access in different service area. Imagine these areas as circles expanding from a central point. The larger the circle, the farther the reach, ensuring a broader range of accessible locations.

The paragraph delineates the demographic and catchment areas surrounding bus stop utilizing the 500m accessibility distance standard. It systematically calculates the served and unserved populations for each distance impedance level, and the results are presented. Then it addresses the concept of duplicate coverage areas, where multiple bus stops are located within a walking distance. It discusses the implications of having multiple stops in close proximity and presents data on the overlap areas between service areas of consecutive stations.

As a result of coverage Area Analysis, almost all public bus stations have the highest level of service area overlap of station. The duplicate coverage area is the region where several stops are spread out below the standard walking distance of one another. The analysis shows that most public bus stops are located relatively close to one another, while some are located far away. Since consumers only need to be able to walk to one stop, not two public bus terminals, duplicate coverage is typically not essential but the stations with the smallest overlaps might need the creation of new ones.

Think of the duplicate coverage area as a chessboard. Each square represents a bus stop. The analysis is like strategizing the placement of chess pieces. While some squares (bus stops) might be neighbors for a smooth journey, others are strategically placed at a distance. The goal is to ensure efficient coverage without unnecessary duplication.

Accessibility-oriented planning is crucial for individuals with disabilities, elderly populations, low-income households, and other demographics encountering obstacles in accessing essential resources. By prioritizing the enhancement of access to transportation, employment opportunities, healthcare services, and other vital amenities, this type of planning can help mitigate disparities and improve the overall well-being of community members.

Through the implementation of accessibility-oriented planning, communities strive to create an environment that is inclusive and accommodating to the diverse needs of its residents. By ensuring that transportation systems are accessible and convenient, individuals with disabilities can enjoy increased mobility and independence, enabling them to participate more fully in social, educational, and economic activities. Similarly, elderly populations can benefit from improved access to essential services, enabling them to age in place and maintain a high quality of life.

Moreover, accessibility-oriented planning contributes to reducing socioeconomic and spatial inequalities within communities. By enhancing access to employment opportunities, individuals from low-income households can overcome barriers to economic advancement and improve their financial well-being. Accessible healthcare services ensure that individuals can receive timely medical care and improve health outcomes, regardless of their physical or financial limitations.

In addition to addressing social and economic disparities, accessibility-oriented planning enhances the overall livability of an area. By providing convenient access to essential resources, communities become more attractive and competitive, fostering economic growth and attracting businesses and residents. This, in turn, contributes to the vitality and vibrancy of the community.

Furthermore, accessibility-oriented planning has a positive impact on the health and wellness outcomes of community members. By facilitating access to healthcare services, recreational facilities, and green spaces, individuals are encouraged to engage in active and healthy lifestyles. This, in turn, reduces the prevalence of chronic diseases and promotes overall well-being.

So, accessibility-oriented planning is a crucial component of creating equitable and inclusive communities. By enhancing access to transportation, employment opportunities, healthcare services, and other essential amenities, this type of planning mitigates disparities, improves well-being, and contributes to the overall livability and competitiveness of an area.

When accessibility-focused planning is integrated into an area, urban and traffic planners will prioritize the needs of individuals over infrastructure systems. This shift emphasizes sustainable objectives, including social inclusivity, economic urban development, and ecological conservation within the city.

In conclusion understanding accessibility-focused planning concept is vital for urban planners and transportation authorities. It allows them to optimize the placement of bus stops, creating a well-connected network without excessive redundancy. Ultimately, the aim is to enhance the overall efficiency of public transportation systems, ensuring that commuters can access their desired routes conveniently and with minimal walking distance.

CHAPTER 5: CONCLUSION AND RECOMMENDATION

5.1 Conclusion

The research paper discusses the importance of a well-functioning transportation system in cities, focusing on Addis Ababa, Ethiopia specifically from Mexico to Hayahulet road. It emphasizes the role of accessibility in urban development and the need for effective policies and strategies to enhance accessibility. The concept of accessibility is explored from various perspectives, considering factors such as mobility, affordability, and land use patterns.

It highlights the significance of accessibility-based planning, which promotes multimodal transportation and compact neighborhoods. It encourages the development of areas where essential services and activities are within a 15-minute walk or bike ride, leading to economic, social, and environmental benefits.

Additionally, it addresses the limitations of traditional transport planning, which prioritizes private vehicles and ignores non-motorized travel, such as walking and cycling. It emphasizes the importance of using Geographic Information Systems (GIS) to assess the spatial accessibility of public transportation networks and offers solutions to improve the situation, especially in developing countries like Ethiopia.

The findings from this study shed light on the percentage of the population within the standard walking time and distance of public transportation services, and identified areas of duplicate bus stop coverage. This indicates that the public transportation system may have to be reevaluated and strategically adjusted to improve the spatial accessibility and reduce inconsistencies.

From the analysis we can conclude that the objective-based analysis result reveals that the areas that can be reached within certain distances and the people that can use public transportation within these bounds are displayed in the results, and shows duplicate coverage areas, where multiple bus stops are located within a walking distance and it shows it is waste of resource to put the public bus stations intervals below the standard. In terms of spatial accessibility, most public bus stations are well accessed, some stations were found to have large areas of overlaps, while some others with small overlap areas.

By investigating the spatial accessibility of bus stations along the Mexico to Hayahulet Road in Addis Ababa, this research aims to contribute to the development of a more efficient and

inclusive public transportation network. The findings will serve as a basis for informed decision-making in urban planning and transportation policies, ultimately enhancing the overall quality of life for residents in Addis Ababa.

5.2 Recommendation

Based on the analysis results and findings, this study has forwarded the following recommendations.

- ✓ Solving the problem of GIS-based analysis on spatial accessibility of public transportation network is important for promoting equitable access to transportation, reducing traffic congestion, supporting economic development, and improving quality of life.
- ✓ Improving the physical infrastructure of bus stations, such as installing wheelchair ramps and improving lighting and signage.
- ✓ Increasing the frequency and coverage of public transportation services, particularly in areas with limited accessibility.
- ✓ Ensure that bus stops are accessible to people with disabilities by providing features such as ramps, accessible seating, and audio announcements.
- ✓ Improve pedestrian infrastructure, such as sidewalks, crosswalks, and pedestrian crossings, to ensure that they are safe and accessible for all users.
- ✓ An increase in service area coverage is typically correlated with an increase in the population that can be reached, according to the correlation analysis. However, service area coverage and population accessibility may not necessarily indicate a higher number of actual users. The actual number of users may be influenced by other factors, such as the quantity of people who use private and public vehicles and the type of land use.
- ✓ For public bus stations with small amount of service area coverage, an improvement in the density of road network is considered as one of the solutions. But I think it is more than enough to serve the population at the current time and to the near future.
- ✓ Plan bus routes that cover a wide area and provide convenient access to popular destinations, like shopping centers, schools, and healthcare facilities.
- ✓ Provide real-time information on bus schedules, routes, and accessibility features to help users plan their trips and navigate the system.

- ✓ Ensure that public transportation is integrated with other modes of transportation, such as bike-share systems and ride-hailing services, to provide users with a seamless and accessible travel experience.
- ✓ Therefore, it is recommended that policymakers and urban planners should take into account the results of this study in their efforts to optimize bus stop locations, and hence, enhance efficient and equitable transportation services. Further research should be conducted in city areas to create a comprehensive view of public transport accessibility across Addis Ababa. As we advance in the digital age, GIS-based analysis should continue to be utilized as a crucial tool in assessing and improving of public transport systems.

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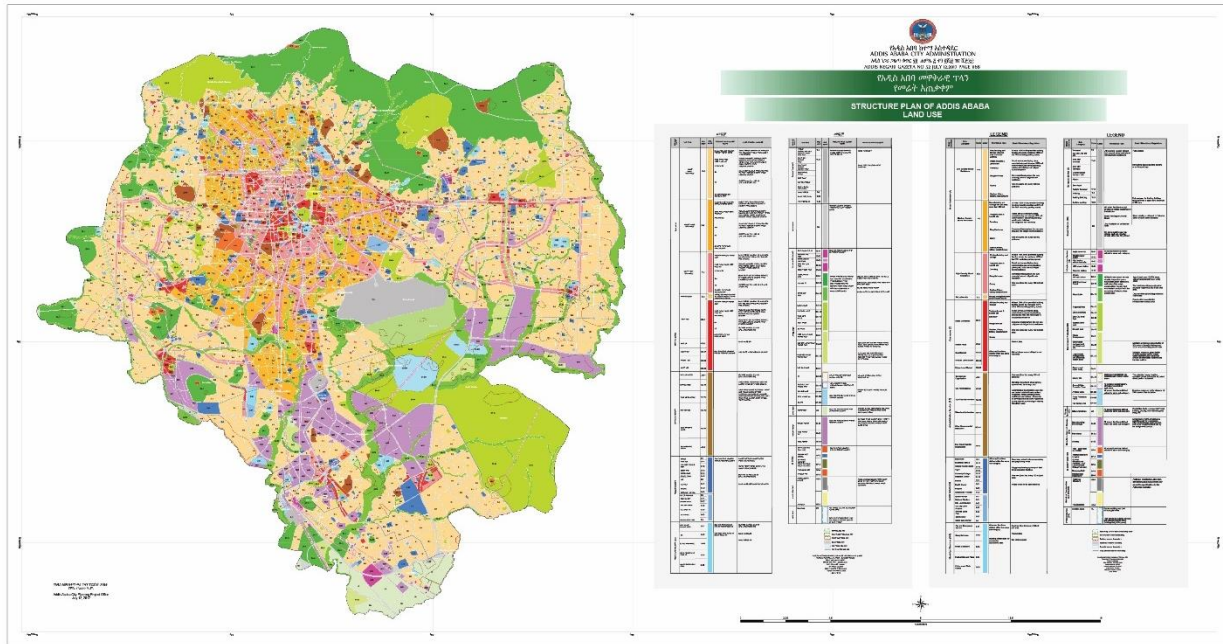
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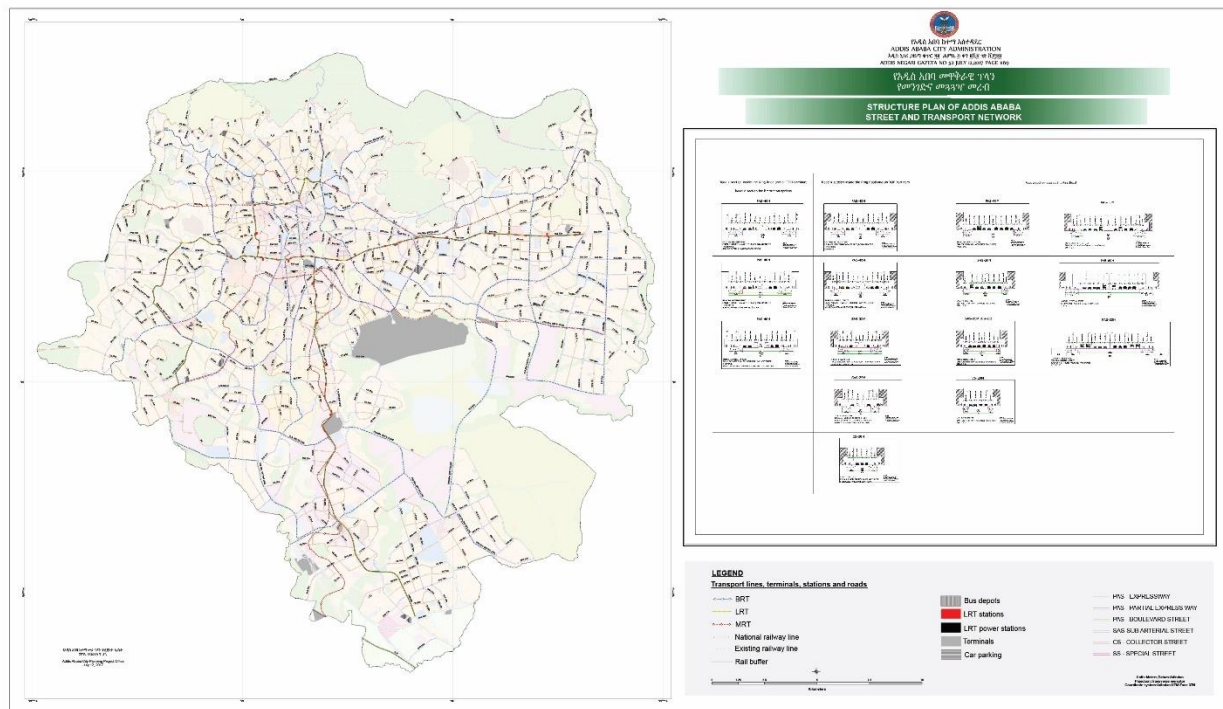
Appendices

Appendix A



Source: - Addis Ababa City Planning Project Office, July 12, 2022

Appendix B



Source: - Addis Ababa City Planning Project Office, July 12, 2022

Appendix C

✓ Bus Stations X, Y coordinate system from Mexico to Hayahulet

No.	Name of the Place for Bus stations	X-Coordinate	Y-Coordinate	Distance between Bus Stations (m)
1	Debre worke Right Side	472256.85	996018.2	152.6
2	Hotel and Tourism Right Side	472402.16	996064.83	536.7
3	Leghar Right Side	472931.8	996151.68	292.8
4	Addis Ababa Stadium Right Side	473223.91	996171.53	800.5
5	Estifanos Right Side	474014.48	996046.12	298.3
6	Kirkos Sub-city Right Side	474311.34	996017.54	348.8
7	Bambis Right Side	474657.42	995973.88	707.8
8	Urael Right Side	475354.33	996097.47	178.1
9	Plaza Right Side	475510.7	996182.4	400.3
10	Weha Lemat Right Side	475864.19	996370.25	267.74
11	Zerihun Right Side	476115.01	996463.92	232.8
12	Rebeka Right Side	476340.7	996521.19	-

No.	Name of the Place for Bus stations	X-Coordinate	Y-Coordinate	Distance between Bus Stations (m)
1	Debre worke Left Side	472253.15	996058.95	132.5
2	Hotel and Tourism Left Side	472375.98	996108.58	558.7
3	Leghar Left Side	472928.65	996190.47	302.1
4	Addis Ababa Stadium Left Side	473228.67	996225.5	844.5
5	Estifanos Left Side	474060.52	996080.24	249.3
6	Erecha Park Left Side	474308.96	996059.6	279.4
7	Bambis Left Side	474586.78	996029.44	749.5
8	Urael Left Side	475326.55	996149.85	182.1

9	Plaza Left side	475490.07	996230.02	454.5
10	Weha Lemat Left Side	475895.14	996436.13	220.2
11	Zerihun Left Side	476102.31	996510.75	233.5
12	Rebeka Left Side	476330.43	996560.74	-

Source: - 2003 Line map

Annex

Annex 1: Publishable Article

Investigating spatial accessibility of public transportation network in Addis Ababa, Ethiopia: The case of Bus stations along Mexico to Hayahulet Road Corridor

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Abstract

This research paper investigates the spatial accessibility of public transportation networks in Addis Ababa, Ethiopia: the case of Bus stations along Mexico to Hayahulet Road Corridor, using Geographic Information Systems (GIS) in the context of time and distance. It highlights the underestimation of nonmotorized travel and the need for accessibility-based planning to address issues like road problems and low transport accessibility in developing countries. Accessibility-based planning aims to enhance individuals' ability to reach essential destinations, irrespective of transportation mode, reducing travel time and improving connectivity. The methodology is particularly meticulous in terms of measuring the accessibility of bus stops, with a specific focus on walking distances regarded through the average comfortable walking paces and travel time to access different services and activities to be reached within a 15-minute walk. Based on the analysis the first method results illustrate, the existing Bus Stations from Mexico to Hayahulet are accessible to 31300 (62.6 %) individuals settled in 2.79 ha but less than half of the population in that area which are 18700 (37.72 %) individuals settled in 1.68 ha doesn't have an access to the specified road with a 500m travel distance standard. The accessibility based on time result showed that, around 68.5% of the population can access the bus stations within the standard limit whereas 31.5% of the population will have to walk an extra mile in order to access the nearest public bus stations. By analyzing the accessibility of these bus stations,

valuable insights can be gained to inform urban planning and transport accessibility across Addis Ababa.

Keywords: Spatial accessibility; Public transportation network; Geographic Information Systems (GIS); Sustainable transportation system

Introduction

Cities can be a better place to live if the transport system allows them the freedom of movements and enhance the accessibility to basic services (health, education) and to working places (Minister of Transport and Logistics, 2022).

Providing comfortable, safe, dependable, efficient, equitable transport service for the city of Addis Ababa is a condition to accelerate the development of the city, and make a competent city on regional, continental and international levels. The provision of implementable policy and strategy is a key factor to the stated needs (Ethiopia Ministry of transport, 2011).

Accessibility refers to people's ability to reach desired services and activities, which is the ultimate goal of most transport activity. Many factors affect accessibility, including mobility (physical movement), the quality and affordability of transport options, transport system connectivity, mobility substitutes, and land use patterns (Litman, 2022).

Accessibility may be assessed from a variety of angles. It is frequently measured for specific users, modes, activities, locations, times, and scales, such as the number and types of jobs or stores available to low-income non-drivers in a specific neighborhood, or aggregated to measure multiple people's ability to access multiple services and activities in an area (Levinson & Wu, 2020).

Accessibility-based planning justifies more multimodal planning and development policies which create more compact neighborhoods, so any household that wants can find suitable homes in areas where it is easy to get around without driving, often called 15-minute neighborhoods, meaning that commonly-used services and activities can be reached within a 15-minute walk or bike ride. This helps achieve various economic, social and environmental goals (Duany & Steuteville, 2021).

(Simmonds & Still, 1998) defined accessibility as “a way of measuring the ease with which a particular category of persons can reach a defined set of destinations, from a given origin (origin accessibility), or the ease with which a given destination (destination accessibility) can be reached by a particular set of potential individuals. Access is the ultimate goal of most travel activity, so accessibility-based planning tends to best reflect what users want from a transportation system, and offers the widest range of potential solutions to transport problems. Accessibility-based planning increases support for slower but more affordable and resource-efficient modes, such as walking, bicycling and public transit (Litman, 2022).

Walking is a particularly important mode, both by itself and to provide access to motorized modes, including parked cars and public transit. Walkability indicators are an important but often undervalued accessibility factor (Pajares et al, 2021; Rowlands, 2020).

So, public transportation that is effective and easily accessible is essential for urban growth and raising the standard of living for citizens in the modern world. Transportation planners and policymakers use Geographical Information System (GIS) to examine the spatial accessibility of public transportation networks in order to accomplish this. The purpose of this research paper is to examine the function of GIS in spatial accessibility of the public transportation network in the case of Mexico to Hayahulet Road Path; by assessing the existing situation of the public transportation road network based on time and distance framework. Furthermore, by identifying if it has an adequate spatial accessibility of public transportation system in the area and finally offering viable solutions to the city's concerns.

Methodology

The research encompasses a comprehensive assessment of the city's transit systems, of the public transportation network. Employing a mixed methods approach, the study integrates quantitative data, such as road centerline and population density figures, with qualitative insights from field observations and interviews. This approach allows for a robust spatial and non-spatial data analysis grounded in theoretical and practical considerations.

The study deploys a various of data collection techniques, ranging from primary methods like surveys to secondary methods involving the examination of satellite imagery and land-use and road network base maps. The methodology is particularly meticulous in terms of measuring the

accessibility of bus stops, with a specific focus on walking distances regarded through the average comfortable walking paces, acknowledged to be between 3 to 4 miles per hour.

Spatial analysis is conducted utilizing GIS tools and Network Analyst, enabling researchers to perform service area analyses and define accessibility based on distance intervals. The study's findings are presented through various formats, including tables, maps, and graphical representations, which facilitate a clear understanding of the accessibility landscape.

Mostly, the process of this study needs spatial and non-spatial data collection of the road path of the selected road network, bus stations on both sides of the road, the surrounding area services and land use map, analysis of spatial distribution pattern, the adequacy of the accessibility of the existing physical condition and public transportation network of the Mexico to Hayahulet road, and the researcher's main goal is to investigate the spatial accessibility of the public transportation system. Specifically, if it fulfills the standard of road network based on time and distance.

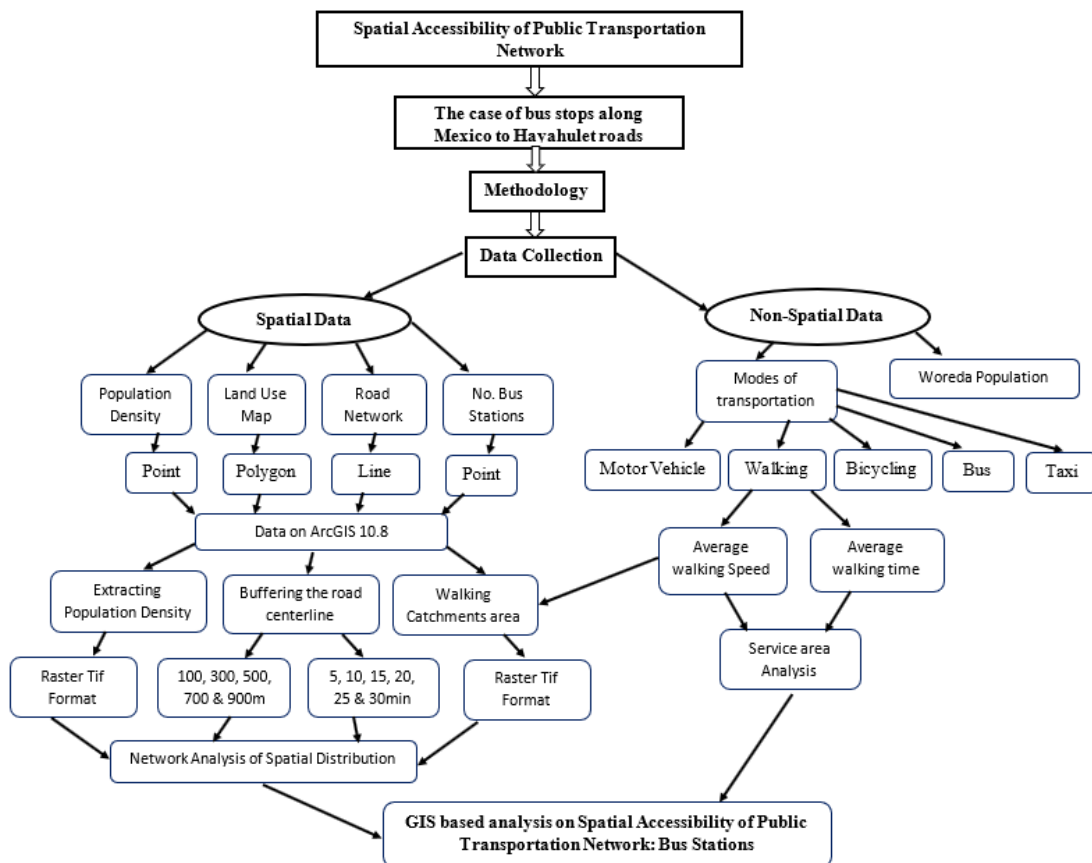


Figure 3.1: - Research methodology
Source: Authors Computation, 2023

Based on the literatures reviewed the standard spatial accessibility to public transportation is 15-minute neighborhoods, meaning that commonly-used services and activities can be reached within a 15-minute walk or bike ride. So, to measure that we can convert the growth population density to the road path we will analyze and buffer the road centerline with (5, 10, 15, 20, 25 and 30 min) walking time on ArcGIS Software. Calculation of percentages, proportions, ratios, and comparison of figures in comparison with urban plan standards was used as an approach to interpret the research findings.

The overall spatial accessibility metric for bus stops and the percentage of the population served by bus service, calculated by measuring the service area of the road center lines for example we can take these intervals to buffer the road center line (100, 300, 500, 700 and 900 meters) and with these buffer zones we are gone divided it by the total population of the influenced zones.

By using network analysis, we can determine the service area and all available routes within a certain walking distance can fall inside the buffered area. It helps in assessing how accessible the Network Analyst tool's results are. Concentric service areas demonstrate how accessibility changes with walking distance. They are utilized to determine the number of individuals, amount of land, or quantities of other entities within a neighborhood or region. Distance-based service areas are also useful for predicting travel distances from demand points to bus stations. In this particular study, the service area was generated from bus stations, which were used as service points based on distance.

Data analysis – data was collected from primary and secondary sources and was analyzed. By identifying the spatial accessibility of public transportation network by assessing the existing situation of public transportation network along the path of Mexico to Hayahulet road in time and distance framework. And also, by identifying if it has an adequate spatial accessibility of public transportation system in the area. Geographic Information Systems (GIS), maps, and other tools, such as Google Earth, had provided the means to quantify and describe the spatial accessibility of public transportation network.

Results

Data Analysis for existing situation of public transportation network

Collecting public bus stations on the road path of Mexico to Hayahulet is very essential for the research to be conducted. The researcher identified the location of the bus stations using hand

held GPS and Satellite images with google earth software and identified around 24 locations on each side of the roads.

To analyze the spatial accessibility of public transportation along the path of Mexico to Hayahulet road based on time

To analyze the time, take different kinds of land uses to the nearest bus stations and conducted it using Network Dataset Analysis. So, in order to measure that it has to be converted to total growth of population density of the road path and analyze the buffer of the road centerline with (5, 10, 15, 20, 25 and 30 min) walking time on ArcGIS 10.8 Software.

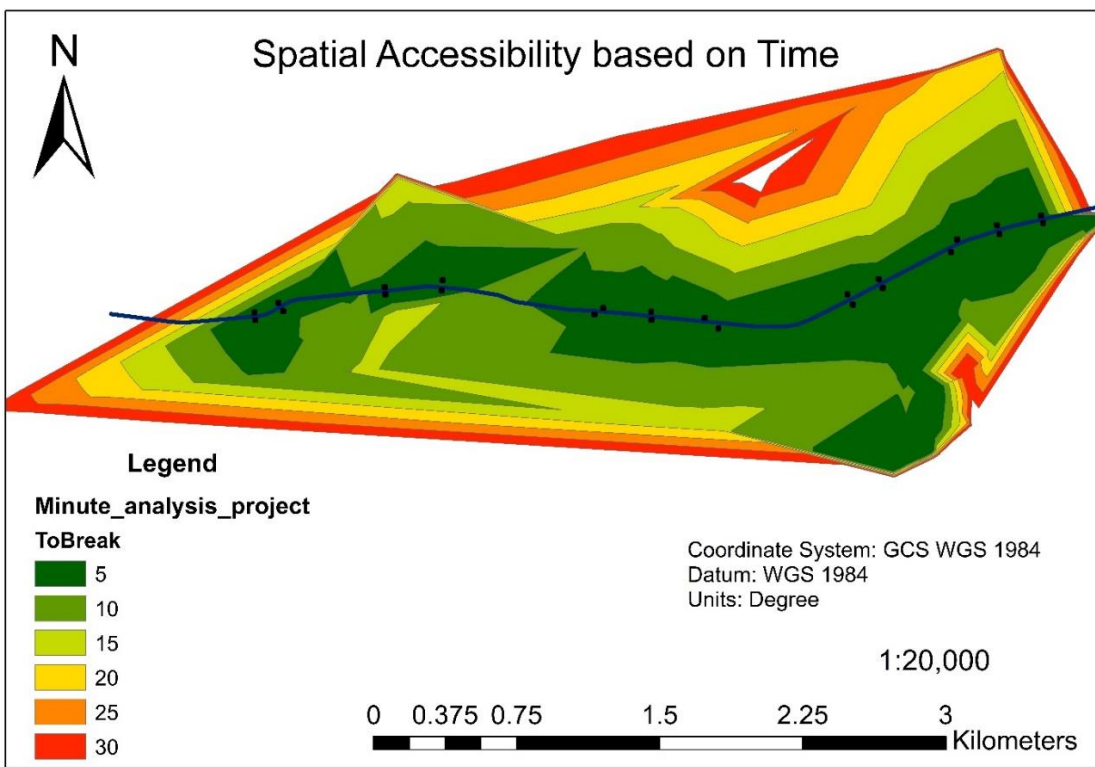


Fig 4.7 Spatial Accessibility based on time

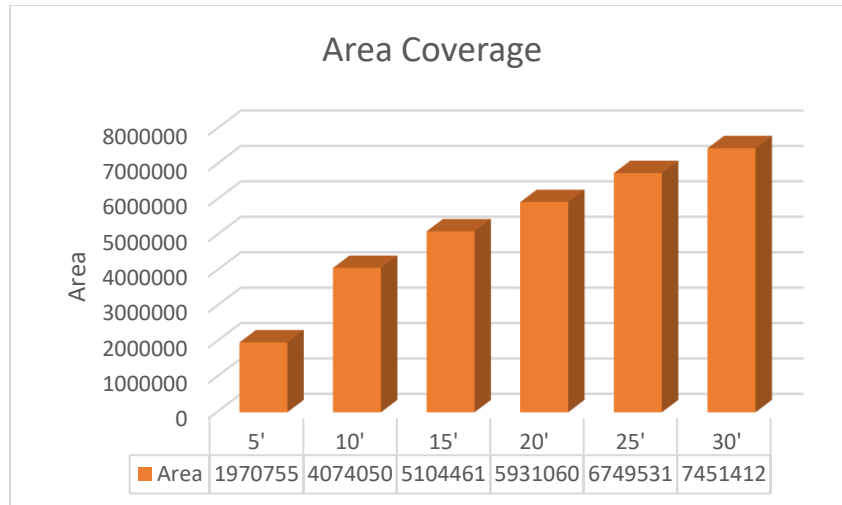


Fig 4.8 Area Coverage based on time

This Figure 4.2 illustrates, it covers 1,970,755 m² in 5 minutes, 4,074,050 m² in 10 Minutes, 5,104,461 m² in 15 Minutes, 5,931,060 m² in 20 Minutes, 6,749,531 m² in 25 Minutes, and with 7,451,412 m² in 30 Minutes being the largest coverage area. These indicate that when the amount of time increases, it will cover a larger area. But the standard spatial accessibility to public transportation is 15-minute neighborhoods, so, as we can see from the fig 4.1 around 68.5% of the population can access the bus stations within the standard limit whereas 31.5% of the population will have to walk an extra mile in order to access the nearest public bus stations.

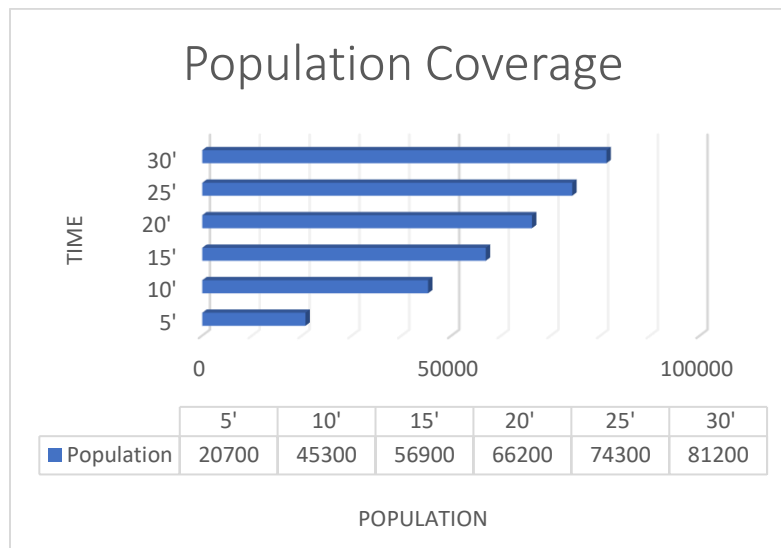


Fig 4.9 Population Coverage based on time

As we can see in the Figure 4.3, in 5 minutes 20700 individuals will access it, in 10 Minutes 45300 individuals will access it, in 15 Minutes 56900 individuals will access it, in 20 Minutes 66200 individuals will access it, in 25 Minutes 74300 individuals will access it, and in 30 Minutes 81200 individuals will access it. Based on the standard of spatial accessibility to public transportation is 15-minute neighborhoods, meaning that commonly-used services and activities can be reached within a 15-minute walk or bike ride. So, from the analysis 56900 individuals will access it that is 70.07% will have a standard walking time from there residents.

Analysis of the spatial accessibility of public transportation along the path of Mexico to Hayahulet road based on distance

First, determine the area of interest and the public transportation system to be analyzed, then calculate the distance between each public transportation stop and road network. This can be done using GIS software and spatial distance measures such as Euclidean distance or network distance.

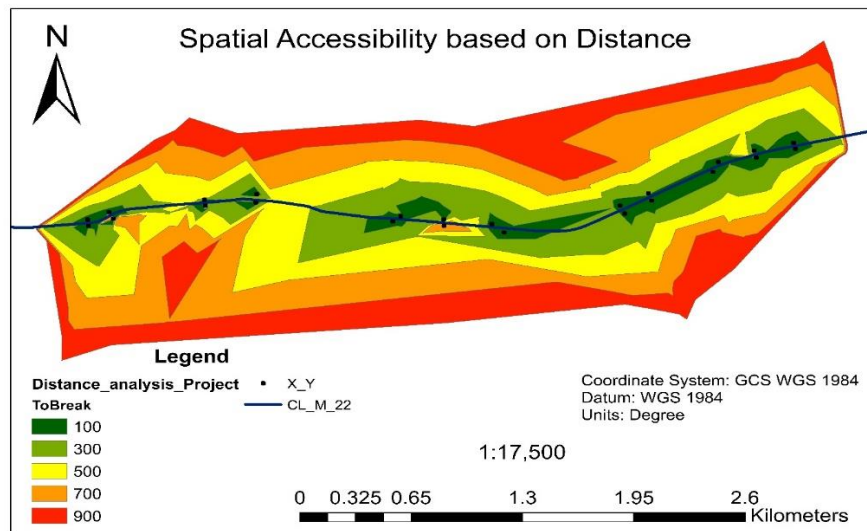


Fig 4.11 Spatial Accessibility based on distance

Service area on integrated public transport stops

In order to calculate the service area accessibility towards the public bus stations we need to have the total area of the land use and total population in the area based on the existing road network. When transportation service stops are spaced evenly, the area is considered to have a good service area. However, places with limited public transportation stops are considered to be less accessible.

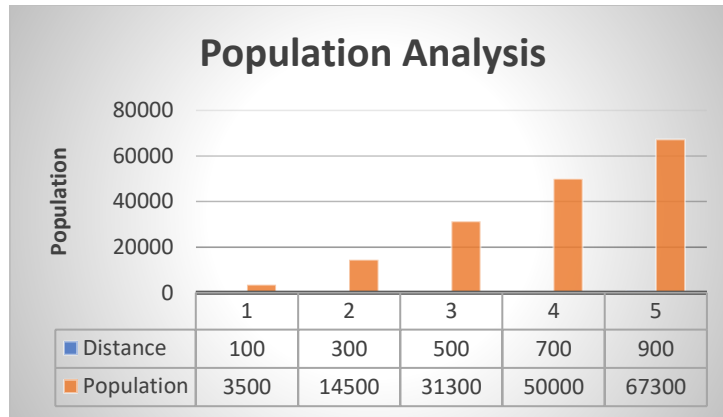


Fig 4.13 Population Analysis based on Distance

As we can see in the Figure 4.7, in 100m 3500 individuals will access it, in 300m 14500 individuals will access it, in 500m 31300 individuals will access it, in 700m 50000 individuals will access it, and in 900m 67300 individuals will access it. Based on the standard of spatial accessibility for public transportation is 500m, meaning that commonly-used services and activities can be reached within a 500m walking distance. So, from the analysis 31300 individuals will access it that is 46.5% will have a standard walking distance from there residents.

Service Area Accessibility Analysis

The research delineates the population and catchment area surrounding each bus stop based on the 500m accessibility distance standards. The population net density multiplied by the catchment residential area sections has been used to calculate the serviced population for each bus station location. By calculating Ava.net population density in (ha).

$$\text{Population density} = \text{Area} / \text{population}$$

Travel impedance (m)	Residential Area				Population			
	Served		Unserved		Served		Unserved	
	ha	%	ha	%	Number	%	Number	%
500	2.79	62.27	1.68	37.72	31300	62.6	18700	37.4

Table 4.5 Service area analysis result at 500m travel impedance

The overall service area accessibility result indicates that, the existing Bus Stations from Mexico to Hayahulet are accessible to 31300 (62.6 %) individuals settled in 2.79 ha with a 500m travel distance standard. But less than half of the population in that area which are 18700 (37.72 %)

individuals settled in 1.68 ha don't have an access based on the standard which is 500m to the specified road. As a result, about 18700 inner city people are more disadvantaged, as they must travel further to access the public bus stations which is found in the city center. They are also anticipated to travel further than usual in order to get Public Bus Stations but can access other alternatives surrounding them.

Duplicate Coverage Area

In accessibility-based planning compact neighborhoods uses services and activities has to be reached within a 15-minute walk. The service area accessibility results at 500m traveling distance have been considered as a base for this spatial accessibility analysis and are presented in figure 4.11. The area where multiple stops are located within a predetermined walking distance is known as the duplicate coverage area. As we can see from the figure below most of the public bus stations are less apart from the standard and some are very far apart. In most cases, duplicate coverage is unnecessary since users only need to be able to walk to one stop not two public bus stations.

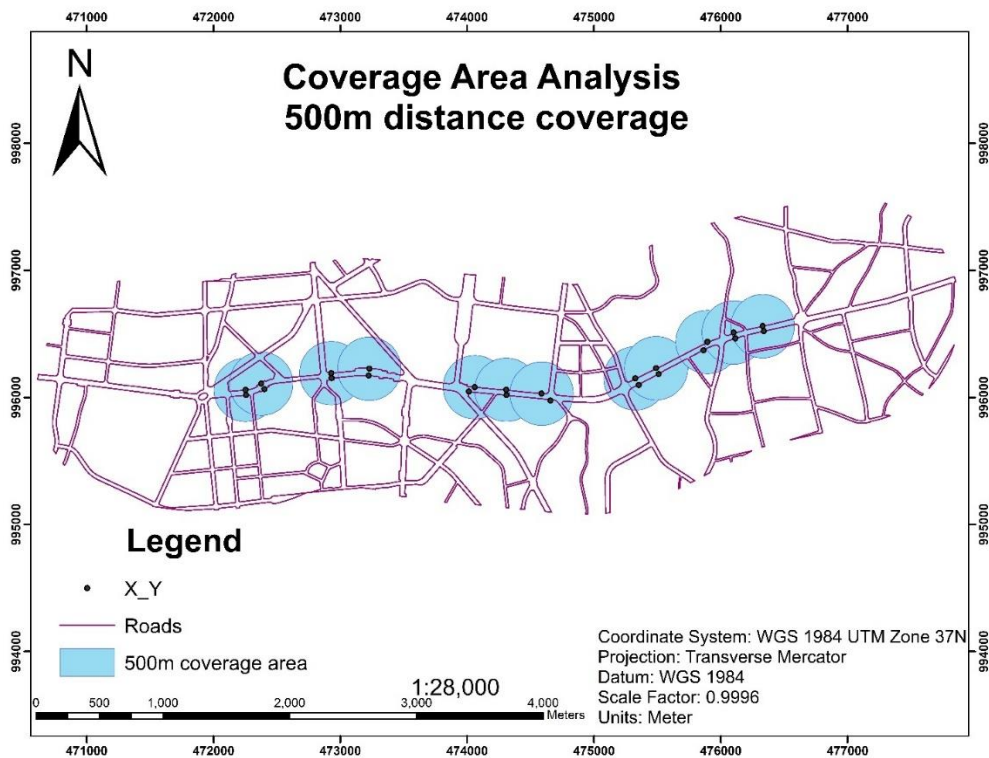


Fig 4.4 Coverage Area Analysis based on the standard 500m walking distance

The standard public bus station distance in Addis Ababa can vary depending on the location and the density of the population. In urban areas with a high demand for public transport, bus stations are generally closer to one another, typically around 1-2 kilometers apart. This allows for convenient access to bus services and reduces the walking distance for passengers. In suburban or rural areas, where the population density is lower and there is less demand for public transportation, bus stations may be further apart. In these areas, bus stations can be spaced out anywhere from 5 to 10 kilometers apart or even more.

The correlation coefficient between the distance from stations to stations and the overlap areas using 500m walking distance is -0.998 , indicating the finding that as distance between stations increases, overlap between subsequent service areas decreases; or the shorter the distance between stations, the larger the overlap between service areas of stations.

Discussion

The article focuses on the spatial accessibility of public transportation, particularly bus stations along the Mexico to Hayahulet Road in Addis Ababa, Ethiopia. It employs ArcGIS 10.8 for geospatial data analysis, emphasizing its importance in dissecting and interpreting spatial data.

The paper discusses the existing public transportation network, highlighting irregularities in station spacing that can confuse passengers and drivers. It also describes the features of user-friendly bus terminals, including waiting spaces and connectivity to adjacent train stations.

Service area accessibility analysis reveals that a significant portion of the population faces challenges accessing public bus stations within the city center. By revealing 62.6% of the population has access to bus stations within a 500m travel distance standard, while 37.72% face limited accessibility. This leads to increased travel for the disadvantaged population. Formulas are provided to calculate accessibility percentages, disadvantaged population, and extended travel, offering a quantitative understanding of accessibility dynamics.

The analysis explores the duplication of bus station coverage area, considering factors like urban density, transportation hubs, population distribution, city planning decisions, economic centers, and variations in demand. Understanding these factors is crucial for optimizing bus station placement and ensuring efficient coverage without unnecessary duplication.

Time-based and distance-based accessibility analyses are discussed, comparing them to a treasure hunt and mapping out the reach of accessible locations. It investigates into demographic and catchment areas around bus stops, addressing duplicate coverage areas and their implications. The chessboard analogy is used to strategize bus stop placement, emphasizing the importance of efficient coverage without redundancy for urban planners and transportation authorities. The ultimate goal is to enhance the overall efficiency of public transportation systems, ensuring convenient access for commuters with minimal walking distance.

Time-based accessibility analysis is important, equating it to a treasure hunt where shorter time intervals represent better accessibility. Additionally, distance-based accessibility analysis is likened to mapping out the proximity of favorite places, emphasizing that shorter distances indicate better accessibility. Each time interval in this analysis signifies a new level of accessibility, expanding like circles from a central point to ensure a broader range of accessible locations.

Furthermore, the article systematically calculates served and unserved populations at different distance impedance levels, particularly utilizing the 500m accessibility distance standard. It addresses duplicate coverage areas, where multiple bus stops are located within walking distance. The analysis distinguishes between bus stops located close to each other and those strategically placed at a distance. The goal is to create an efficient network without unnecessary duplication, akin to strategizing the placement of chess pieces on a chessboard.

Understanding the concept of duplicate coverage is deemed vital for urban planners and transportation authorities. It enables them to optimize bus stop placement, fostering a well-connected network that enhances the overall efficiency of public transportation systems. The aim is to ensure commuters can access their desired routes conveniently with minimal walking distance, ultimately contributing to a more streamlined and user-friendly public transportation experience.

Conclusion

The research paper discusses the importance of a well-functioning transportation system in cities, focusing on Addis Ababa, Ethiopia specifically from Mexico to Hayahulet road. It emphasizes the role of accessibility in urban development and the need for effective policies and strategies to

enhance accessibility. The concept of accessibility is explored from various perspectives, considering factors such as mobility, affordability, and land use patterns.

It highlights the significance of accessibility-based planning, which promotes multimodal transportation and compact neighborhoods. It encourages the development of areas where essential services and activities are within a 15-minute walk or bike ride, leading to economic, social, and environmental benefits.

Additionally, it addresses the limitations of traditional transport planning, which prioritizes private vehicles and ignores non-motorized travel, such as walking and cycling. It emphasizes the importance of using Geographic Information Systems (GIS) to assess the spatial accessibility of public transportation networks and offers solutions to improve the situation, especially in developing countries like Ethiopia.

The findings from this study shed light on the percentage of the population within the standard walking time and distance of public transportation services, and identified areas of duplicate bus stop coverage. This indicates that the public transportation system may have to be reevaluated and strategically adjusted to improve the spatial accessibility and reduce inconsistencies.

From the analysis we can conclude that the objective-based analysis result reveals that the areas that can be reached within certain distances and the people that can use public transportation within these bounds are displayed in the results, and shows duplicate coverage areas, where multiple bus stops are located within a walking distance and it shows it is waste of resource to put the public bus stations intervals below the standard. In terms of spatial accessibility, most public bus stations are well accessed, some stations were found to have large areas of overlaps, while some others with small overlap areas.

By investigating the spatial accessibility of bus stations along the Mexico to Hayahulet Road in Addis Ababa, this research aims to contribute to the development of a more efficient and inclusive public transportation network. The findings will serve as a basis for informed decision-making in urban planning and transportation policies, ultimately enhancing the overall quality of life for residents in Addis Ababa.

Recommendation

Based on the analysis results and findings, this study has forwarded the following recommendations.

- Solving the problem of GIS-based analysis on spatial accessibility of public transportation network is important for promoting equitable access to transportation, reducing traffic congestion, supporting economic development, and improving quality of life.
- Improving the physical infrastructure of bus stations, such as installing wheelchair ramps and improving lighting and signage.
- Increasing the frequency and coverage of public transportation services, particularly in areas with limited accessibility.
- Ensure that bus stops are accessible to people with disabilities by providing features such as ramps, accessible seating, and audio announcements.
- Improve pedestrian infrastructure, such as sidewalks, crosswalks, and pedestrian crossings, to ensure that they are safe and accessible for all users.
- An increase in service area coverage is typically correlated with an increase in the population that can be reached, according to the correlation analysis. However, service area coverage and population accessibility may not necessarily indicate a higher number of actual users. The actual number of users may be influenced by other factors, such as the quantity of people who use private and public vehicles and the type of land use.
- For public bus stations with small amount of service area coverage, an improvement in the density of road network is considered as one of the solutions. But I think it is more than enough to serve the population at the current time and to the near future.
- Plan bus routes that cover a wide area and provide convenient access to popular destinations, such as shopping centers, schools, and healthcare facilities.
- Provide real-time information on bus schedules, routes, and accessibility features to help users plan their trips and navigate the system.
- Ensure that public transportation is integrated with other modes of transportation, such as bike-share systems and ride-hailing services, to provide users with a seamless and accessible travel experience.
- Therefore, it is recommended that policymakers and urban planners should take into account the results of this study in their efforts to optimize bus stop locations, and hence, enhance

efficient and equitable transportation services. Further research should be conducted in other areas of the city to create a comprehensive view of public transport accessibility across Addis Ababa. As we advance in the digital age, GIS-based analysis should continue to be utilized as a crucial tool in the assessment and improvement of public transport systems.

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