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## **ANALYZING THE MOBILITY DIFFERENCES BETWEEN NEIGHBORHOODS IN ADDIS ABABA**

By

**TIGIST GETACHEW YENEALEM**

FEBRUARY, 2025

EiABC, AAU

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## **ANALYZING THE MOBILITY DIFFERENCES BETWEEN NEIGHBORHOODS IN ADDIS ABABA**

A Thesis Submitted to The School of Graduate Studies of Addis Ababa University,  
Ethiopian Institute of Architecture, Building Construction and City Development  
(EiABC), in partial fulfillment for Master's degree in Urban Planning.

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Addis Ababa, Ethiopia

This thesis is submitted to the Graduate Programs Director of the Ethiopian Institute of Architecture, Building Construction and City Development (EiABC), Addis Ababa University, in partial fulfilment of the requirements for the Masters of Science degree in Urban Planning.

Title of Thesis:

ANALYZING THE MOBILITY DIFFERENCES BETWEEN NEIGHBORHOODS IN  
ADDIS ABABA

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## DECLARATION

I declare that, this thesis prepared for the partial fulfilment of the requirements for the degree of Masters of Urban planning entitled “Analyzing the mobility differences between neighborhoods in Addis Ababa” is my original work, and it has not been submitted by any other person for an award of a degree in any other university or institutions and that all sources of materials used for the thesis have been fully acknowledged.

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February 2025

## Certification

Certification here with, we state that Tigist Getachew Yenealem has carried out this research work on the topic entitled “Analyzing the mobility differences between neighborhoods in Addis Ababa” under my supervision and it’s sufficient for defense.

Dr. Berhanu Woldetensae

Signature \_\_\_\_\_

Date \_\_\_\_\_

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Tigist Getachew Yenealem, February 2025.

## **ABSTRACT**

*Addis Ababa is one of the fastest growing cities in Africa and administrative and financial capital of Ethiopia. However, in Ethiopian cities, the rate of urban physical growth has exceeded the rate of infrastructure and service provision in addition the scarce availability of data in Ethiopia remains a major impediment to precisely analyzing urban mobility challenges. This study is unique in that it employs third-party travel time data and very little land-use information. The smallest administrative unit i.e. Woreda was chosen as a traffic analysis zone; as well as travel time and distance between zones was gathered using Quantum Geographic Information System travel time plugin. The mobility and accessibility conditions in different neighborhoods of Addis Ababa were calculated using the neighborhood mobility index based on the free flow travel time and the peak hour travel time index. In this study it was found that all neighborhoods were above the acceptable threshold of Neighborhood Mobility Index 1.5, which means residents in Addis Ababa travel an additional of 50% of the free flow travel time, and among these, Woredas in the Central Business District counter more congestion relative to Woredas in the peripheries. Although, it reveals that they enjoy far more access; are able to reach more than 75% of the destinations within 30 minutes. while as we go further from downtown people have to travel further for jobs, shopping and social interactions. Furthermore, distance by physical routes divided by straight line distance, which unlike the above two analysis, showed no particular relationship between living in the city core or outside. Apparently, zones next to each other share similar values and to some extent it is displayed that zones in the periphery had less direct roads because of the lack of transport infrastructure in these regions. Conclusively, the pragmatic finding indicate that whereas people living far away have to travel longer to access activity's, residents living in the center also have to counter more congestion. The study suggests that priority must be given to efficient land use, Infrastructure Improvements and public transportation.*

**Key words:** Addis Ababa, Congestion, Mobility, Neighborhoods, QGIS

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## **ACRONYMS AND ABBREVIATION**

A.A	Addis Ababa.
AACRA	Addis Ababa City Road Authority
AA-LRT	Addis Ababa Light Rail Transport
ANOVA	Analysis of Variance
API	Application Programming Interface
CAD	Computer Aided Design
CBD	Central Business District
CSS	Central Statistical Service
GCA	Greater Cairo Area
LOS	Level of Service
MI	Mobility Index
NMI	Neighborhood mobility index
TAZ	Traffic Analysis Zones
QGIS	Quantum Geographic Information System

## CHAPTER 1 INTRODUCTION

In this chapter the general concepts of transportation, Ethiopia's transportation background, the problem statement, objective of this research and research questions, scope and limitation of the research, and lastly organization of the document are included.

### 1.1 Background of the Study

The ultimate objective of transportation equity is to guarantee equal access to social and economic opportunities by ensuring fair levels of access for everyone to all locations (Savvides, 2013). It is concerned with the effectiveness of transportation, its price, and the degree of mobility of individuals (Randal et al., 2020). Equity in urban mobility for different neighborhoods within the city is a critical factor for social justice and sustainable development (ElDessouki, 2022). Mobility inequality can be defined as disadvantages to individuals and groups produced by unequal access to resources for physical accessibility as well as can be broken down into two main concepts of mobility in relation to accessibility and inequality in terms of socioeconomic imbalance and its effects (Ferreira et al. 2012 cited in Hidayati et al. 2021). It is an important factor for evaluating urban policy and transportation since it can assist reduce social exclusion and promote the public health and well-being of urban people (Jamei et al., 2022).

Mobility is the capacity of people and things to move freely, rapidly, and cheaply to their destinations at a predetermined target speed that either indicates free-flow or circumstances compatible with social objectives (Lomax.'et al', 1997 as cited in Schrank, 2001). Mobility is entwined with congestion and accessibility. Since an important component of measuring mobility is congestion, Congestion is the inability to reach a destination in a time and cost that are satisfactory to the traveler, when traffic is moving at speeds below the designed capacity of a roadway (Downs, 2004). Accessibility refers to the number of places or opportunities that may be reached in a certain amount of time from a particular (set of) place(s) (Hansen, 1959 ; Schrank, 2001). With this measure, the emphasis is shifted to the relationship between the transportation network and land use. However, access requires mobility. If it takes you a long time to get somewhere, there are

no secure options for transportation, and it's expensive, you don't have access because you lack mobility (Mobility lab, 2018).

The concept of mobility often bases travel measurements on some kind of travel time (e.g., real travel time, speed, or delay), with cost, modes, and number of trips serving as limiting factors (Schrank, 2001). The most used metrics for Traffic and Circulation are Average travel time, Congestion, Variation in travel time, Average traffic speed, Number of personal trips per day and Occupancy (Peralta-quirós, 2015). Measuring mobility using congestion as an indicator, one can compare the travel speed under crowded conditions to the travel speed in free flow conditions (Afrin and Yodo, 2020). Setting of a threshold that is directly related to travel speeds is most appropriate. This is in contrast to the traditional planning use of LOS, which compares volumes with capacity and does not explicitly account for speed (Suarez, 2009). Most measures require data that is hard to find in a developing country like Ethiopia, therefore the neighborhood mobility index was chosen as it uses minimum land use information and travel time from online sources (ElDessouki, 2022).

Urban mobility has become a critical issue in Ethiopia, In Ethiopian cities, the rate of physical growth of the urban area has outpaced the growth of the infrastructure and the provision of services (Asres, 2020). Addis Ababa is by far the strongest economy of all Ethiopian cities generating about a quarter of the national GDP (Gebre & Van Rooijen, 2009). Accounts for 25 percent of the urban population (World Bank, 2014). Total population as of 2024 estimated to be 4,030,000 with an annual growth rate of 4.4 percent (CSS, 2024). Urban growth, poor transportation infrastructure, a lack of strong administration, gaps in transportation laws and regulations, and natural terrain all have an impact on Addis Ababa's transportation system (Lerango, 2011). Even though Addis Ababa has a low rate of vehicle ownership compared to global standards (Desalegn & Solomon, 2020), people are moving more and more in that direction and Lack of proper road infrastructure contributes to these issues by causing traffic jams, car emissions, and accidents in the transportation systems (Asres, 2020). In the UTS (2004/2006) and Addis Ababa Traffic Management Final Inception Report (2011), there are six corridors mentioned that need immediate attention. Generally Two types of mismatch were

detected in Addis Ababa, showing that the peripheral areas lack road infrastructure and roads in the central areas carry more than their capacity (Ayalneh, 2012).

The city has set many goals over the years. According to the Federal Democratic Republic of Ethiopia Ministry of Transport in August 2011, the general objective of the Addis Ababa City Transport Policy is stated as; to provide safe, efficient, comfortable, affordable, reliable and accessible transport service for the urban dwellers (Transport policy of Addis Ababa., 2011). By 2020, the Addis Ababa City Transport Bureau hoped to see the city with a road network that meets standards, urban public transportation services, and road traffic safety comparable to that of middle-income nations (AACRTB, 2016). However, One of the primary obstacles to recognizing and accurately assessing issues related to urban mobility in Ethiopia is the limited availability of data (Sub Saharan Africa Transport Policy Programme, 2018). Studies are mostly done on a specific part of the city, such as (Teferi, 2020), (Asres, 2020), (Mena Kuleno et al., 2018), (Tadele et al., 2017), (Ayalneh, 2012), and (Haregewoin, 2008). On the plus side, the popularity of smartphones and internet has opened a lot of doors for researchers these days; to gather real-time travel information from online resources like Google Map. This research identified the mobility, accessibility conditions in different neighborhood of Addis Ababa using the QGIS travel time plugin, based on the free flow travel time and the peak hour travel time index. This study is unique in nature as it uses minimal land-use information and third-party travel time data.

## **1.2 Problem Statement**

With an estimated four million residents roughly 25% of the nation's total urban population and more than 10 times *Adama*, the second-largest urban center. Addis Ababa is one of Africa's fastest expanding cities (World Bank, 2014). While the overall car ownership is currently low, it nearly reflects the high car ownership rate trend in US cities for a particular income level (Street, 2011), with a total vehicle fleet estimated at 500,000, or 60% of the nation's fleet in 2015, Traffic congestion remains one of the city's largest problems (AARTB, 2016; Asres, 2020). Urban growth, poor transportation infrastructure, a lack of strong administration, gaps in transportation laws and regulations,

and natural terrain all have an impact on Addis Ababa's transportation system (Lerango, 2011).

Although equity issues are important in all cities, in wealthier ones, only a small portion of the population uses public transit; in many developing cities, however, the urban poor comprise the majority of the population (Gtz, 2010). Low income can affect mobility in developing economies by restricting access to necessities like work and education (Hidayati et al., 2021). Mobility equity assures that all members of the community have access to transportation and other urban services, it is crucial for urban planning. It promotes DE carbonization, social participation, spatial fairness, less traffic, safer roads, better infrastructure, easier access to services, and greater economic gains (Tammaru, Sevtsuk and Witlox, 2023).

In the UTS (2004/2006) and Addis Ababa Traffic Management Final Inception Report (2011), there are six corridors mentioned that need immediate attention. Two types of mismatch were detected in Addis Ababa, showing that the peripheral areas lack road infrastructure and roads in the central areas carry more than their capacity (Ayalneh, 2012). Since then, various efforts to improve transportation have been made as well as the completion of the Ethiopian light rail system. Even though much has been expected from AA-LRT to alleviate the transportation problems in Addis Ababa, its mobility share among other mass transport is only 6% and it is getting lesser every day (Ashenafi & Tekolla, 2015). There hasn't, however, been any recent comprehensive research in the entirety of Addis Ababa revealing which parts of the city require immediate attention and which have greater mobility. To make matters worse the scarce availability of data in Ethiopia remains a major impediment to identifying and precisely analyzing urban mobility challenges (Sub Saharan Africa Transport Policy Programme, 2018). In developing nations, the lack of subject matter specialists and technical planners makes the planning issue even worse, as do the ministries' limited cooperation and bureaucratic communication difficulties. Thus, usually the planning's accomplishment falls short of objectives for social equity and development (Agarwala, 1983 ; Rakodi, 2001 as cited in ElDessouki, 2022). This study used the QGIS travel time plugin to identify the accessibility and mobility conditions in several Addis Ababa neighborhoods, basing on

the free flow travel time and the peak hour travel time index. The study is distinctive in that it makes use of third-party travel time data and minimal land-use information to help develop an inclusive, unbiased, and trustworthy outcome.

### **1.3 Objective of Research**

#### *1.3.1 General objective of the research*

The aim of this research is to measure mobility and accessibility in different neighborhoods of Addis Ababa as well as to study the relationship with location.

#### *1.3.2 Specific objectives*

- To measure mobility of *Woredas* in Addis Ababa
- To measure accessibility of *Woredas* in Addis Ababa
- To examine the relationship between location in the city with mobility and accessibility
- To measure route directness in Addis Ababa

### **1.4 Research Questions**

- How much mobility is there in different *Woredas* of Addis Ababa?
- How much accessibility is there in different *Woredas* of Addis Ababa?
- What is the relationship of location with mobility and accessibility?
- How much Route directness is there in different *Woredas* of Addis Ababa?

### **1.5 Significance of the Study**

In order to determine the mobility and accessibility conditions in multiple Addis Ababa neighborhoods, the study used QGIS software which makes use of third-party trip time data and little land-use information to assist in creating an inclusive, objective, and reliable result that reflects the caliber of trips taken by Addis Ababa inhabitants. The findings of this study will help urban planners, offices like Addis Ababa City Road Authority and Addis Ababa city government plan and development commission by identifying mobility and accessibility situations of Addis Ababa's zones using congestion

as a mobility indicator and will enable them to tailor upcoming road network improvement initiatives and land use developments to solve those issues.

### **1.6 Scope of the Study**

The accessibility and mobility conditions in multiple Addis Ababa neighborhoods were identified through the use of the QGIS travel time plugin and using the neighborhood mobility index. The study covers all of Addis Ababa by breaking it down into different zones; the smallest administrative unit *Woreda* was chosen as a traffic analysis zone. The study focuses on road networks which in Addis Ababa case encompasses private vehicles and public buses as they all share the same road network.

### **1.7 Limitation of the Study**

The study excludes Addis Ababa light rail due to the size of the area we are investigating and the complexity of its design. In addition due to the lack of available information on socioeconomic data and the study area being large the study focuses only on mobility and accessibility in relation of location.

### **1.8 Organization of the Document**

The structure of the thesis is organized into five chapters. The first chapter is the introduction part; includes: background of the study, statement of the problem, research objectives, research questions, scope and limitation of the study and significance of the study. The second chapter, literature review; presents brief descriptions of the theoretical backgrounds and empirical evidence about the study. Basic concepts of mobility, accessibility and congestion with their respective measures, comparison of these measures and mobility in Addis Ababa are discussed. The third chapter; research methodology starts with the description of study area; briefly demonstrates research design and methods of analysis. The fourth chapter; called findings of the study presents research findings and discuss the results in relation to previous literature and research questions. The fifth chapter is conclusion and recommendation.

## CHAPTER 2 LITERATURE REVIEW

Urban mobility, accessibility and congestions are all intertwined with each other. One cannot achieve a comprehensive solution to transportation problems without analyzing these components. In this section we will discuss each briefly; mobility and accessibility, mobility measures, congestion and congestion measures, comparisons of congestion measures, mobility in Addis Ababa and trends to improve urban mobility and Accessibility are briefly discussed.

### **2.1 Mobility and Accessibility**

The movement of people or things is referred to as mobility. It is presumptively understood that "travel" refers to person or ton miles, and "trip" refers to person or freight vehicle trips. It is presumptive that any increase in travel distance or speed is advantageous to society (Litman, 2003). whereas Accessibility refers to the number of places or opportunities that may be reached in a certain amount of time from a particular (set of) place(s) (Schrank, 2001). Accessibility takes into account both land use patterns (where activities are located) and mobility (people's ability to move about). Traffic and mobility improvements, mobility replacements (such telecommuting and delivery services), and more accessible land use are all part of creating accessibility (Litman, 2003).

Accessibility is framed as the most sustainable approach compared with mobility but in recent years definition of mobility has been modified as a combination of many things. Sustainable urban mobility is a system that incorporates economic viability, environmental stability and social equity by meeting the needs of transport and land use of both current and future generation in an efficient manner (Kayal et al., 2012). The idea of accessibility heavily incorporates mobility. Three perspectives on accessibility exist: as an instrument of the effectiveness of mobility, of access to transportation, and of access to opportunities (Venter, 2017). Access requires mobility. Mobility is the availability and caliber of transportation alternatives. If it takes you a long time to get somewhere, there are no secure options for transportation, and it's expensive, you don't have access because you lack mobility (Fortunati, 2018).

This means that urban mobility is a means to ensuring an end, namely accessibility: citizens must reach destinations in order to satisfy their needs and access the locations of activities. Mobility must also be sustainable and account for technicalities as well as other means for achieving accessibility (J. Barceló, L. Montero, 2016). Equity in urban mobility for different neighborhoods within the city is a critical factor for social justice and sustainable development since all residents contribute through taxes to finance most of the urban transportation infrastructure projects (ElDessouki, 2022).

## 2.2 Urban Mobility in Developing Countries

The majority of the developing world is seeing a sharp decline in accessibility and mobility (Rodrigue, 2021). The fast rate of motorization, local demand conditions that greatly exceed facility capacity, the incompatibility of urban structure with expanded motorization, a stronger relationship between land use and transportation, inadequate road maintenance, and a lack of consensus among responsible officials regarding the best ways to address the issue are some of the issues that impact mobility and its improvement (Gakenheimer, 1999). In developing nations, generally cities have major transportation issues due to Fast urbanization, fast economic expansion and affluence, and fast motorization (World Bank, 2020).

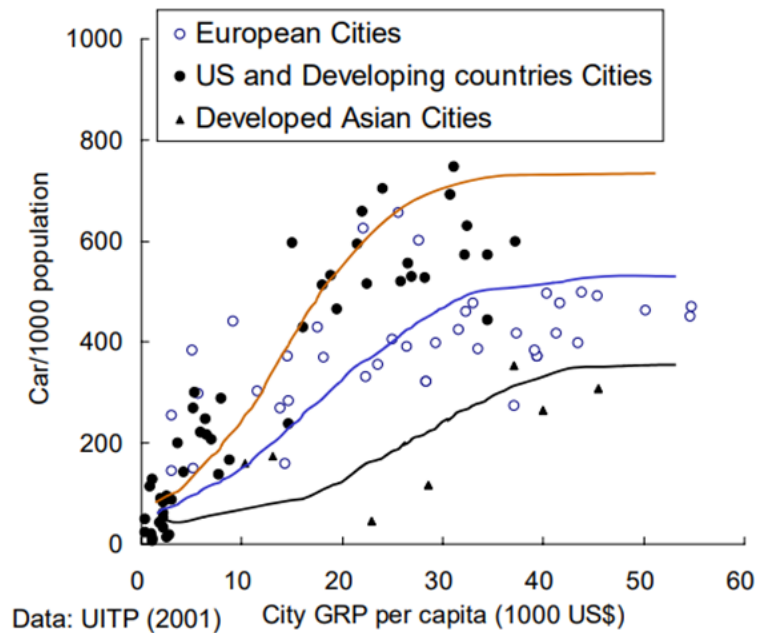


Figure 2-1 Car ownership vs Income level (Source: Street, 2011, P.4115)

Even though equity concerns are crucial in all cities, but in wealthy ones, public transportation systems that are utilized by a small percentage of the population; The urban poor, however, make up the bulk of the population in many developing cities (Gtz, 2010). Automobile travel is probably a major factor in the rise in per capita pass-km since income level and automobile ownership rate are positively connected. Even if the total rate of car ownership in developing cities is currently low, for a given income level, it roughly resembles the trend of US cities which is high car ownership rate. This suggests that if the current tendency continues, urban areas in developing countries are likely to emulate the mobility patterns of US cities (Gtz, 2010; Street, 2011) (Figure 2-1).

The pressure from motorization, which is producing a gradual fall in the modal share of public transport, is the main obstacle to sustainable mobility in developing nations. Since the service level provided by the public transportation system, which is mostly based on the conventional bus system, is insufficient to match that provided by private vehicles, the share of public transportation is certain to decline significantly as income levels rise (Street, 2011). For instance, between 2005 and 2015, public transportation's share in Africa fell from 74% to about 50% in Maseru. Because of this, traffic has gotten worse, particularly in the morning and afternoon, accidents have gone up, and pollution is now a big problem (World Bank, 2020). Denser and more populated cities are slower, partly due to congestion, especially around their cores, according to a study that compared 154 major Indian towns. greater uncongested mobility, worse congestion, and generally greater mobility are all associated with urban economic development (Akbar, 2018). A study on Greater Cairo evaluated the efficacy of transportation projects. The New Administrative Capital and the new urban satellite cities had good mobility, while the core of Cairo city had poor mobility on average. Notwithstanding these disadvantages, Cairo's central districts have relatively better accessibility due to their close proximity to significant urban centers (ElDessouki, 2022). Although fewer people in poor countries possess cars than in wealthy ones, this results in much higher traffic congestion and air pollution. As the population grows and motorization rises, the infrastructure and institutional capacities are being overextended (Jiang et al., 2008).

### 2.3 Measuring Mobility and Accessibility

In order to assess quantifiable and achievable goals that are closely related to the community's vision and objectives, performance metrics offer a data-driven methodology (Randal et al., 2020). Another, more specific reason to track travel patterns is to assess how well projects, programs, regulations, and other mechanisms intended to achieve community objectives are performing, either as intended or as actualized (JICA, 2008). Performance metrics are a useful tool for practitioners, planners, and policy makers to determine how best to meet a community's transportation needs in a cost effective way while ensuring that the general public benefits the most (Kayal et al., 2012).

Table 2-1 The most used metrics to measure mobility

PERSPECTIVE	METRIC
Traffic and Circulation	Average travel time Congestion Variation in travel time Average traffic speed Number of personal trips per day Occupancy

(Adapted from source: Braga et al., 2019, p. 13)

Mobility can be measured at the individual level or at area level: these are some of mobility measures at Area level, Area measures relate to an area, corridor, or region and how mobility conditions impact travelers at a large scale (Schrank, 2001).

**Total delay** is the sum of times lost due to congestion expressed in person or vehicle hours it identifies the congestion conditions of an area or segment (Lomax et al., 2005).

Total Segment Delay (person – minutes) =

$$\begin{aligned}
 & [actual\ travel\ time\ (m) - Free\ flow\ Travel\ Time(m)] * vehicle\ Volume \\
 & * Vehicle\ Occupancy
 \end{aligned}$$

Data elements;

- Actual Travel Time & Speed
- Free- Floww Travel time and speed
- Vehicle volume
- Vehicle occupancy
- Units ( person-hours)

**Delay per mile** is used to compare congestion levels across road segments of varying length in other words a measure of time an individual spends in traffic expressed in miles (Lomax et al., 2005).

Delay per mile (annual hours per mile) =

$$(Actual\ travel\ time(min) - free\ flow\ travel\ time(min)) \\ * vehicle\ volume(vihecles) * vehicle\ occupancy\left(\frac{person}{vehicle}\right) * (60min)$$

Data elements;

- Actual travel time and speed
- Free flow travel time and speed
- Vehicle volume
- Vehicle occupancy

Units and ranges;

- Person-hour per mile

**Access** is the ability to reach a destinationn within a time frame deemed acceptable, it is typically calculated for individuals as the number of travel objectives that can be reached with in an acceptable amount of travel time (Cascetta et al., 2013). Accessibility is a measure of the number of opportunities that can be reached in a given time. Most often, accessibility is expressed in terms of number of jobs reachable from a home origin in a certain amount of time. Different accessibility measures require their own formulas, including gravity, activity, counter and other measures (Schrack, 2001).

$$accessibility\ opportunities = \sum objective\ fulfillment\ opportunities$$

Where travel time  $\leq$  the acceptable travel time

Data elements;

- Travel time to destination
- Distance to destination
- Land use data
- Individual characteristics

Units & ranges

- Quality of destination opportunities

**Route directness** is an index measuring how direct an identified route is for various model commuters as opposed to actual distance between two points. It shows that how conducive surrounding land uses and infrastructure are to individual accessibility (Stangl, 2019).

$$Route\ directness = \frac{distance\ between\ origin\ and\ destination}{Actual\ distance\ by\ traveled\ road\ network}$$

Data elements

- Straight line distance between origin and destination
- Distance between origin and destination via infrastructural network
- distance

These measures may be less meaningful to individual travelers and their mobility choices, but concepts such as total delay, expressed in person- or vehicle-hours, allow for an analysis of mobility trends (Moran Toledo, 2011). The concepts of total delay, wasted fuel, congestion cost, congestion duration, and total travel time can be used to identify the total extent of a mobility issue or assess the impacts of major improvement projects to a corridor or region (UK Government, 2016). Expressing total delay across segments with a common denominator (e.g., delay per mile) allows for a direct comparison and ranking

of corridors or region. Area measures are especially adept in large policy and funding discussions and may be used for creating targets.

However, these measures on their own generally are not meaningful to the general public other than to show the relative magnitude or ranking of the issue (Schrank, 2001). These area measures should be used in conjunction with accessibility, connectivity, and other measures that create a more complete picture of regional transportation. It may be most helpful to use delay to identify mobility problem areas and then other area measures, accessibility measures, or connectivity measures to find and test solutions (Miller, 2018).

## **2.4 Congestion**

The main indicator of mobility is congestion. Congestion is the inability to reach a destination in a time and cost that are satisfactory to the traveler, when traffic is moving at speeds below the designed capacity of a roadway (Downs, 2004). According to the fundamental relationship of traffic flow, when the density on the highway is zero, the flow is also zero because there are no vehicles on the highway. As the density increases, so does the flow. However, when the density reaches its peak, also known as the jam density ( $k_j$ ), the flow becomes zero. since vehicles tend to line up end to end (Garber, N.J. and Hoel, 1996). Traffic congestion wastes time and energy, causes pollution and stress, decreases productivity and imposes costs on society. There are two principal categories of causes of congestion, and they are; (a) micro-level factors (e.g. relate to traffic on the road) and macro-level factors that relate to overall demand for road use. The micro level factors are, for example, many people and freight want to move at the same time, too many vehicles for limited road space. On the other side, macro level factors e.g. land-use patterns, employment patterns, income levels, car ownership trends, infrastructure investment, regional economic dynamics, etc. also may lead to congestion (Mohan Rao & Ramachandra Rao, 2012).

There are variety of causes for congestions, The demand for transport is “derived”: journeys are usually made due to the need to travel to the places where various kinds of activities are carried on, such as work, shopping, studies, recreation, relaxation, etc. (Suarez, 2009). consequently The demand for transport is marked by peak periods in

which a large number of journeys are concentrated and Transport takes place in limited road spaces, and the forms of transport which have the most desirable characteristics (private car users) are those which use the most road space per passenger (Heyns, 2015). Moreover urban road networks: design and maintenance problems, some driving habits and insufficient information on traffic conditions make congestion worse. There is also an institutional problem consequence of decisions taken without coordination and without considering their broader repercussions (Chaudhary et al., 2020).

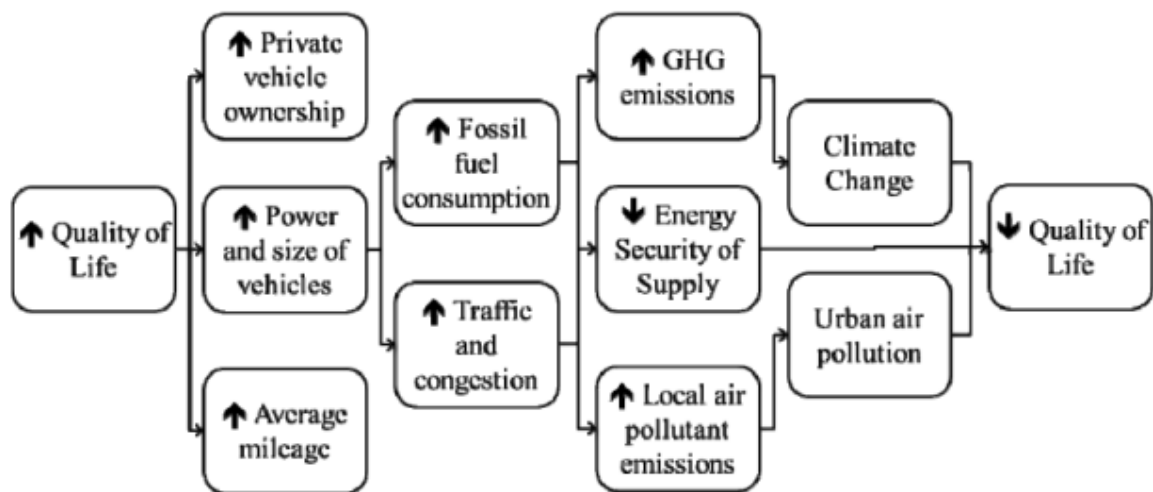


Figure 2-2 The vicious circle of public and private transportation modes (source: O ET AL., 2013, p.21)

On the surface, congestion is the problem of too many cars with insufficient roads or fast growing numbers of commuters outpacing the provision of competitive public transport. Deep down, it is the problem of inefficient land use patterns that segregate the close relationship between living, consumption and production space (Wen et al., 2019). It is now required of policy makers to adopt a transport planning systems approach, which goes beyond implementing a single TDM measure or a few measures piecemeal (Heyns, 2015). Developing integrated strategies specifically aimed at reducing road-based traffic congestion is no longer an option in LUM and transport planning. Implementing a balanced set of policies that address supply, demand, and LUM measures as part of a methodical process is essential to controlling traffic congestion (Chaudhary et al., 2020). (Figure 2-2)

## 2.5 Measuring congestion

The general definition of congestion is an excess of demand for driving. There is not enough road travel infrastructure available to meet demand levels at a given service level. Travel speeds decrease as a result, and delays are clarified (Wang & Debbage, 2021). Congestion can be quantified in a variety of ways, according to this broad definition. To evaluate the degree of congestion, one can consider average speed, flow/density, delay, and variability in journey time. Parameters Used to Measure vehicle traffic is listed in table 5, this table summarizes units commonly used to measure vehicle traffic.

Table 2-2 Units commonly used to measure vehicle traffic

Parameter	Typical Units	Reciprocal	Typical Units
Flow	Vehicles per hour (Veh/h)	Headway	Seconds per vehicle (s/veh)
Speed	Kilometers per hour (Km/h)	Travel time	Seconds per km (s/km)
Density	Vehicles per lane- km (veh/lane-km)	Spacing	Meters per vehicle (m/veh)

(Source: Wwww.vtppi.org, 2020, p. 3)

### 2.5.1 Congestion Indicators

When it comes to measuring congestion, there are two main methods: the operational method, which is preferred by those in charge of building and maintaining road networks, and the economic method, which is typically used to rank public transportation spending accordingly (Thomson & Bull, 2006). The former usually focuses on the performance of the roadway that can be seen (speed, flow, density, queue length and duration), (Aftabuzzaman, 2007) The latter has generally concerned with converting physical measurements into monetary values. There are three main ways that these indicators are actually derived: temporal/speed indicators that are extrapolated or derived from the former (such as link travel time and delay), spatial indicators (such as density, queue length, congested lane kilometers, etc.), or measurements related to points (such as vehicle count and flow) (see Table 2-1).

Table 2-3 Indicators of congestion

Indicator	Description	Notes
1. Speed Based Indicators		
Average Traffic Speed	Average speed of vehicle trips for network	Does not adequately capture congestion effects
Peak Hour traffic speed	Average speeds of vehicle trips during peak hours	Can serve as a benchmark for reliability measures based on actual average or median speeds
2. Temporal/Delay-based indicators		
Annual Hours Of Delay	Hours of extra travel time due to congestion	All delay-based indicators depend on a baseline value for calculating the start of “delayed” travel when this baseline is free-flow speed, the term “delay” becomes misleading since it is not at all clear that travelers on the network would ever be able to achieve delay-free speeds at peak hours.
Annual Delay Per Capita	Hours of extra travel time divided by area population	
Annual Delay Per Road User	Annual Delay Per Road User	
Average Commute Travel Time	Average commute trip time	
Estimated Travel Time	Estimated travel time on a roadway link (used in conjunction with variable message signs)	
Congested Time	Estimate of how long congested “rush hour” conditions exist	

Delay per road kilometer	Difference between reference travel time and congested travel time per network kilometer	
Travel Time In Congestion Index	Percentage of peak-period vehicle or person travel that occurs under congested conditions Travel	The use of the travel time index and the travel time rate also depend on the identification of a baseline value for signaling the start of congested conditions
Travel Time Index	The ratio of peak period to free-flow travel times, considering both reoccurring and incident delays (e.g., traffic crashes).	when this value is based on free flow speeds, the same reservation as noted for other “delay” type indicators holds
<b>3. Spatial Indicators</b>		
Congested Lane Miles/kms	The number of peak-period lane miles/kms that have congested travel	Spatial indicators also depend on threshold values. These may be based on the median/average speeds typically achieved or on free-flow speeds (see note above)
Congested Road Miles/kms	Portion of roadway miles/kms that are congested during peak periods	
Network Connectivity Index	An index that accounts for the number of nodes and interchanges within a roadway network	This is an indicator of the potential for congestion to arise, whether or not this potential is realized depends on a number of other factors
<b>4. Service level/capacity indicator</b>		
Roadway Level Of Service (LOS)	Intensity of congestion delays on a	These indicators have had the favor of roadway

	Particular roadway or at an intersection, rated from A (uncongested) to F (extremely Congested).	managers. They typically reference the design capacity of a roadway and are typically implicitly used to maximize throughput up to the design capacity of the roadway link in question.
Roadway Saturation Index	Ration of observed flow to design capacity of roadway	
5. Reliability Indicators		
Buffer time Index	See planning time index below	These indicators try to capture how road users typically make trip decisions on congested networks they explicitly take into account the importance to many users of making trips “on time” rather than simply making trips at a high rate of speed
Congestion Variability Index	An index relating the variability of travel speeds on the network	
Planning time index	An index that accounts for a time buffer that allows an on time arrival for 95% of trips on a network	
Mean vs. variance travel times		
Distribution of travel times: Measure of the difference between Percentile - mean		
6. Economic cost/efficiency indicators		
Annual Congestion Costs	Hours of extra travel time (generated by travel below reference speed) multiplied by a travel time value, plus the value of additional fuel	As noted above, the selection of free-flow speeds when trying to account for “congestion costs” is highly problematic

	consumption. This is a monetized congestion cost.	
Current marginal external congestion costs	The additional external costs (not borne by users) of every additional vehicle/use entering the network	
Total deadweight loss	The sum total of the overall losses (costs benefits) incurred for a given level of use/traffic	
Average deadweight loss per vehicle/km	The dead weight loss divided by the Number of vehicles/km giving rise to that loss.	
7. Other indicators		
Congestion Burden	The exposure of a population to congested road conditions (accounts for availability and use of alternatives)	
Excess Fuel Consumption	Total additional fuel consumption due to congestion	Again, determining the point of reference for “additional” fuel consumption can be problematic if based on free-flow speeds
Excess Fuel Consumption Per Capita	Additional fuel consumption divided by area population	

(Source: World Bank, 2011)

Speed Based Indicators; Peak Hour traffic speed and Temporal/Delay-based indicators; Travel Time Index are more aligned with the objective of these research, since we are measuring congestion intensity in a large area and the we have limited information.

### *2.5.2 Comparison of congestion measures*

Congestion is caused by a reduction in speed, which is the primary cause of time loss and leads to increased vehicle operating costs, fuel consumption, and emissions of air pollutants and greenhouse gases (GHGs). Consequently, it makes the most sense to define a threshold that is directly correlated with trip speeds (Suarez, 2009). This contrasts with the conventional use of LOS in planning, which does not specifically take speed into consideration and instead compares volumes with capacity (Heyns, 2015). A speed-based threshold account for more of the impacts of congestion than would a threshold based on capacity. Given that traffic speed is a very sensitive characteristic that is directly related to vehicle operating costs and road user safety, speed-based congestion measurement criteria can be implemented. This metric can easily measure using a variety of affordable methods that are ideal for developing nations (Mohan Rao & Ramachandra Rao, 2012). It is clear that any congestion metric does not fulfil all of the assessment criteria, a range of features have been suggested for a measure of congestion (Afrin & Yodo, 2020).

### *Travel time and delay measures*

Advantages of Time based congestion measures provide guidance on identifying major issues, enabling policy makers to better address problems within the state and solutions that are most likely to have the greatest impact(Mohan Rao & Ramachandra Rao, 2012).Travel time index has the advantage of expressing traffic congestion in terms of both space and time. It is easy for public to understand the main concept of this index(Muhammad Ali & Faraj, 2013).

On the contrary the time-based measures of congestion provided a stronger basis for more generalized conclusions(Www.vtpi.org, 2020). Travel time measures do not comprise the finer traffic events; it is not responsive to exceptional conditions related to climate events, accidents or construction activity interferences. The use of ratio measures

is limited for a particular road type or facility and the value cannot be used effectively for a geographic area. Congested travel or congested roadway length does not represent the different magnitude of congestion. Travel time index requires separation of recurring and incident delay. Measurement of non-recurring data can be difficult. The use of ratio measures is limited for a particular road type or facility and the value cannot be used effectively for geographic area.

### *Volume and LOS measures*

These measures are Comprehensible by most non-technical audiences(Mena Kuleno et al., 2018). This is the representative variable in traffic flow analysis. It is widely used because it is very easy to collect this data in the field.

The disadvantages of this measure are LOS cannot provide a continuous range of values of congestion and these methods provide no distinctions between different conditions are reached. Byrne and Mulhall (1995) questioned level of service analysis a measure of congestion because it only depicts place -specific congestion phenomenon and does not reflect overall or regional congestion situation. The use of a stepwise LOS measure can occasionally be deceptive, according to Hamad and Kikuchi (2002), particularly when the situation is close to a threshold. One limitation of the Lane-Mile Duration Index is its inability to capture the impact of various highway functions on traffic congestion.

### *Speed measures*

Travel speed is closely linked measure that can be used to illustrate the reduction in mobility people feel during congestion. To determine how bad the congestion is, one can compare the travel speed under crowded conditions to the travel speed in free flow conditions (Afrin & Yodo, 2020). Measuring the decreased travel speeds over time can also be used to estimate how long the congestion will last. The model forecast data makes it rather easy to determine travel speed, while field surveys allow for firsthand observation of the speed (Bertini, 2005). Congestion is a function of reduction in speeds, Therefore, the setting of a thresh old that is directly related to travel speeds is most appropriate. This is in contrast to the traditional planning use of LOS, which compares volumes with capacity and does not explicitly account for speed (Suarez, 2009). A speed

based threshold account for more of the impacts of congestion than would a threshold based on capacity. Data collection using latest technology like GPS which is effective and economical technology can be applied and these data easy integrated with Geographical Information System. This data may be summarized at any analysis level desired: link, corridor or region wide. Although, the use of a range of speed for entire study area reflects the lack of consensus among urban areas as to the appropriate threshold, which reflects local conditions, also Result is relative to free flow speed, which is difficult for motorist to comprehend (Suarez, 2009).

As we discussed earlier speed indicators are more reflective of the congestion intensity, are easy to interpret also the information needed for these measure is easily available from online sources like google maps and Bing maps large data otherwise impossible to collect can be gathered through these technologies. Because we are analyzing a large area (Addis Ababa) field observation and collection of data is almost impossible.

## **2.6 Mobility in Addis Ababa**

To address growing congestion, public authorities made significant investments in the capital city of Addis Ababa over the past ten years. An LRT was built, and partnerships with significant donors were formed to enhance bus services, make investments in traffic management and infrastructure, and create a BRT system. The city spends over US\$260 million annually on new road construction, which accounts for more than 35% of its annual capital budget, while only about US\$6 million is allocated to maintenance and insufficient money is being invested in traffic management (Sub Saharan Africa Transport Policy Programme, 2018). Even though much has been expected from AA-LRT to alleviate the transportation problems in Addis Ababa, its mobility share among other mass transport is only 6% and it is getting lesser every day (Ashenafi & Tekolla, 2015). There hasn't, however, been any recent comprehensive research revealing which parts of the city require immediate attention and which have greater mobility.

There are six corridors mentioned In Addis Ababa Traffic Management Final Inception Report (2011) and the UTS (2004/2006), that need immediate attention. These are; Ayat – CMC – Megenagna – Laghar – Mexico – TorHailoch (the East-West corridor), Urael –

Grand Palace – Shiro Meda , Kaliti – Meskel Square– Laghar – Piassa (using Debre Zeit and Churchill roads, North-South corridor), Menelik Square – Kolfe, Wingate – Abune Petros and Mexico Square – Mekanissa. In addition to these more corridors were identified later in research. The results of these indicators show that there is indeed mismatch within the current road network of the city. Two types of mismatch were detected in the city, showing that the peripheral areas lack road infrastructure and roads in the central areas carry more than their capacity (Ayalneh, 2012). In the study “Evaluating Transport Network Structure: Case Study in Addis Ababa”, it can be observed that total trip production ranges from 1433 in zone 110 to 57817 in zone 89 Whereas Trip attraction level ranges from 1903 in zone 110 to 146177 in zone 35. Zones 35 and 26 (locally known as Merkato and Piazza) have high trip attraction values as they are main business centers of the city. The variety of trip attraction values is far greater than production. This demonstrates that the activities responsible for attraction levels, primarily jobs and shopping malls, are concentrated in the Central Business District around the city's core and surrounding areas.

Also trips passing through each zone higher values can be observed in the central areas. As one gets toward the periphery, these values decline because of their remoteness and low demand. Zone 35, sometimes referred to as Merkato locally, has the highest value for the Euclidian-based travels. This area, which has a high population density and plenty of job opportunities, is the city's primary business district. Zone one, sometimes referred to as Bole locally, has the highest value among the network-based journeys (Ayalneh, 2012). Generally zone which belongs to the CBD has the highest values as many OD pairs pass through this zone.

Similarly the mobility index was computed, for an ideal network, the MI value should be one, but since this cannot be achieved we need to have some tolerable value. According to this analysis, 74% of the total OD pairs have an MI value of less than 1.41. Figure6 shows the plot of the MI in all the zones where higher values are observed in the peripheral areas (Ayalneh, 2012). This indicates that even if the zone centers are close to one another, passengers must travel farther to reach their destination because of the network's inefficient cross-shaped topology.

The mobility index formula is given below:

Mobility Index(MI)

$$= \frac{\textit{travel distance by physical route from origion to destination}}{\textit{travel distance by staight line distance}}$$

Despite the fact that there is a lack of studies comparing the level of mobility over the entirety of Addis Ababa, studies have been conducted in a number of the city's busiest neighborhoods. According to a study done on the busiest intersections of Addis Ababa Abem, St. Mikael, and Ethio-China, there is heavy traffic congestion at all three throughout the morning and evening rush hours, particularly in the morning. In comparison to other intersections, the Ethio-China intersection has a large volume of traffic. Total congestion costs are about \$ 44,748.1 \$ 47,823.4 and \$76,949 \$ for Abem, St. Mikael and Ethio-China intersection respectively. The following factors have been linked to traffic congestion: Lack of effective mass transit, an imbalance between traffic volume and road capacity, traffic diversion, inadequate traffic control, a difficulty with population growth, as well as on-street parking (Engdasew, 2021). Another study on the congested areas of Megenagna Diaspora and Lamberat Semen Bus Terminal shows that the annual total cost of traffic congestion for the Megenagna Diaspora intersections (roundabout) in 2020 was 1,033,292.87 and the annual total cost for the Lamberat Semen Bus Terminal intersection was 899,757.40 ETB (Teferi, 2020).

Relationship that exists between mobility and income levels in variables such as the possession of mobility assets, trip generation rates and differentiated use of modes of transport, trends that seem to be common to most urban contexts, including European cities. (Peralta-quirós, 2015) However, a study in Buenos Aires Metropolitan Region shows, other quantitative variables seem to be more closely related to the urban structure than to income levels and thus encourage an analysis based on the identification of different territories, according to their inclusionary potential (Blanco & Apaolaza, 2018).

The unplanned and uncontrolled urbanization is resulting urban physical growth rate that is faster than the rise in infrastructures and service delivery in Ethiopian cities including the problem of traffic congestion, which is closely related to these unplanned expansions

of the city (Asres, 2020). The main aspects that cause traffic congestion in the suburban area are the increase in car use, urban sprawl and fixed work hours (Cullen, 2019).

In 2016 the total vehicle in Addis Ababa by category was comprised of 233,672 commercial vehicles, 175,290 private vehicles, 24,654 governmental vehicles, 20,913 taxi, 12,847 loan company's vehicles, 3,901 buses and so on. From this data we can see that we have extremely higher number of vehicles with low occupancy and taking a lot of space (i.e. mini buses and private vehicles) than that of higher occupancy like public mass transports like buses (Lerango, 2011). In addition The road coverage in Addis Ababa is about 7% of the total land use of the city, which is below the standards 20-30%. To achieve the standard road coverage, construction of new roads and up grading the existing gravel and earth coated roads are required by allocating more financial resources and by developing a rational master plan (Asres, 2020).

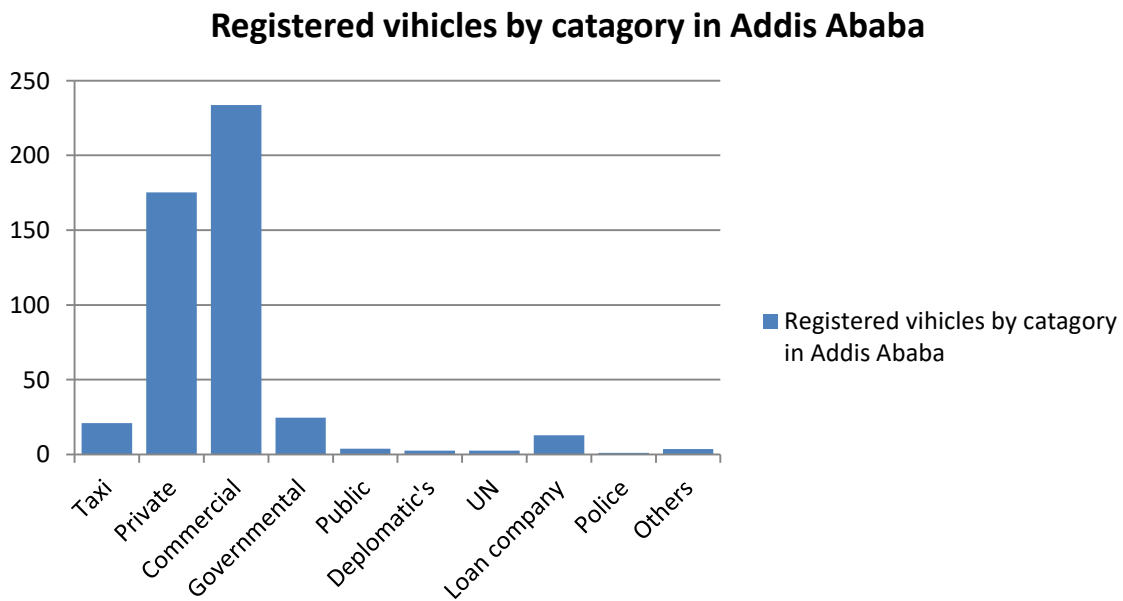


Figure 2-3 Registered vehicles by category in Addis Ababa (adapted from (source: Asres, 2020))

Not only the urban sprawl and car use development have contributed to traffic congestion. It is also caused by peak hour traffic due to fixed work hours. Working hours vary starting between 7 a.m. and 9 a.m. and finishing between 4 p.m. and 6 p.m. Therefore, traffic peak hours usually occur during this time frame (Altmann,2019 as cited

in Cullen, 2019). It can therefore be assumed that roads are under occupied outside and over occupied within these hours, this leads to traffic congestion during peak hours. In Addis Ababa, Monday and Friday have high traffic variation from the normal weekdays of Tuesday, Wednesday, Thursday, and Weekends (Saturday and Sunday) have low traffic volume. Period recording traffic data was generally classified in three classes according to (Teferi, 2020) such as:

- A. Morning Peak Period: it includes the time from 07:00 - 10:00 AM,
- B. Inter-peak Period or Mid-day period: the lowest traffic volume which includes from 11:00 AM - 02:00 PM and
- C. Evening Peak Period: includes from 04:30 PM - 07:30 PM.

However, the scarce availability of data in Ethiopia remains a major impediment to identifying and precisely analyzing urban mobility challenges (Sub Saharan Africa Transport Policy Programme, 2018). This leads towards the use of a measure that requires minimal land-use information and utilizes online third-party travel-time data. A recent study developed a neighborhood mobility index (NMI) that expresses the relative congestion encountered by residents in each neighborhood during their daily trips to work or school with low dependency on data, where it needs minimal land-use information and third-party travel time data. The fundamental principles of the index are the ratio between the peak-hour travel time and the free-flow travel time for the routes connecting an origin to key attractors in the city (ElDessouki, 2022). Another larger study that measured vehicular mobility within cities by decomposing it into uncongested mobility and a congestion factor and Applied it using novel large scale data on counterfactual trips in 154 Indian cities collected from Google Maps was able to compare and contrast mobility disparities between cities of India (Akbar, 2018). These studies pave the way for the use of technology in our research, particularly in situations when data is hard to come by in impoverished nations like Ethiopia.

## **2.7 Elements of Transportation Analysis**

In this section key elements and definitions of some of the transportation terms which are relevant to this study are discussed.

### 2.7.1. Trips

One of the major components of assessing traffic flow is trip. According to the four steps planning book Trip is defined as a one way person movement by a mechanized mode of transport. General has two trip ends (Weisbrod, et al, 2001).

1. Origin – the starting point of a trip
2. Destination – the end point of a trip

Most trip productions originate from home and end non home points (trip attractions).there are four types of trips according to trip purpose (Transportation Land-Use Modeling & Policy, 2022).

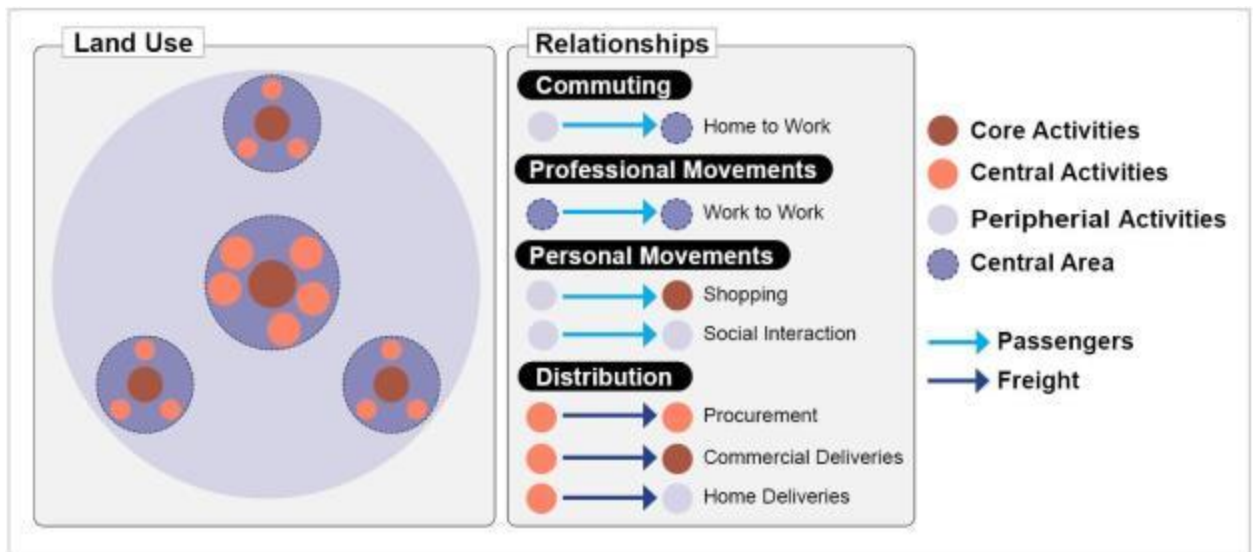


Figure 2-4 Relationships between land use and various trip purposes (source: Rodrigue, 2020, p. 327)

1. Commuting is the first and most common kind of travel that occurs primarily between residential areas and CBDs (workplaces) and is important for land use and transportation modeling.
2. The second type of mobility pattern is called professional movements. It mainly concerns work-based movements between workplaces within central areas or clusters.
3. Personal movements include various activities such as social gatherings, leisure trips, and shopping trips.

4. Distribution is the last category, in which freight movement and distribution are the main goals of such trip generations. Online shopping, deliveries, and distributing raw materials to manufacturing clusters are among the different activities in this category.

#### *2.7.2. Traffic Analysis zones*

Traffic Analysis zones are geographic areas dividing a region into relatively similar areas of land use and land activity to make mobility analysis easier because analyzing each individual block while dealing with a large area might be time taking and impossible (Miller & Ph, 2021).

- TAZ's represent origins and destinations
- While creating TAZ roadway networks, physical geography and administrative boundaries should be considered
- TAZ's are then simplified to a single node called centroid

#### *2.7.3. Centroids*

Centroids are points that identify the center of activity within a zone and connect that zone to the transport network. The goal is to locate the centroid to best represent the average trip time in and out of the TAZ (Meyer, 2016).

#### *2.7.4. The Gravity model*

They are the most common method appropriate for trip distribution, easy to understand and accurate. One can add population, employment, socio- demographic and transportation systems (Transportation Land-Use Modeling & Policy, 2022).

The level of attractiveness of a zone depends on

- Uniqueness (regardless of distance)
- Distance between the zones
- Closeness to other services
- Urban or rural

The gravity model is based on Newton law of Gravitation, Attraction is directly proportional to mass (population) and inversely proportional to distance.

$$T_{ij} = P_i \left[ \frac{(A_j F_{ij} K_{ij})}{(\sum_t A_j F_{ij} K_{ij})} \right]$$

Where:

- $T_{ij}$  = number of trips that are produced in zone i and attracted to zone j
- $P_i$  = total number of trips produced in zone i
- $A_j$  = number of trips attracted to zone j
- $F_{ij}$  = a value which is an inverse function of travel time
- $K_{ij}$  = socioeconomic adjustment factor for interchange

## **2.8 Trends to Improve Urban Mobility and Accessibility Equity**

Here are some ways that legislators and urban planners can make cities more accessible, sustainable, and enjoyable. The secret is to customize these tactics to each city's particular needs and issues rather than offering universally applicable solutions (Salazar-Ferro et al., 2023).

**Development of Multi polarity:** Creating various hubs of activity and commerce is the idea behind multipolarity in cities. This approach spreads out urban functions, which lessens traffic congestion and the need for lengthy commutes (Salazar-Ferro et al., 2023).

**Densification:** In addition to optimizing land use, promoting denser urban development in certain locations encourages effective public transit and active mobility alternatives (Tammaru et al., 2023).

**Higher Capacity Public Transport:** By making investments in strong public transportation systems with larger capacity cars, more people will be able to travel conveniently throughout the city, which will lessen the need for private vehicles (Gtz, 2010).

**Non-motorized Mobility Improvements:** By establishing bike and pedestrian-friendly spaces in strategic areas of the city, people are encouraged to walk or ride their bikes, which lowers the need for automobile transportation overall (Randal et al., 2020).

**Transit-Oriented Development (TOD):** The goal of TOD is to build thriving, mixed-use communities around public transportation hubs. It provides incentives for people to live, work, and play close to transportation hubs (Gtz, 2010).

**The 15-Minute City:** This innovative idea imagines cities where people may walk or ride their bikes within 15 minutes of their residences to access the majority of their daily necessities, such as employment, shopping, and leisure (Tammaru et al., 2023)..

**The 20-Minute Neighborhood:** Like the 15-minute city, the 20-minute neighborhood seeks to further eliminate the need for long commutes by putting necessary services and amenities within a 20-minute radius (Calvert, 2021).

There are a number of methods that work together to address problems rather than just one. Solution like compact development would reduce travel time by densification of activities in one place, and non-motorized approaches make short trips easier while they decrease our carbon emission which is good for the environment. Mass transits are also major solution that we should look into, which decreases private ownership of vehicles and increase vehicles occupancy.

## **2.9 Lessons Learned from Literature**

Transportation is dynamic and keeps changing according to population and economic growth, public and private decision, market and governmental actions. Urban mobility has a huge impact on the urban economy, as well as the well-being of individuals. Even though Mobility and accessibility has different definitions, one significantly impacts the other. If you don't have mobility you don't have access and vice versa.

Performance metrics are a useful tool for practitioners, planners, and policy makers to determine how best to meet a community's transportation needs, the most used travel metrics to measure traffic and circulation are Average travel time, Congestion, Variation in travel time, Average traffic speed, Number of personal trips per day and Occupancy. In

addition Mobility can be measured at the individual level or at area level: this study will be focused on area level measures (Schrank, 2001).

Congestion is the main indicator of mobility. Land-use patterns, employment patterns, income levels, car ownership trends, infrastructure investment, regional economic dynamics and fixed working hours all have an impact on congestion. Despite some efforts by the government, congestion is remains one of the big problems in Addis Ababa. Commonly used congestion parameters include flow (Vehicles per hour (Veh/h), speed (Kilometers per hour (Km/h) and Density (Vehicles per lane-km (veh/lane-km). speed indicators are more reflective of the congestion intensity, are easy to interpret also the information needed for these measure is easily available from online sources like google maps and Bing maps large data otherwise impossible to collect can be gathered through these technologies.

For a developing country like Ethiopia, information is hard to come by; especially for this big of a sample size. So carefully selecting congestion measures is necessary. For these reasons we can't afford to waste our limited fund which makes a study like this crucial. A speed based threshold account for more of the impacts of congestion than would a threshold based on capacity. Data collection using latest technology like GPS which is effective and economical technology can be applied and these data easy integrated with Geographical Information System.

## **2.10 Research Gap**

Previous Studies, such as (Teferi, 2020), (Asres, 2020), (Mena Kuleno et al., 2018), (Tadele, Advisor and Teklu, 2017), (Ayalneh, 2012), (Haregewoin, 2008) are done on traffic congestion, rarely in the whole Addis Ababa, most of them are studied on a specific part of the city. However there is no recent study which compared and contrasted the mobility and accessibility differences between communities as a whole and studied the relationship with location. In previous traditional methods it was difficult to investigate this large size of study area and as well very difficult to gather this much data, but in this study by leveraging the advancement of technology and the popularity of smart phones, it's possible to gather data from online sources.

## CHAPTER 3 RESEARCH METHODOLOGY

### 3.1 Study Area

Addis Ababa is geographically located at the heart of the nation, 9°2'N latitude and 38°45'E longitude. Its average altitude is 2,400 meter above sea level, occupying a total of 540 sq. km land area surrounded by mountainous landscape. Addis Ababa serves as social, economic and political center, holding 65% of industries of the country (G. Gebre & D Van Rooijen, 2009).

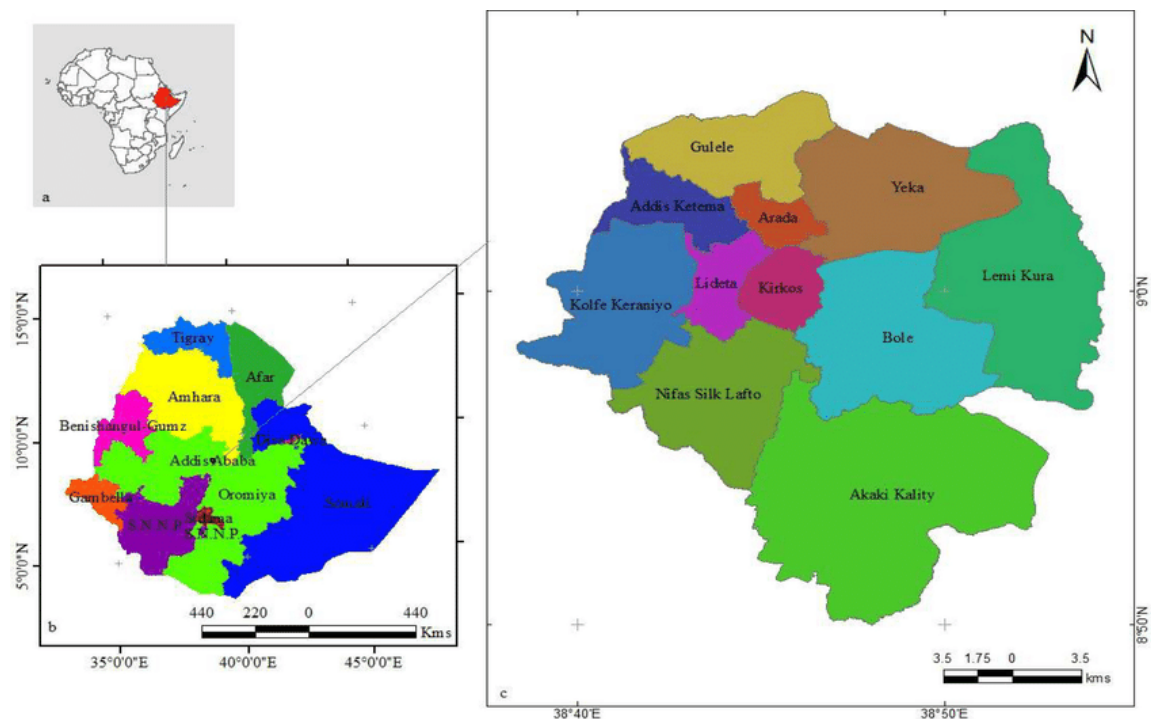


Figure 3-1 Addis Ababa Location Map (source: Ayele et al., 2022, p.88)

It is a seat for African Union, United Nations Economic Commission for Africa, and other international organizations. The city is divided into 11 sub-cities and 116 *Woredas*, which are the lowest administrative units (Shiferraw, 2022). Addis Ababa accounts for 25 percent of the urban population, with The remainder roughly evenly split between the medium-sized cities of 20,000 – 500,000, and small cities of under 20,000 people (World Bank, 2014). Total population as of 2024 estimated to be 4,030,000 with an annual growth rate of 4.4 percent (CSS, 2024).

Urban growth, poor transportation infrastructure, a lack of strong administration, gaps in transportation laws and regulations, and natural terrain all have an impact on Addis Ababa's transportation system (Lerango, 2011). Even though Addis Ababa has a low rate of vehicle ownership compared to global standards, people are moving more and more in that direction; as well as Lack of proper road infrastructure contributes to these issues by causing traffic jams, car emissions, and accidents in the transportation systems (Asres, 2020). The following factors have been linked to traffic congestion: Lack of effective mass transit, an imbalance between traffic volume and road capacity, traffic diversion, inadequate traffic control, a difficulty with population growth, as well as on-street parking (Engdasew, 2021).

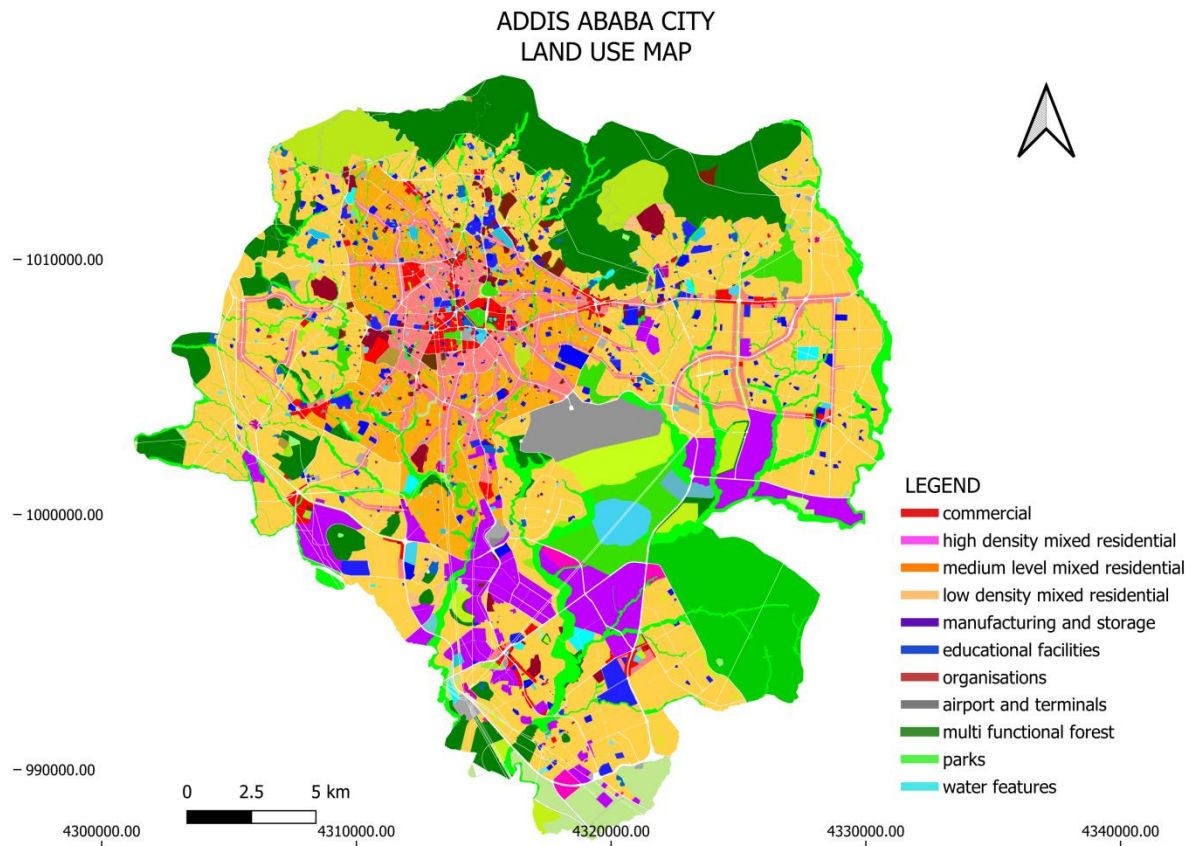


Figure 3-2 Land use map of Addis Ababa (Source: Addis Ababa City Roads Authority, 2010)

Most commercial centers are around the CBD, accompanied by high density and medium density mixed residential area. As we go further away from the city center mainly low

density mixed residential, industries and green lands are found (Figure 3-2). In addition According to Urban Transport Study (2004/2006) the availability of road is poor. The share of roads in land use pattern is low at about 7% where as an efficient system needs 20 to 25%. The road network also suffers from inadequacies like absence of balanced hierarchy, capacity limitation and low connectivity (Ethiopian Roads Authority, 2004/2006). The city is divided into 11 sub-cities called kifle-ketemas and 116 Woredas, which are the lowest administrative units (Shiferraw, 2022)( Figure 3-3). Total population as of August 2019 estimated to be 4,592,000 with an annual growth rate of 4.4 percent (CSA, 2019).

Table 3-1 Population Size of Addis Ababa, Area and Density by Sub City

Sub city	2010 pop	2024 pop	Area sq./km	Density (2010)	Density (2024)
Central Area Total			41.12	23,052	31,832.9
Lideta	214,796	296,724	9.18	23,398	32,322.8
Kirkos	235,441	325,502	14.62	16,104	22,264
Arada	225,999	311,175	9.91	22,805	31,400
Addis Ketema	271,444	375,568	7.41	36,659	50,683
Peripheral Area total			485.87	4,053	5,600.3
Akaki Kality	195,273	266,587	118.08	1,654	2,257.7
Nifas Silk	335,740	465,317	68.3	4,916	6,812.8
Kolfe keraniyo	456,219	630,826	61.25	7,448	9,818
Gulele	284,865	393,631	30.18	9,439	13,042.7
Yeka	368,418	510,064	85.98	4,285	5,932.4
Bole	328,900	454,605	122.08	2,694	3,723.8

(Adapted from Source; central stastical service, 2024)

A large number of residents are located in Kolfe keraneyo sub city, Yeka subcity, Nifas silk lafto and Bole sub city. Lemi Kura is not included in this table as it was part of the other 10 prior sub cities and there is no separate available information. However most people are concentrated in the CBD, These sub cities are responsible for small portion of the total area (8%) but they account for over 32 % of the city's population, sub cities such as Arada, Kirkos, Gulele and Addis ketema sub cities (see Table 3-1).

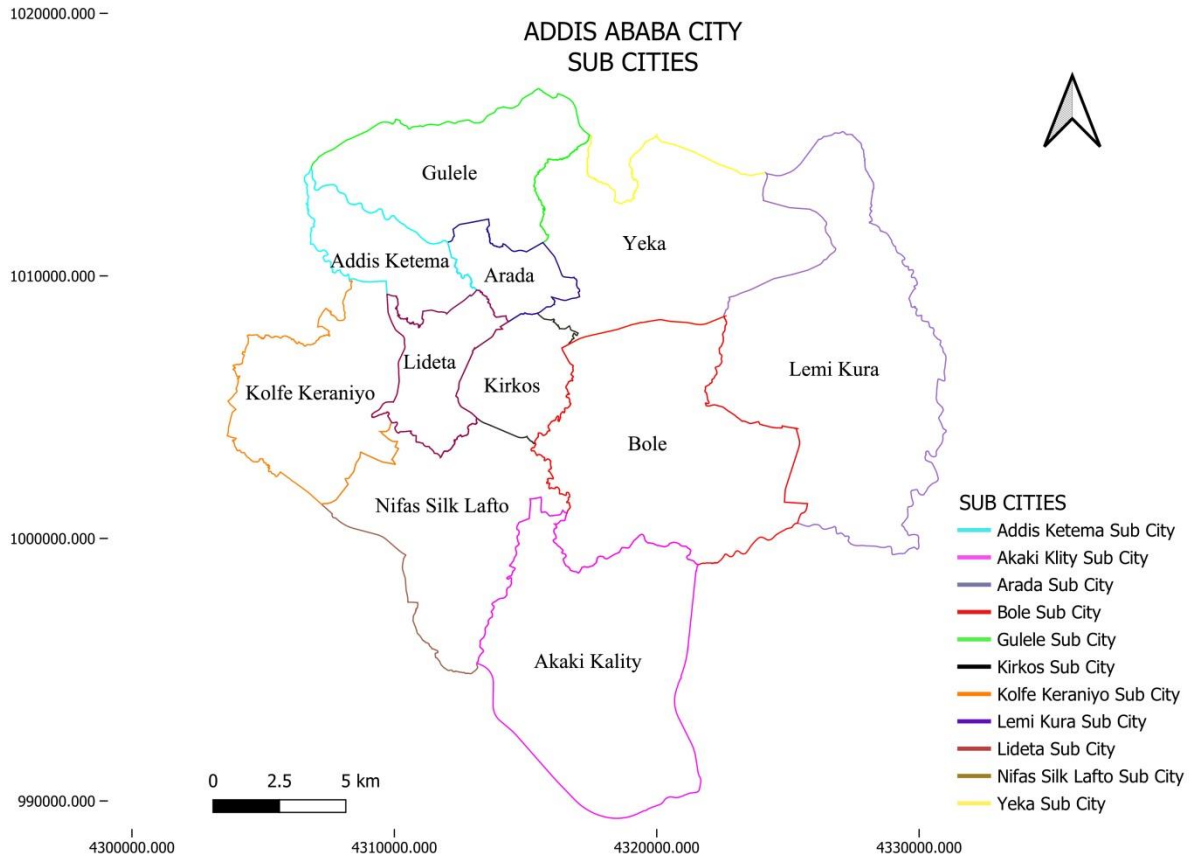


Figure 3-3 Addis Ababa map with its Sub Cities (Source: Addis Ababa city government plan and development commission, 2022)

Table 3-2 Road hierarchy

SI .No.	Road hierarchy	Unit	Total Length	Length in 7m width	No. Of Bridges	Pavement Status
1	Arterial	km	308	1,195	108	Very good
2	Sub Arterial	km	108	242	44	Very good
3	collector	km	100	100	49	good
4	Local	km	126	126	31	good
cumulative		km	642	1,662	232	
Gravel road		km		1,662		
Total road coverage		km		3,324		

(Source: AACRA, 2012)

The population growth in the city is by far out pacing economic growth, resulting in a large slum and squatter settlements (Azagew & Worku, 2020). The urban physical growth rate has been faster than the rise in infrastructures and service delivery in Ethiopian cities (World Bank, 2014). The physical horizontal expansion, economic advancement and rapid population growth in Addis Ababa results in many transportation service problems like: congestion, inaccessibility and unsafe conditions for the transport users (Asres, 2020). This makes a reliable mobility analysis necessary for the planning, designing, and implementation of the present and future transportation systems, and that was the primary goal of this study.

### **3.2 Research Design**

Quantitative methodology is used in this study, It refers to a set of strategies, techniques and assumptions used to study psychological, social and economic processes through the exploration of numeric patterns (Sciences et al., 2017). Quantitative research gathers a range of numeric data. Which is perfect for this study, because of the larger sample sizes, Impartiality and accuracy of data, Faster and easier to run, Data is anonymous and Offers reliable and continuous information (Anpar Research LTD, 2020).

This paper has Descriptive and correlational designs. Which allow to measure variables and describe relationships between them (IvyPanda, 2022). This study used graphs, scatter plots and maps to visualize data and check for any trends or outliers. In this study we will describe what the mobility and accessibility conditions look like for different zones in Addis Ababa and we will compare and contrast the results with their respective location within the city to find out if there is a pattern.

In this research first research questions were formulated based on real world problems as one of Addis Ababa residents and relevant literatures were studied and reviewed, literatures on mobility, congestion and accessibility in the world and in Addis Ababa were reviewed. After that all the necessary steps were identified to make this research happen. Then all the necessary secondary data was gathered from governmental offices in Addis Ababa Addis Ababa City Government Plan and Development Commission and

ACCRA, land use map. Road network map and administration district map were collected.

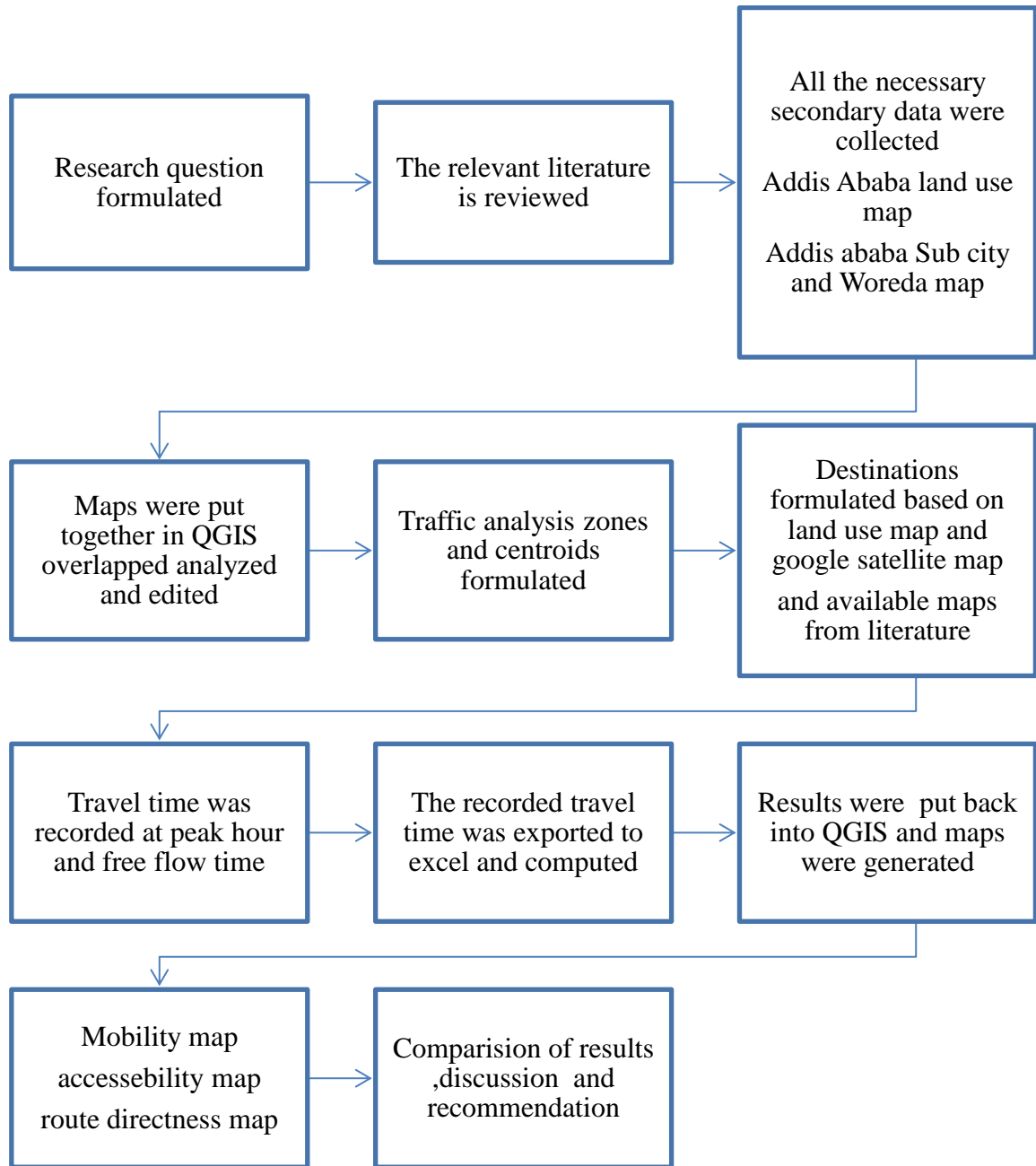


Figure 3-4 Research design

Then it was time to convert these maps to the same format and overlap them for better understanding. After the maps were reviewed centroids were created which simplifies the traffic analysis zones in to a single node. Then major destinations were created based on

the available literature concepts, high density mixed residential areas, commercial areas/markets, industries and higher educational institutes were chosen. Then travel time was recorded between TAZ's and major destinations. The peak hour travel time was recorded at the morning peak hour and the free flow travel time was recorded at night and during Sunday and the results were exported into excel for analysis.

According the neighborhood mobility index formula NMI, accessibility and route directness was calculated for each of the 116 traffic analysis zones. Finally results were put back into QGIS to generate tree maps, such as zone mobility in Addis Ababa, Accessibility of zones in Addis Ababa and route directness in Addis Ababa. Lastly results were discussed and compared with available literature and recommendations were put. The logical procedures used during the research are shown in Figure 3-4.

### 3.3 Source of Data

The required information for the study was collected from secondary sources. Secondary data was gathered from online sources, related literature, both published/unpublished data and documents from relevant offices (Table 3-3).

Table 3-3 Sources of data

Data	Source	Format	Description
AA Sub City & Woreda Boundary Map (Sep, 2022)	Addis Ababa City Government Plan and Development Commission	AUTOCAD	Addis Ababa map which includes 11 Sub Cities and 116 Woredas
Road network map of Addis Ababa	Addis Ababa City Government Plan and Development Commission	AUTOCAD	Major road network of Addis Ababa
Land use map (2010)	ACCRA	AUTOCAD	A detailed land use map
Travel time	QGIS travel time	Excel	Travel time between

	plug in		origin and multiple destinations in seconds/meter
Distance	QGIS travel time plug in	Excel	Distance between origin and multiple destinations in meter

### 3.4 Methods of Data Collection

The relevant secondary data (AA Sub City & Woreda Boundary map, Road network map of Addis Ababa and Land use map) was collected by going to the respective offices in person (see Table 3-3). The travel time and distance data was collected from online source, the QGIS travel time plug in, and enormous data was collected using this technology otherwise not possible. First, QGIS was installed. QGIS can be downloaded and installed from the official website. It is a free and open source project, meaning that it is freely available for anyone. Then the travel plug in was installed to access the necessary travel data.

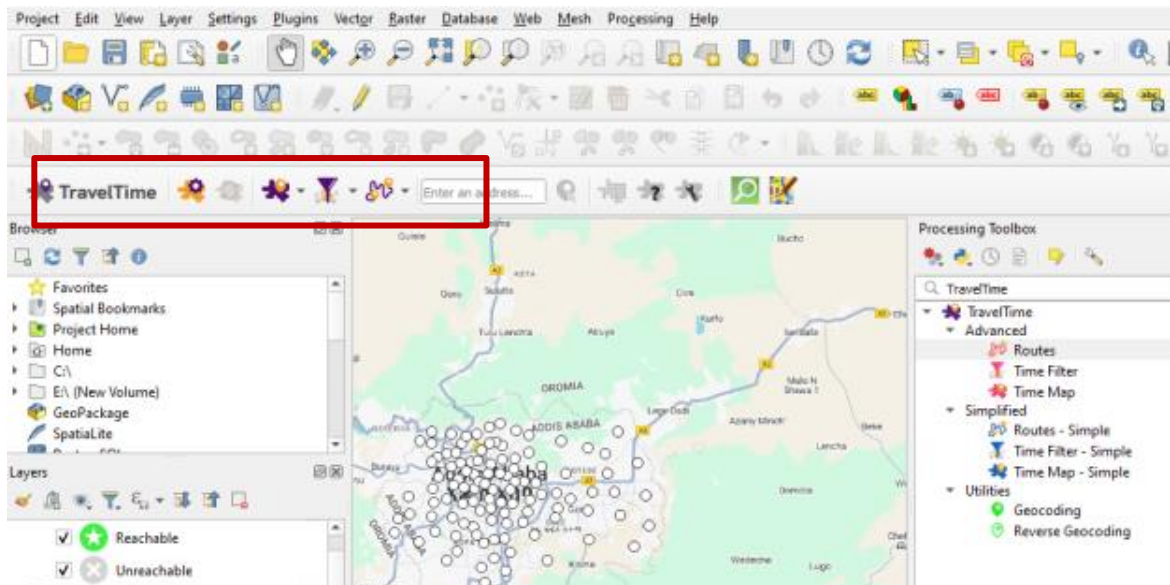


Figure 3-5 QGIS travel time plug in (Base image: google map, retrieved 1 may 2024)

As seen in Figure 3-5 the travel time data was collected from online source; the QGIS travel time plug in, without this technology it would not have been possible to gather such a large amount of data. There are 3 core functions of the Travel Time plugin.

- Time Map - creating Isochrones (reachable areas based on journey time)
- Time Filter - creating Origin-Destination matrices
- Routes - creating detailed A-to-B routes

To install the plugin, the steps were, open the Plugin manager in the Plugin menu. In the dialog, search for Travel Time, and click on install. There's one last step before being able to use the plugin: getting a free API key. This is required to be able to use the Travel Time web service. As well the free API key has a limitation of the number of queries you can make in a minute. You have to wait a while if you reach your maximum limit.

### **3.5 Methods of Data Analysis**

In this section the analysis of mobility, accessibility and route directness of Addis Ababa are discussed. First after gathering all the necessary data the primary requirement is to prepare the data for analysis. Since the data collected are from different sources, different format and period, converting them to same format and updating and checking along different online information up to date sources like google satellite map and open street map was essential to obtain accurate results in later stages. This is done by unifying data, changing data formats joining with online map and editing as necessary. As shown in Figure 3-6; all the data gathered then were joined and overlapped in QGIS. Merging all the maps together was a crucial aspect of the analysis, because some of the maps (i.e. land use map) were not up to date and checking their consistency with online sources was necessary.

The smallest administrative unit i.e. *woreda* was chosen as traffic analysis zones because of its similarity in land use patterns within zones as well as it follows natural and manmade features like waterbodies and highways. The traffic analysis zones were checked with physical boundaries a main road to make sure they follow the four step planning process of creating TAZ's. A Total of 116 neighborhoods, each zone are then reduced to a single point represented by centroid. After centroids were generated, they

were then edited to best represent the activity center as opposed to the geographical center of the area. Then Addis Ababa land use map, traffic analysis map, open street map, google satellite map are all merged together in QGIS to select destination points , commercial centers, high density mixed residence, industrial zones and higher educational centers was chosen as destinations. Totally 42 major destinations were chosen. The Selected mobility, accessibility and route directness indicators are presented in Table 3-4.

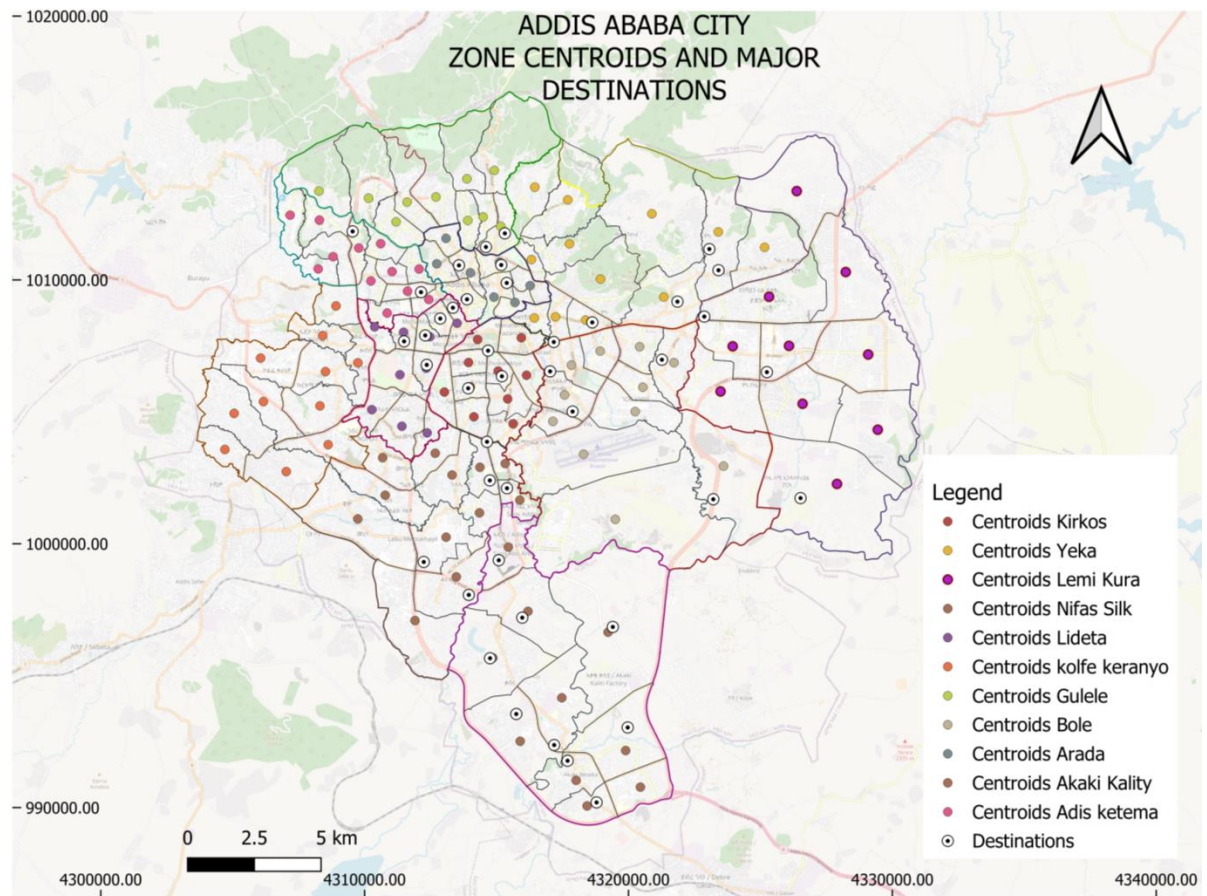


Figure 3-6 Addis Ababa city, zone centroids and major destinations (Base image: open street map, retrieved 1 may 2024)

Table 3-4 Selected mobility, accessibility and route directness indicators

Mobility		
Indicator	Description	Units
congestion		

Free Traffic Speed	Average speed of vehicle trips when there is little traffic and no adverse conditions for network	Second/meter
Peak Hour traffic speed	Average speeds of vehicle trips during peak hours	Second/meter
Accessibility		
Reachable opportunities	Reachable opportunities within 30 minutes	Number of opportunities
Route directness		
distance	Actual distance between origins and destination versus straight line distance	

### 3.5.1 Mobility disparity analysis

Multiple data's were unified and 116 zones and 42 destinations were created, and weight of destinations was assigned based on the population data; according to Ethiopian Statistical Service (ESS): the 2022 urban bi annual employment unemployment survey. The highest proportion about 72.4 percent of the employed persons are absorbed by the total service sectors out of this wholesale and retail trades covers about 20.0 percent, accommodation art and recreation 3.9% and the rest of other service sectors 48.5% represented by other types of services. Manufacturing, mining, quarrying and construction industry divisions are growing in urban areas together constituted 13.9 percent. the number of people enrolled in higher education was 388,186 in 2018 and forecasted to be around 500,000 in 2024 (Mekonnen et al., 2024). From this the number of people who work in service sectors, manufacturing and education was 16:3:1. Based on this each destination was assigned a weight of the route. Travel instances which had very short trips (less than 2km) were not included; the data seem to be unreliable for short distances. The main indicators of the analysis follow the relationship between free flow travel time and peak hour travel time.

Travel time index = peak hour travel time/free flow travel time

based on this The mobility index for a neighborhood is given as follows: (ElDessouki, 2022)

$$NMI = \frac{\sum_{JED} W_{IJ} * TR_{IJ}}{\sum_{JED} W_{IJ}}$$

Where

- *{D}* is the set of major attractors/destinations in the study area.
- *W<sub>ij</sub>* is the weight for the route origin (*i*) and destination (*j*),
- *TR<sub>ij</sub>* is the travel time ratio between the origin (*i*) and destination (*j*). free flow divided by peak hour travel time

The NMI reflects the average congestion residents of that neighborhood encountered daily during their trips from home to work or university. The data required to calculate this measure is obtained conveniently from online third-party service provider travel time API plug in from QGIS. According to the NMI results are categorized it into 4 groups.

1. 1.0–1.25: Optimum situation; the congestion delay is at most 25% of the free-flow travel time.
2. 1.25–1.49: Acceptable; the congestion delay is between 25% to 50% of the free flow travel time.
3. 1.50–1.75: Unacceptable because the average delay exceeds 50% of the free-flow travel time.
4. Greater than 1.75: The worst case; the congestion delay exceeds 75% of the free-flow travel time, and walking might be a better choice.

Travel time was taken from google map during the following hours.

- The morning peak hour of April 22 2024 was chosen to retrieve travel matrix between origins and destinations, to avoid non reoccurring traffic future time predicted by google using the travel time plug in in QGIS was selected.
- Free flow time was taken on Sunday April 21 2024 at mid-day 2:00 pm.

id	search_id	reachable	prop_trave	free_flow_tt_id	prop_dist	TTR	W	WR	TTR*WR	InputID	TargetID	air_distance	x	y	NMI	
1	1	1	1725	1015.83	1	11287	1.69811878	0.000984	9.69076E-07	1.6456E-06	179	9506.174129	38.765101	9.050966	0.0	
2	2	1	1730	1031.04	2	11456	1.67791744	0.00097	9.40695E-07	1.5784E-06	179	9946.813838	38.758659	9.046377	0.0	
3	3	1	1662	958.14	3	10646	1.73461081	0.001044	1.08929E-06	1.8895E-06	179	9174.413917	38.763878	9.040324	1.0	
4	4	1	1547	920.52	4	10228	1.68057185	0.001086	1.18014E-06	1.9833E-06	179	8778.14415	38.76575	9.034292	1.0	
5	5	1	2706	1587.87	5	17643	1.70416974	0.00063	3.96616E-07	6.759E-07	179	14852.26653	38.713284	9.051623	DR	
6	6	1	1993	1273.59	6	14151	1.56486781	0.000785	6.16511E-07	9.6476E-07	179	12299.70264	38.7308	9.014657	1.0	
7	7	1	690	359.19	7	3991	1.92098889	0.002784	7.75089E-06	1.4889E-05	179	2652.151666	38.823862	9.028002	40	
8	8	1	537	231.39	8	2571	2.32075716	0.004322	1.86772E-05	4.3345E-05	179	1533.314364	38.832998	9.022969	1	
9	9	1	767	345.96	9	3844	2.21701931	0.002891	8.35503E-06	1.8523E-05	179	2880.891041	38.837844	9.038569	1	
10	10	1	2401	1607.67	10	17863	1.4934667	0.00622	3.86907E-07	5.7783E-07	179	14713.94831	38.806936	8.884768	1	
11	11	1	896	422.73	11	4697	2.1195622	0.002366	5.59595E-06	1.1861E-05	179	3722.013036	38.834721	9.045679	1	
12	12	1	1997	1281.24	12	14236	1.55864631	0.012488	0.000155948	0.00024307	179	11837.23783	38.736562	9.031182	1	
13	13	1	1801	1162.8	13	12920	1.54884761	0.01376	0.000189335	0.00029325	179	11514.37349	38.737995	9.01665	1	
14	14	1	1839	1178.37	14	13093	1.56063036	0.013578	0.000184364	0.00028772	179	14	10993.06986	38.743113	9.022312	1
15	15	1	1875	1196.37	15	13293	1.5672409	0.013374	0.000178858	0.00028031	179	15	10569.66879	38.747412	9.025951	1
16	16	1	1729	1024.56	16	11384	1.68755368	0.015616	0.000243874	0.00041155	179	16	10095.36744	38.752222	9.028781	1
17	17	1	1802	1180.89	17	13121	1.5259677	0.013549	0.000183578	0.00028013	179	17	11471.70898	38.738506	9.006743	1
18	18	1	1815	1102.23	18	12247	1.64666177	0.014516	0.000210715	0.00034698	179	18	10020.29089	38.752632	8.998858	1
19	19	1	1695	989.64	19	10996	1.71274403	0.016167	0.000261388	0.00044769	179	19	8708.910314	38.764096	9.002902	1
20	20	1	1851	1136.16	20	12624	1.62917195	0.014083	0.000198317	0.00032309	179	20	10677.4205	38.749484	9.040204	1
21	21	1	1885	1151.28	21	12792	1.63730804	0.013898	0.000193143	0.00031623	179	21	9856.644767	38.759027	8.98087	1
22	22	1	1325	823.5	22	9150	1.60898604	0.019429	0.000377496	0.00060739	179	22	6463.262459	38.788163	8.991048	1
23	23	1	942	561.78	23	6242	1.67681299	0.028481	0.000811162	0.00136017	179	23	5328.990332	38.794867	9.021023	1
24	24	1	598	335.61	24	3729	1.7818301	0.008939	7.99048E-05	0.00014238	179	24	2693.563812	38.818575	9.008468	1

Figure 3-7 Travel time attributes

The free flow travel time, the peak hour travel time and distance by air was all collected separately and Then this data was exported to excel format and merged together based on their Id's as you can see in Figure 3-7, the attributes are, search ID, peak hour travel time, travel distance by physical route, free flow travel time, travel time by air distance and coordinates.

### 3.5.2 Accessibility Analysis

Many accessibility measures simply use distance (either straight-line or network path-based, with the latter being generally preferable) as the metric. however, travel time is generally a much better measure of perceived impedance than distance (Miller, 2018).

$$accessibility\ opportunities = \sum objective\ fulfillment\ opportunities$$

Where travel time  $\leq$  the acceptable travel time

Data elements;

- Travel time to destination
- Distance to destination
- Land use data
- Individual characteristics

Here travel time used as the bases for determining the accessibility potential of a given zone. Accessibility was calculated for each of the 116 traffic analysis zones and 42 major destinations in the city. There for the equation was revised as follows;

$$\text{accessibility opportunities of a zone \%} = \frac{\sum \text{destinations} \leq 30\text{min} * 100}{\sum \text{destinations}}$$

Accessibility opportunities of a zone was determined by counting and adding the major destinations reachable from that zone within 30 min. all the destination that took more than 30 minutes to reach was deemed as inaccessible. The results were put in percentages for better understanding, which means if a zone has an accessibility of 50%; it is within 30 minutes' drive to half of the major destinations. And results we can categorize it into 4 groups.

1. Accessibility of opportunities of a zone to 25% of the destinations ; poor
2. Accessibility of opportunities of a zone between 25% - 50 % of the destinations ; average
3. Accessibility of opportunities of a zone between 50% - 75 % of the destinations ; good
4. Accessibility of opportunities of a zone between above 75% of the destinations very good

The peak hour travel times that are below 30 minutes are chosen, since QGIS travel time plug in uses seconds for travel time and meters for distance the value was set to below or equal to 1800 seconds, then destinations reachable within the time limit (1800 seconds) were calculated.

Another way of measuring accessibility opportunities is by using the travel time filter, first the established 42 major destinations are selected as destinations and traffic analysis zones are then selected individually as a starting point. The maximum time was set 30 minutes and driving (private car) was the transportation mode selected. The morning peak hour was the time chosen. And it classified the major destinations into reachable and unreachable according to the time filter 30 min.

### 3.5.3 Relationship between Mobility and Accessibility with Location

The relationship between mobility and accessibility with location was analyzed by observing map results and simplifying results down to sub cities. Mobility and accessibility results were categorized and studied in terms of the city center and their change towards the peripheries. Correlation between mobility and location, accessibility and location in the city; Correlation between mobility and accessibility between Sub cities was analyzed in SPSS software.

The four CBD areas Addis Ketema, Arada, Kirkos and Lideta have the most built up areas and concentration of population. It is discussed throughout the findings of the study that if it's better to live in the city center or outside (see

Figure 3-8 ).

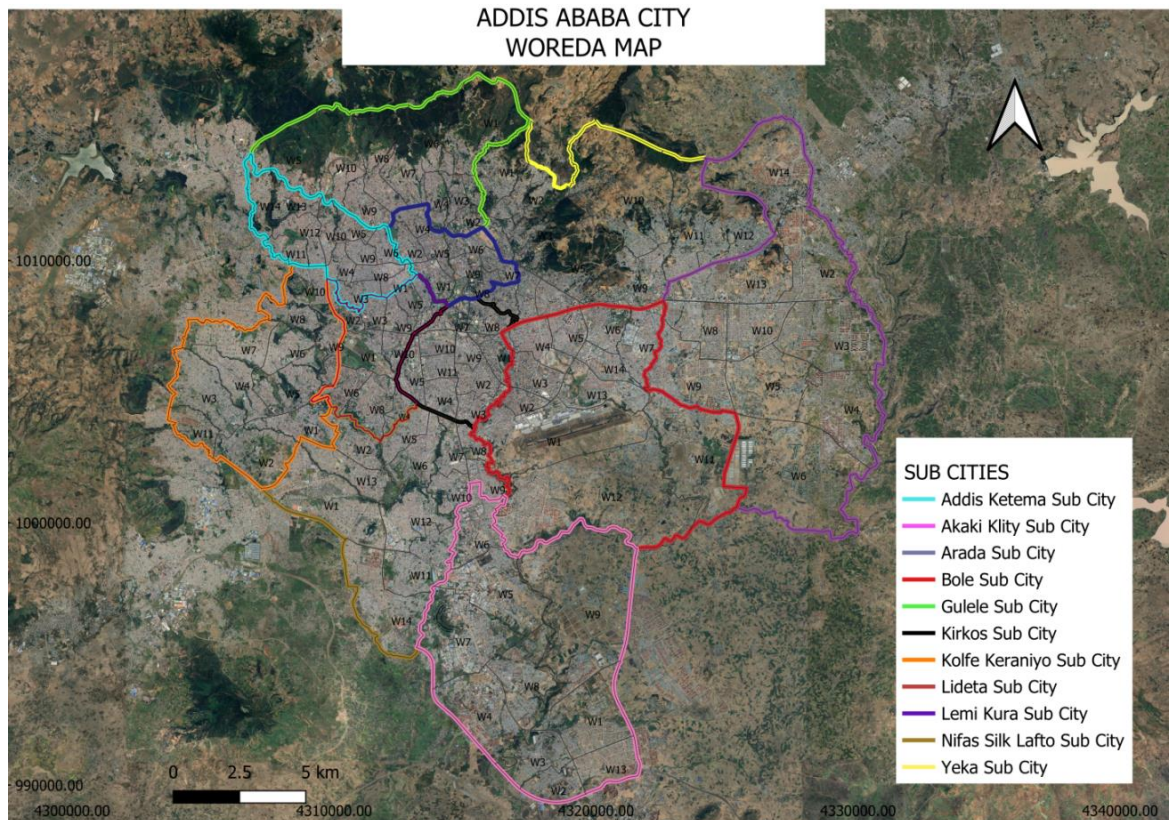


Figure 3-8 Addis Ababa satellite map (Base image: google earth, retrieved 1 may 2024)

### 3.5.4 Route Directness Analysis

Route directness is an index measuring how direct an identified route is for various model commuters as opposed to actual distance between two points. It shows that how conducive surrounding land uses and infrastructure are to individual accessibility.

$$\text{Route directness} = \frac{\text{distance between origin and destination}}{\text{Actual distance by traveled road network}}$$

Data elements

- Straight line distance between origin and destination
- Distance between origin and destination via infrastructural network
- distance

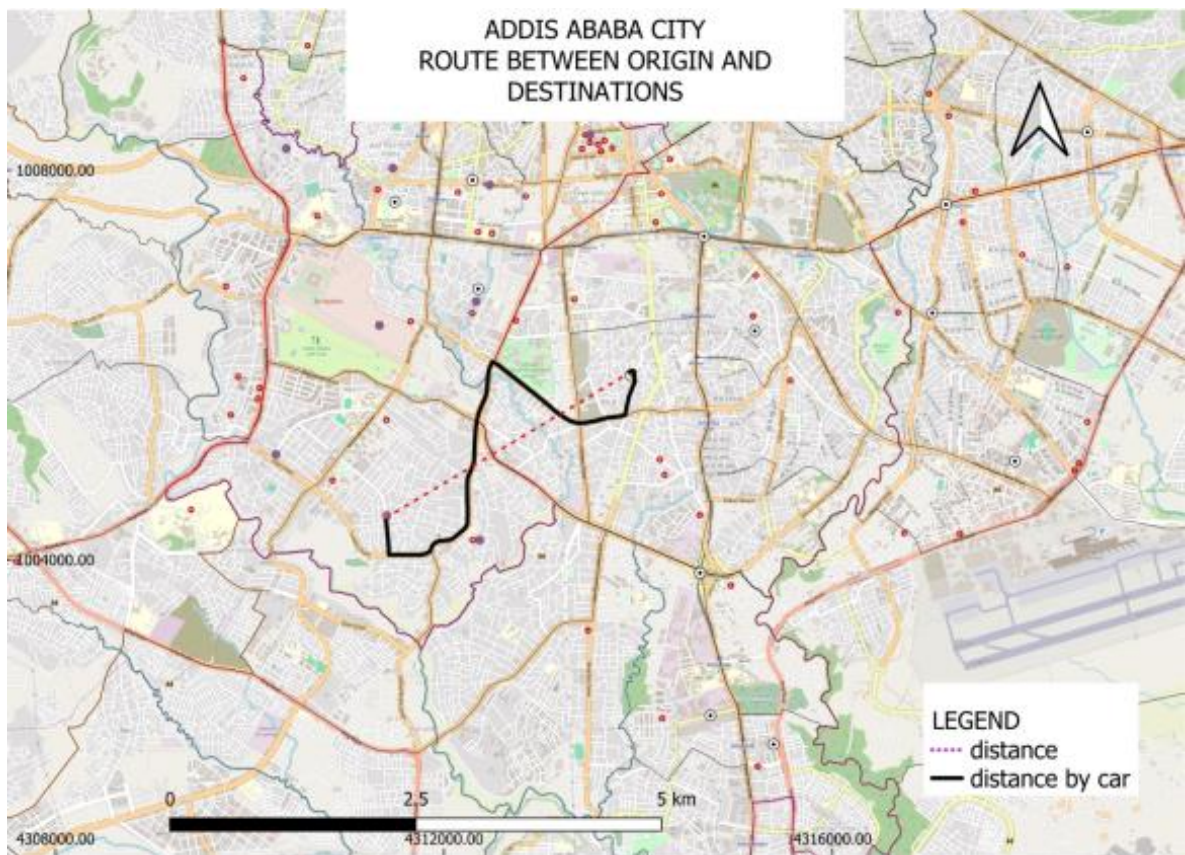


Figure 3-9 Route between origin and destination (Base image: open street map, retrieved 1 may 2024)

Figure 3-9 shows the contrast between distance between two points and the actual distance traveled by car. The ideal situation will be they are equal, but that is not possible due to reasons such as man-made physical structures and natural terrains.

The distance between origins and destinations were retrieved from QGIS using the distance matrix, both the distance by air and distance by physical route. Then the analysis for route directness index was computed for each of the 116 zones. Finally the results were categorized into 3 groups; because the results are quite similar which most are between 1.2 and 1.4, smaller divisions were made.

1. below 1.25; Good
2. 1.26 to 1.35; Average
3. Above 1.36; Poor

### **3.6 Method of Data Presentation**

Data is presented using maps, tables, bar chart, line graph and scatter plots. QGIS is used for generating maps and scatter plots are prepared using SPSS software. Tables, Bar chart and line graph are prepared using Microsoft word.

### **3.7 Validation**

The work of this study has been validated by comparison of the methodology and the output with other previous works, sample traffic, as well as ANOVA and Kendall's correlation.

## CHAPTER 4 RESULTS AND DISCUSSION

This research identified the mobility and accessibility conditions in different neighborhood of Addis Ababa in this chapter the results and discussions are included.

### 4.1 Neighborhood Mobility of Addis Ababa

As discussed in chapter four, after calculation NMI for each of the 116 zone then the results were put back into QGIS to generate a map as you can see in Figure 4-1. Congestion appear to be unacceptable in all the neighborhoods, which was found to be equal to and greater than 1.5, which means an Additional 50% or more of the uncongested travel time, which means if a travel initially takes 30 min in free flow, during peak hours it will take 45 min and more all over Addis Ababa zones.

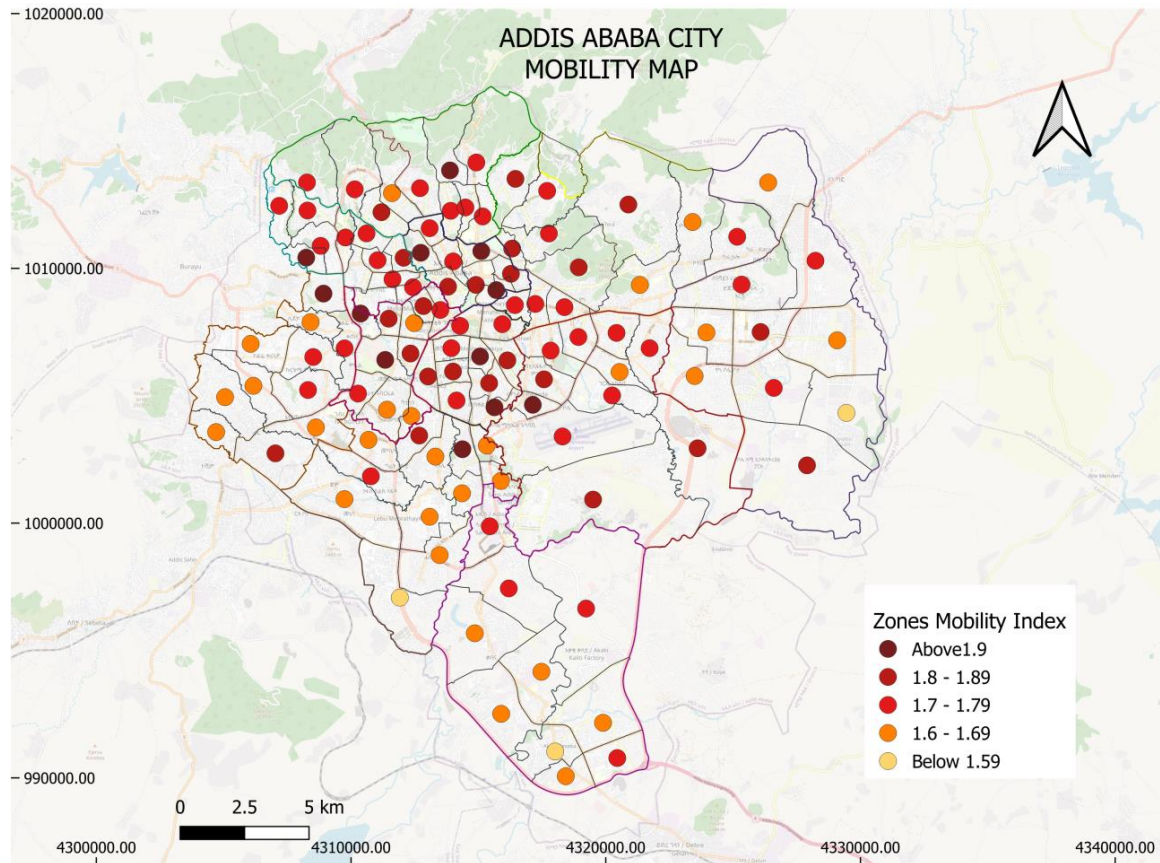


Figure 4-1 Addis Ababa neighborhood mobility map (Base image: openstreetmap, retrieved 1 may 2024)

Although all results are above the acceptable threshold there are still mobility inequalities between zones in Addis Ababa. There is a slight but noticeable difference between zones of different locations, in general the outer zones sub cities like Lemi Kura, Akaki Kality and Nifas Silk generally seem to have lower NMI's than zones around the CBD. While peripherals mostly experience 50% to 70% of additional delay, zones in and around the CBD sub cities like Kirkos, Lideta, Gulele and Arada mostly experience 70% to 100% (2 times the free flow travel time). This means that if the free flow travels time to get to a certain destination was 30 min, if the NMI is 2 or 100% now driving from the CBD will take 60 minute to get to the same destination. If the NMI was 1.5 or 50% it will take 45 minute to get to the same destination. The four central sub-cities are the most congested in comparisons to Peripheral Area. These areas only count for 8% of the total city area, population contained in then accounts for 32% of the city residents. Because activities are concentrated in the CBD, Even if they are closer to activities it's harder to move around because residents from every corner come to the CBD for the same opportunities.

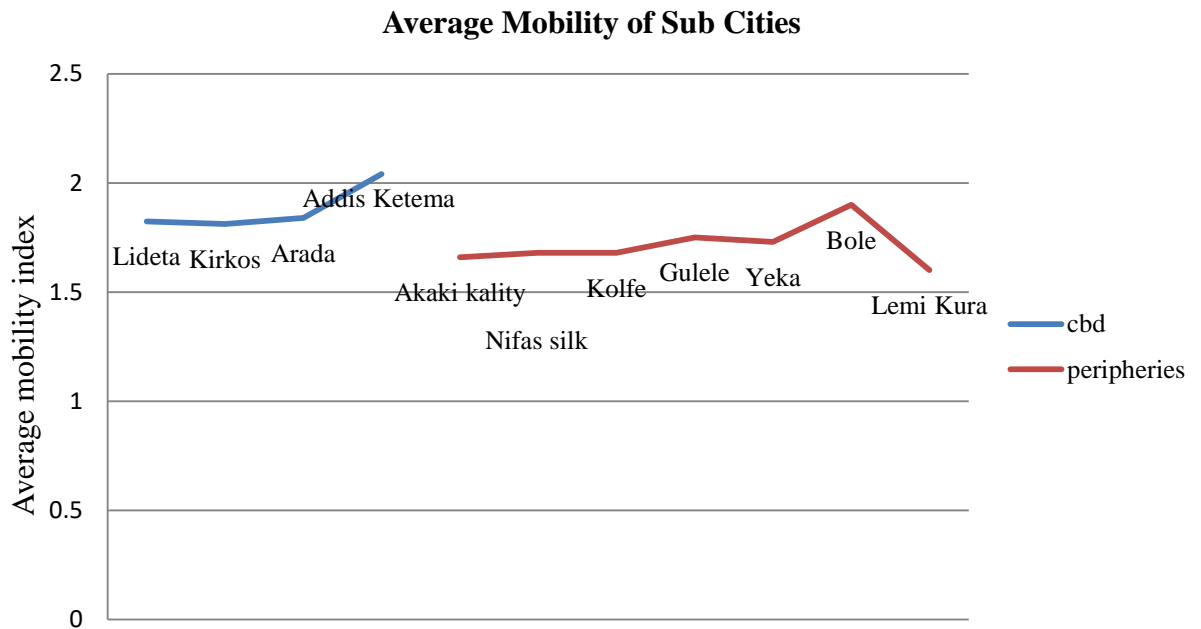


Figure 4-2 Average mobility index of A.A zones

From worst congestion to the least at Sub city level rank as Addis ketema, arada, lideta, kirkos, bole gulele, yeka, kolfe and nifas silk, akaki kality and lemi kura respectively. Consequently these central areas experience more congestion. Some of the peripheral

areas experience worse congestion than the others. There is no obvious reason why some of this zones experience more congestion than the others, one reason is these areas are far away and people must travel longer times to reach their destinations which in turn causes them to encounter more congestion along the way and have a higher neighborhood mobility index. Another reason is the lack of infrastructure in the peripheral areas of Addis Ababa.

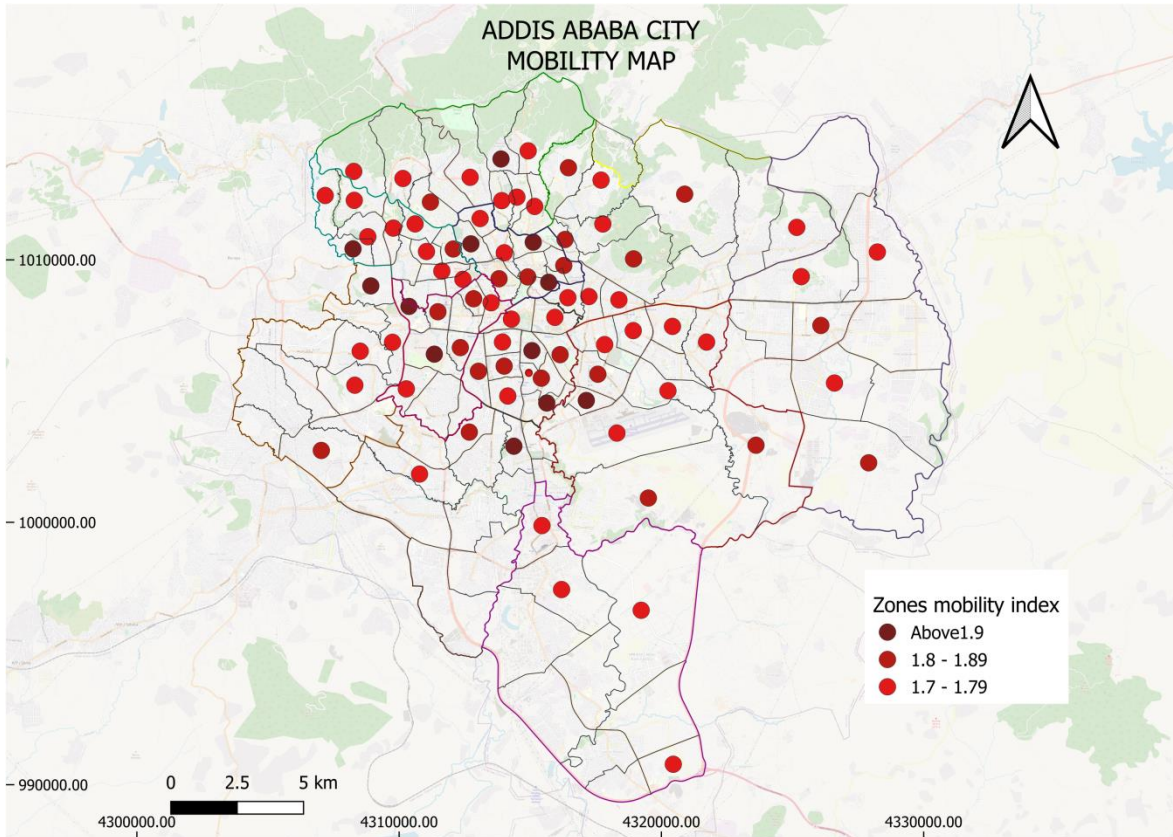


Figure 4-3 Areas with lower mobility in A.A (Base image: openstreetmap, retrieved 1 may 2024)

As we see from Figure 4-3, this figure shows the area where NMI is greater than 1.7, as seen from the figure almost all of the central areas fall into this category. For the reason that they host more people more than their capacity due to the concentration of activities in the central areas they tend to be more congested even if they are way closer to major destinations. In addition as we discussed earlier it's not only the CBD but some of the peripherals also fall into this category.

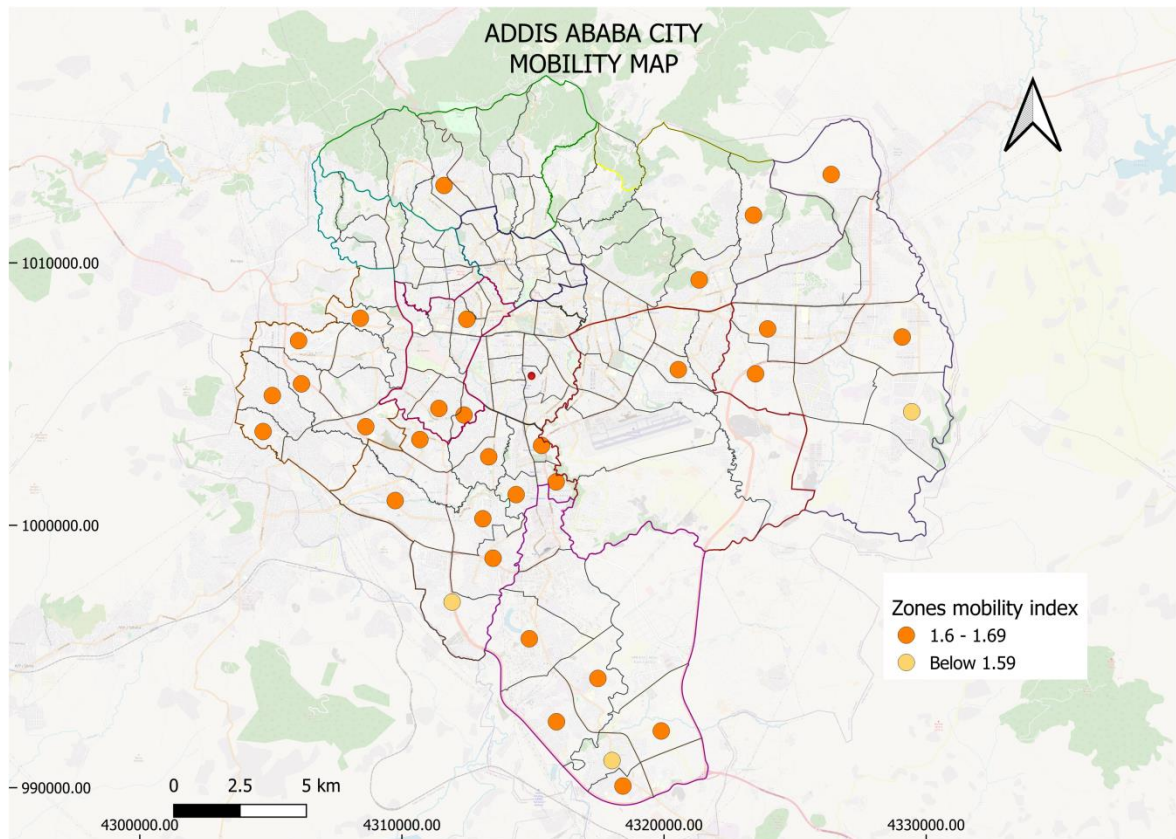


Figure 4-4 Areas with relatively higher mobility in A.A (Base image: openstreetmap, retrieved 1 may 2024)

As seen from Figure 4-4, these are the areas that have relatively higher mobility's, most of these areas fall into the peripherals, its seen than people far away from the CBD are less likely to counter congestion relative to people in the CBD.

#### 4.2 Accesability of Activties

Accessibility opportunities results were put in percentages for better understanding, which means if a zone has an accessibility of 50%; it is within 30 minutes' drive to half of the major destinations. Figure 4-5 and Figure 4-6 shows the amount of reachable destinations within 30 minute or less drive from two different locations. In Figure 4-5 the numbers of destinations reachable from Lemi kura sub city are small, While in Figure 4-6 the starting points was in the CBD Kirkos sub city and as we see in the figure most of the destinations are within 30 minutes or less of a drive.

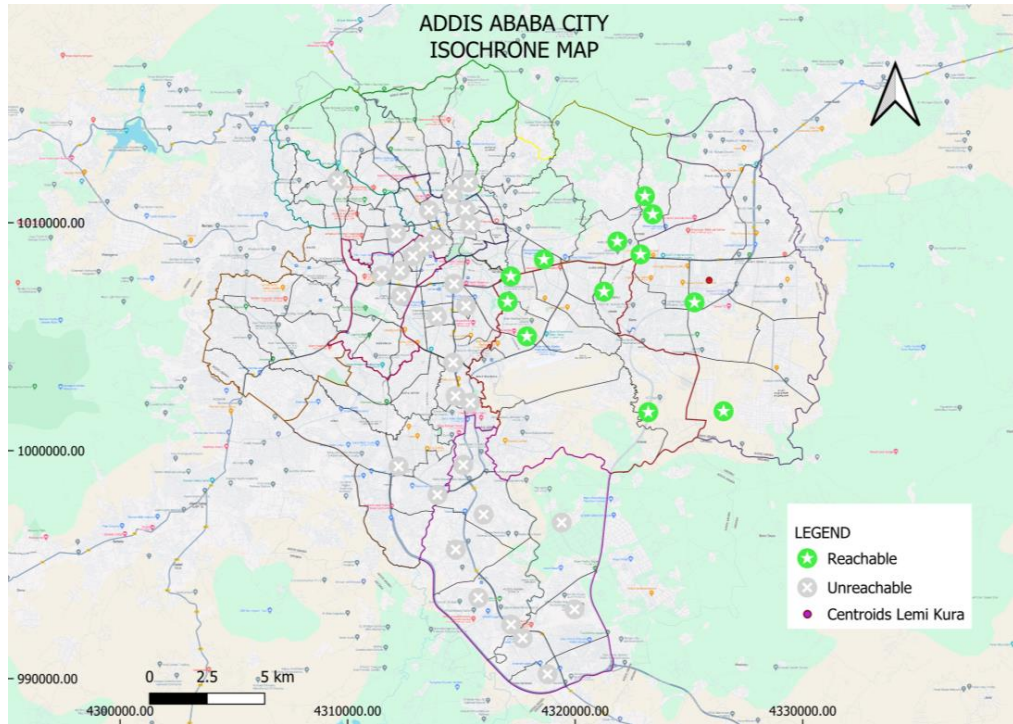


Figure 4-5 Isochrone map, driving from lemi kura sub city (Base image: googlemap, retrieved 1 may 2024)

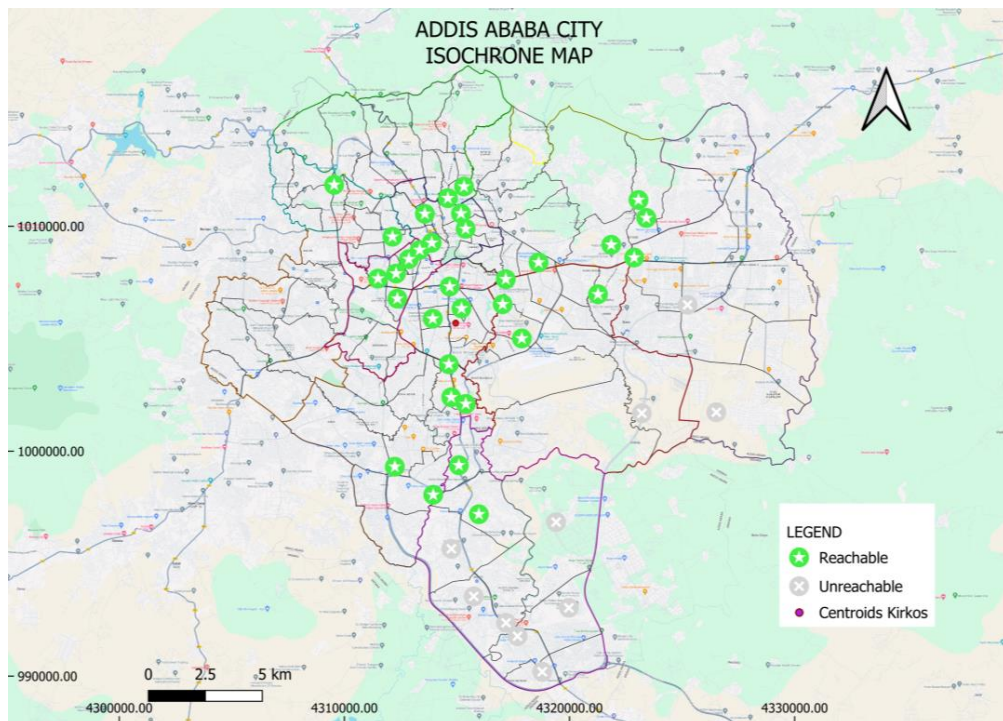


Figure 4-6 Isochrone map driving from kirkos sub city (Base image: openstreetmap, retrieved 1 may 2024)

After calculation of Accessibility for each of the 116 zone then the results were put back into QGIS to generate a map, results are categorized it into 4 groups. The results are presented in Figure 4-7.

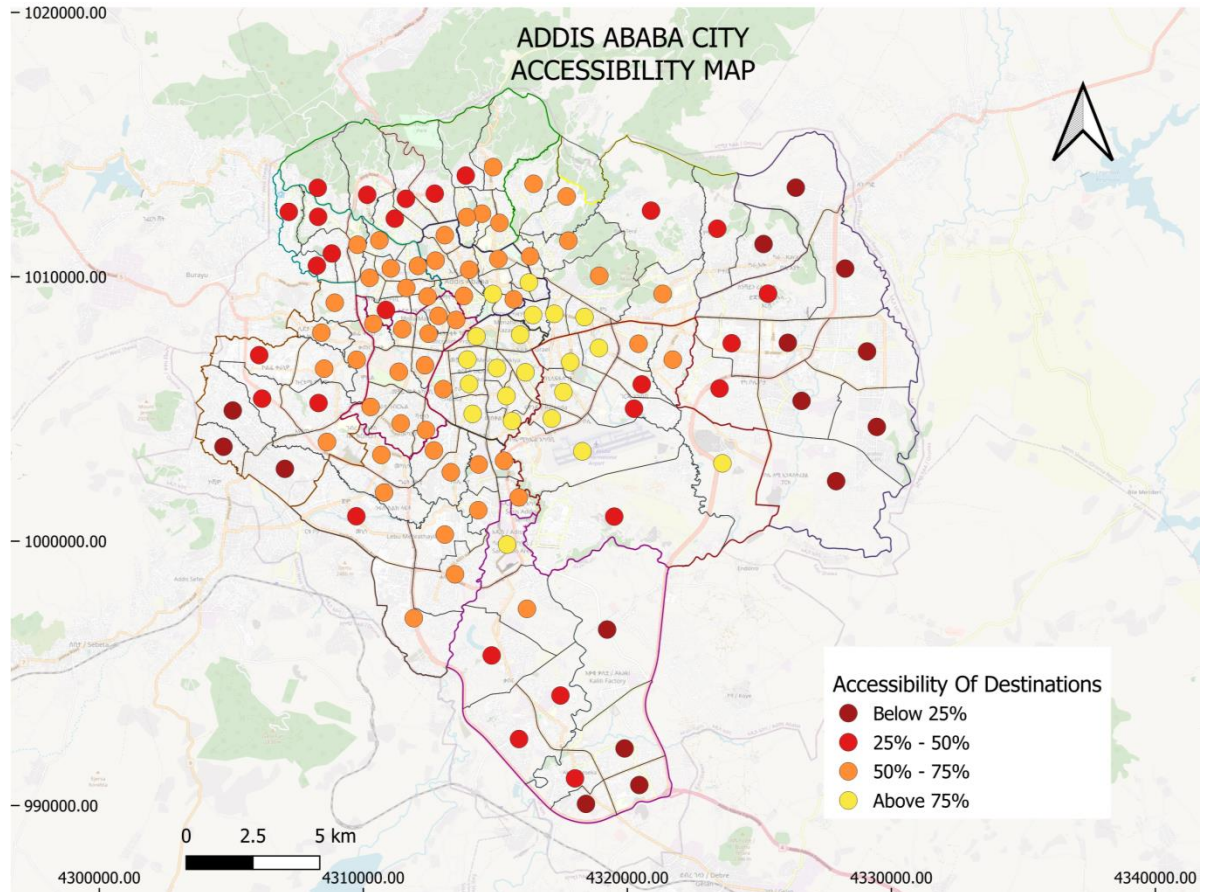


Figure 4-7 Addis Ababa accessibility map (Base image: openstreetmap, retrieved 1 may 2024)

It appears that there is a clear distinction between zones and a clear relationship between location and accessibility. The inner part of the city (CBD) has the most accessibility, sub cities like Kirkos, Lideta, Gulele and Arada, which is ability to reach more than 75% of the destination in 30 minutes. Consequently accessibility decreases as we go further from down town to peripherals, sub cities like Lemi Kura, Akaki Kality and Nifas Silk, this means that people living in the outer part of Addis Ababa have to travel more (above 30 minutes often) to reach potential destinations ( see Figure 4-7). When compared with the mobility map, it looks like that the accessibility of destination and mobility is reciprocal.

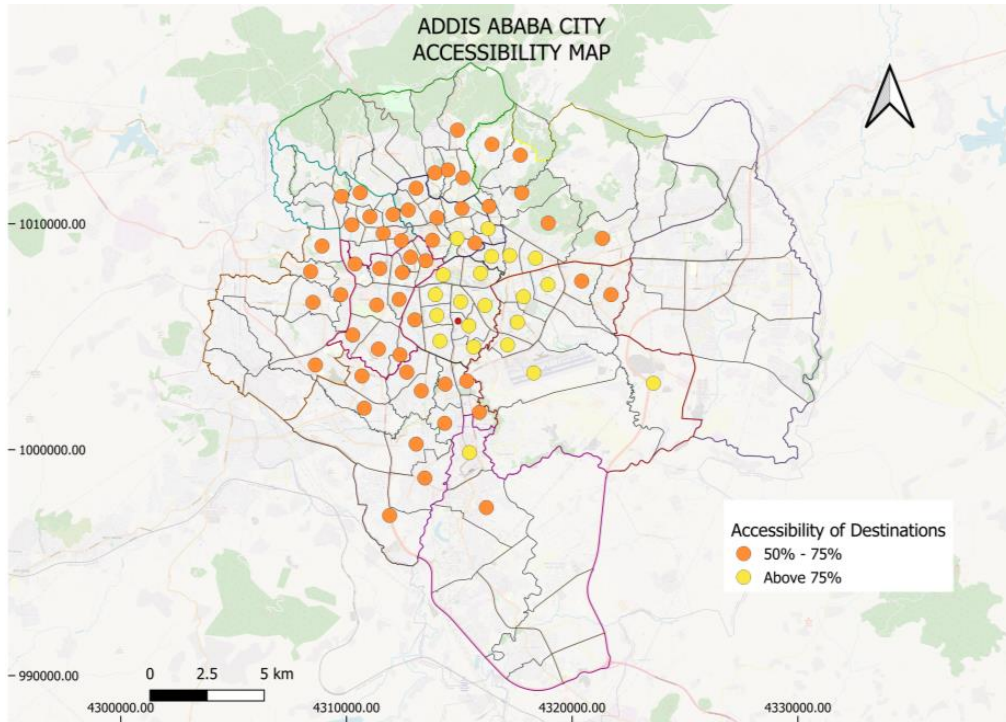


Figure 4-8 Map of zones with high accessibility to destinations (Base image: openstreetmap, retrieved 1 may 2024)

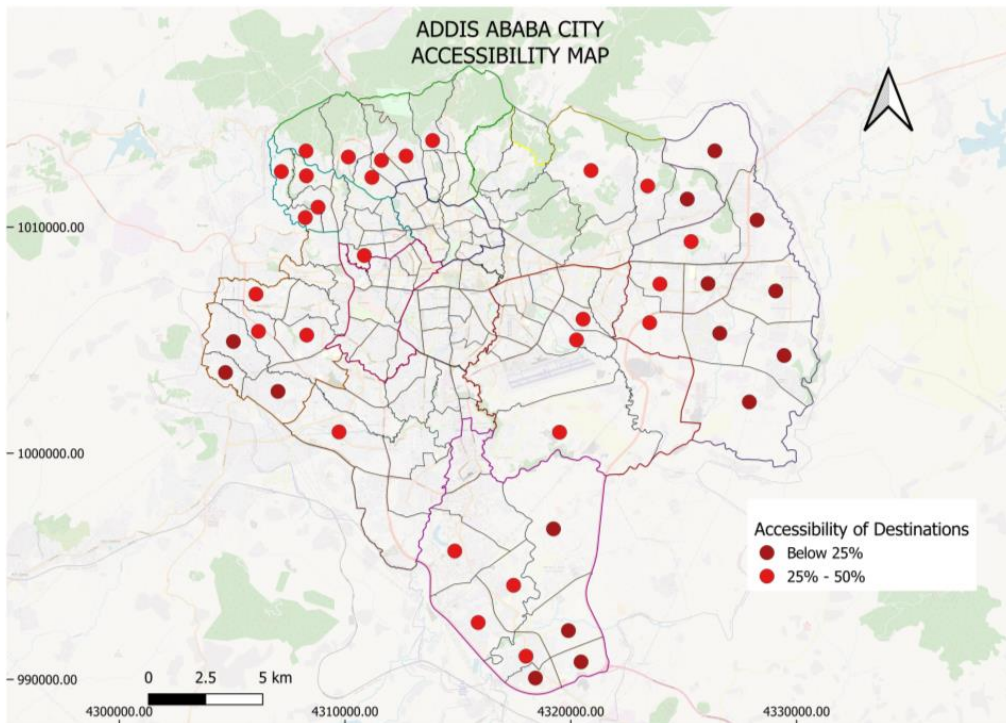


Figure 4-9 Map of zone with low accessibility to destinations (Base image: openstreetmap, retrieved 1 may 2024)

Figure 4-8 and Figure 4-9 briefly shows the difference between different locations in terms of accessibility. From Figure 4-8 its revealed that higher accessibility of opportunities is enjoyed by zones in the CBD and around the CBD, kirkos, lideta, arada some part of Addis ketema, some part of bole and nifas silk lafto and small portion of other sub city zones which are around the central area have better access to major destinations. And on Figure 4-9 zones with low accesses are shown, these are lemikura sub city, akaki kality sub city and most of kolfe keraniyo and some of yeka sub city.

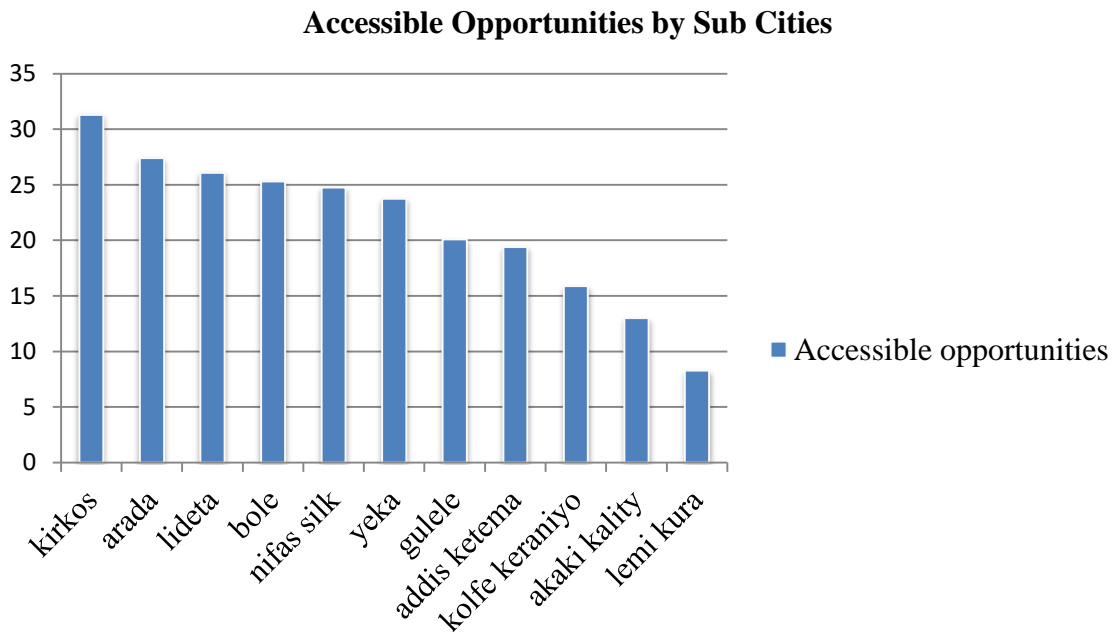


Figure 4-10 Average accessible opportunities by sub cities

It should go without saying that accessibility declines from the CBD outward. The built-up area of Addis Ababa makes up around 54% of the total area; of this, 64% is utilized for residential purposes, while the remaining 18%, 10%, and 8% are used for commercial, industrial, and public uses, respectively. The majority of the city's inhabitants (99%) are concentrated in the built up area, with a density of roughly 7000 per km<sup>2</sup> (UN, 2000). Basic social services (universities, hospitals, big institutions) all are concentrated at or around city center people who live outside the city center have to travel significantly longer to accesses this services. In Figure 4-10; it's seen in descending order from sub cities with the most accessibility to activities to the least.

### 4.3 Relationship between Mobility and Accessibility with Location

From the results 4.1 Neighborhood Mobility of Addis Ababa and 4.2 Accessability of Activities the relationship between mobility and location, accessibility and location and correlation between mobility and accessibility is analyzed using SPSS software.

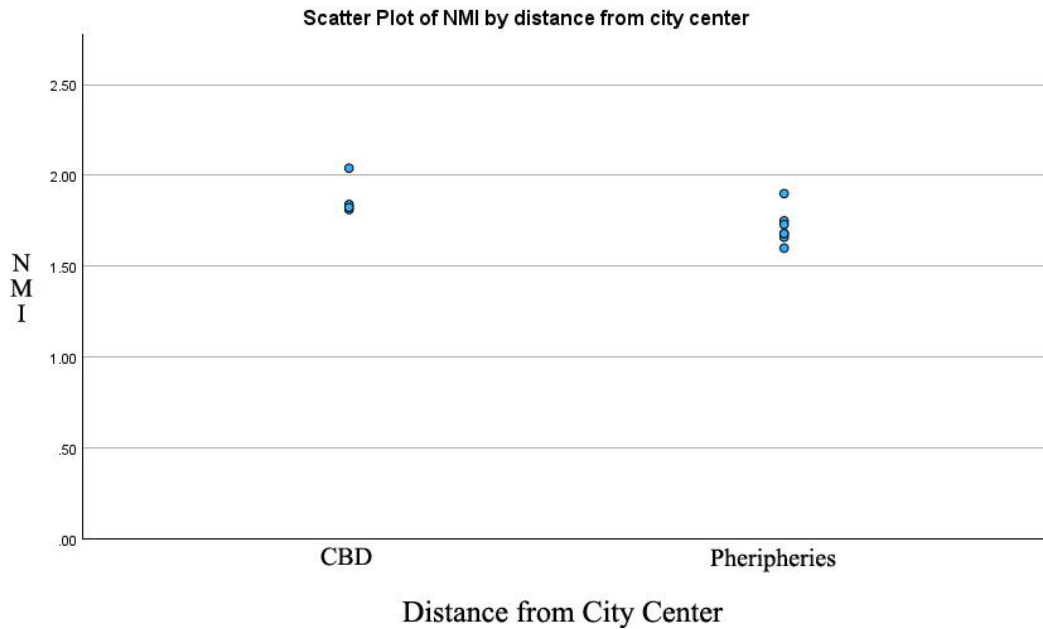


Figure 4-11 Scatter Plot of NMI by distance from city center

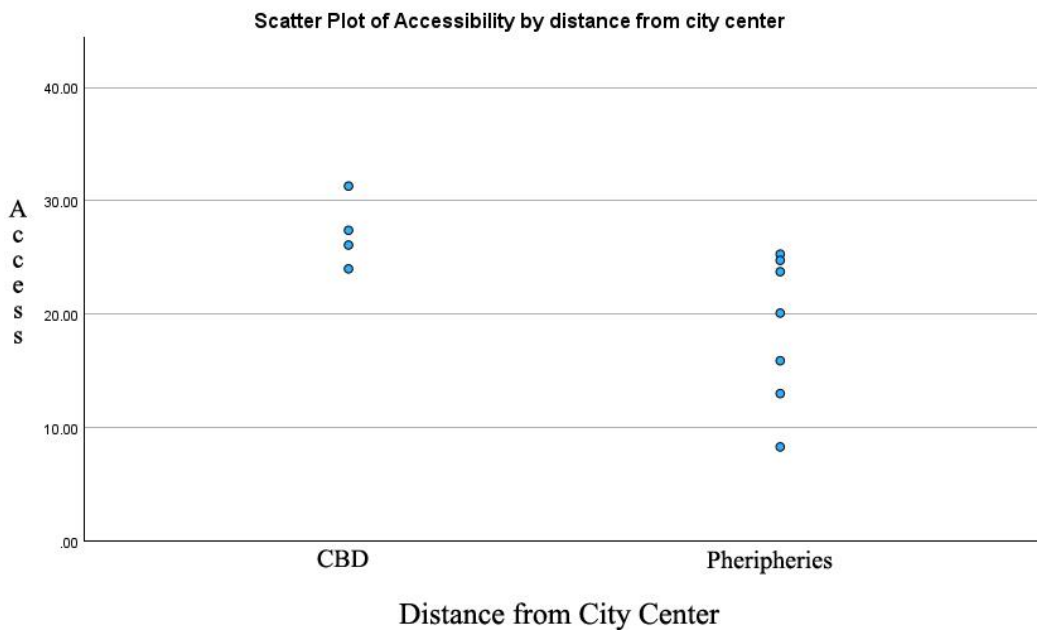


Figure 4-12 Scatter Plot of Accessibility by distance from city center

As we see from Figure 4-11 the figure NMI results for both CBD and peripheries is high, with slight difference in the city center which were generally higher, but also close sub cities like Bole have higher NMI. There is as well a close result with in the groups. The accessibility difference is quite visible; moreover we can see accessibility differences within the group, that some of areas that are closer to the city center have more accessibility

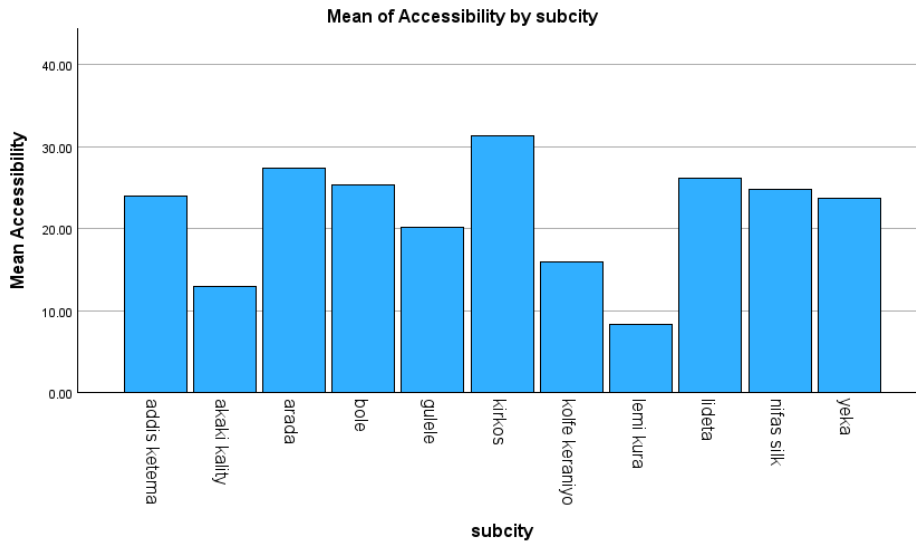


Figure 4-13 Mean of Accessibility by sub city

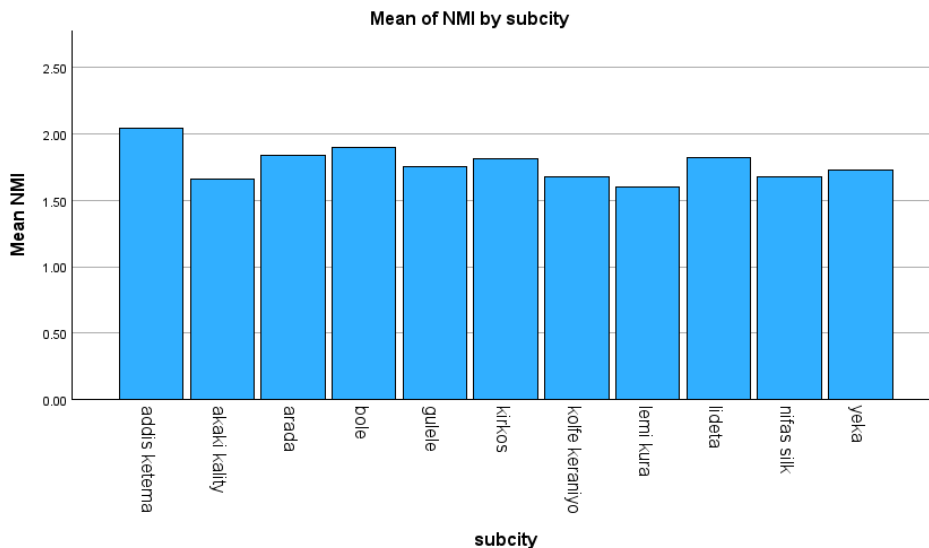


Figure 4-14 Mean of NMI by sub city

The central areas have higher NMI results (more congestion) and good Accessibility. While the peripheries have relatively better congestion, have very low accessibility.

#### 4.4 Addis Ababa Route Directness

Route directness of a zone doesn't appear to be connected to living inside the CBD or the peripheral area rather it is zones in the same regions experience the same results. This might be a result of geographical location and planning of roads in different neighborhoods (see Figure 4-15).

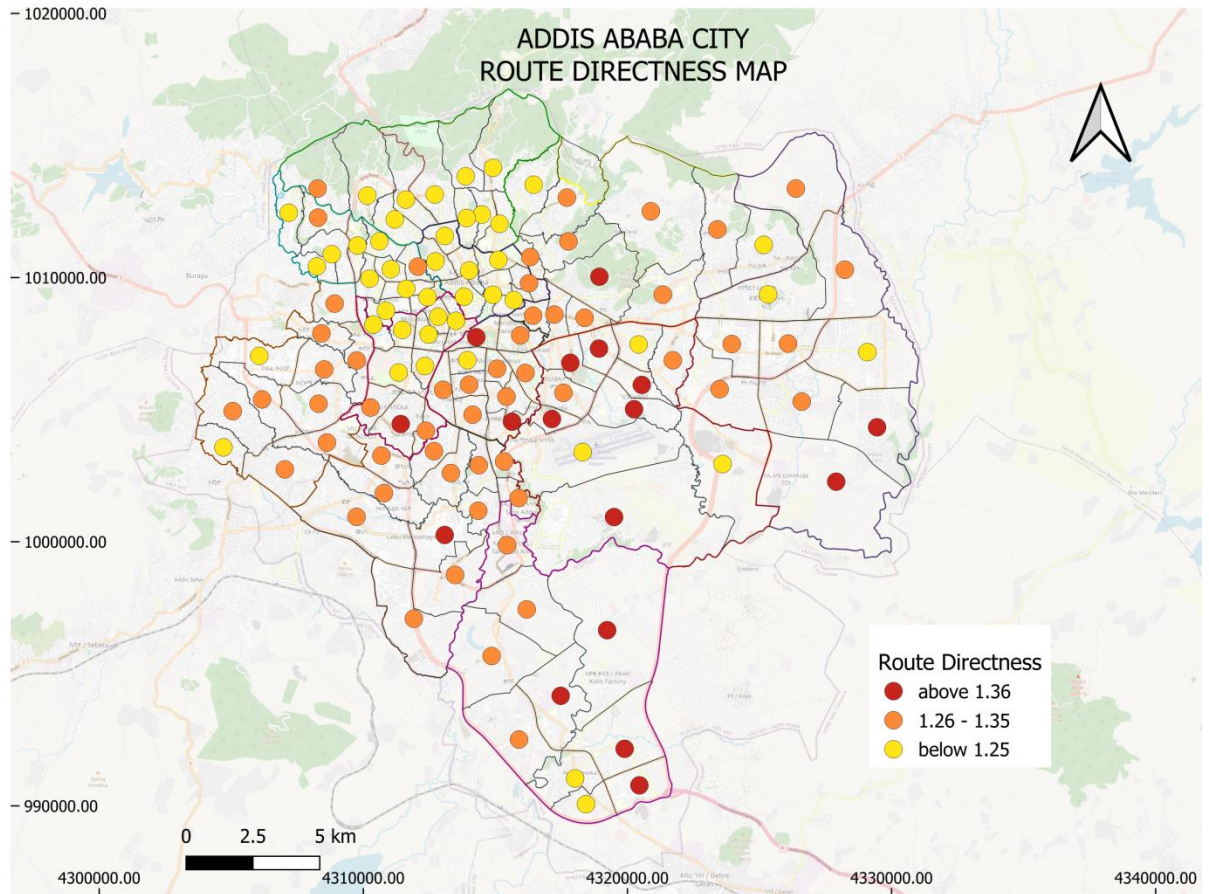


Figure 4-15 Route directness of Addis Ababa zones (Base image: openstreetmap, retrieved 1 may 2024)

Zones around Akaki Kality, Lemi Kura, Bole and few other parts experience less effective routes, as we discussed earlier one cause for this is the lack of infrastructure in the peripheral areas. Because there are not enough roads as we go further from the CBD people are likely to take longer routes. This is briefly seen in Figure 4-16 and Figure 4-17.

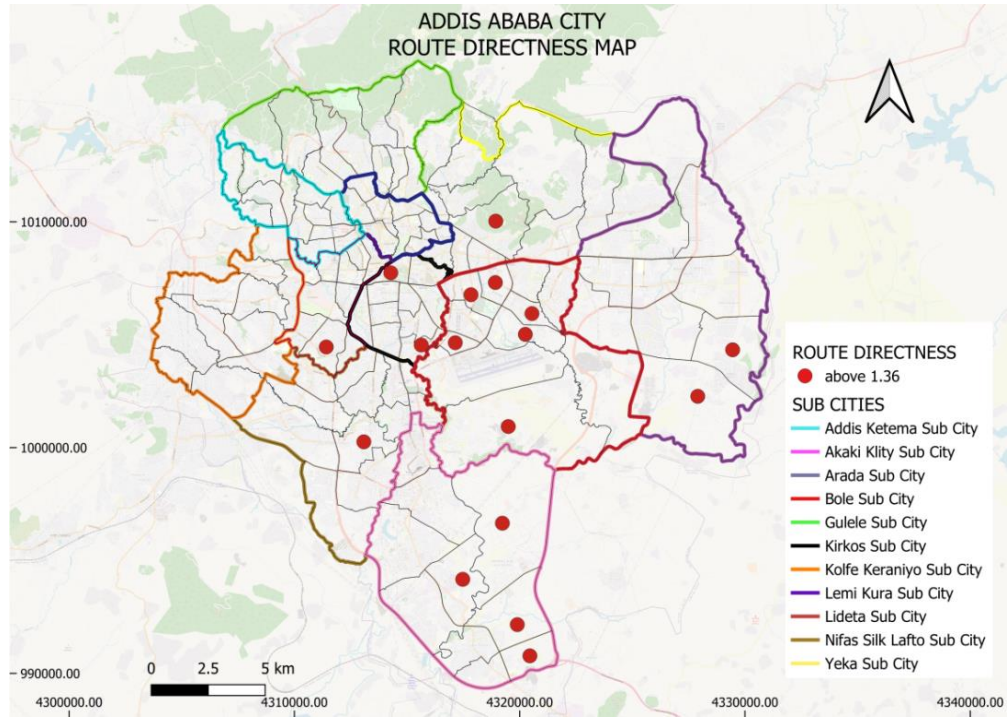


Figure 4-16 High route directness index (Base image: openstreetmap, retrieved 1 may 2024)

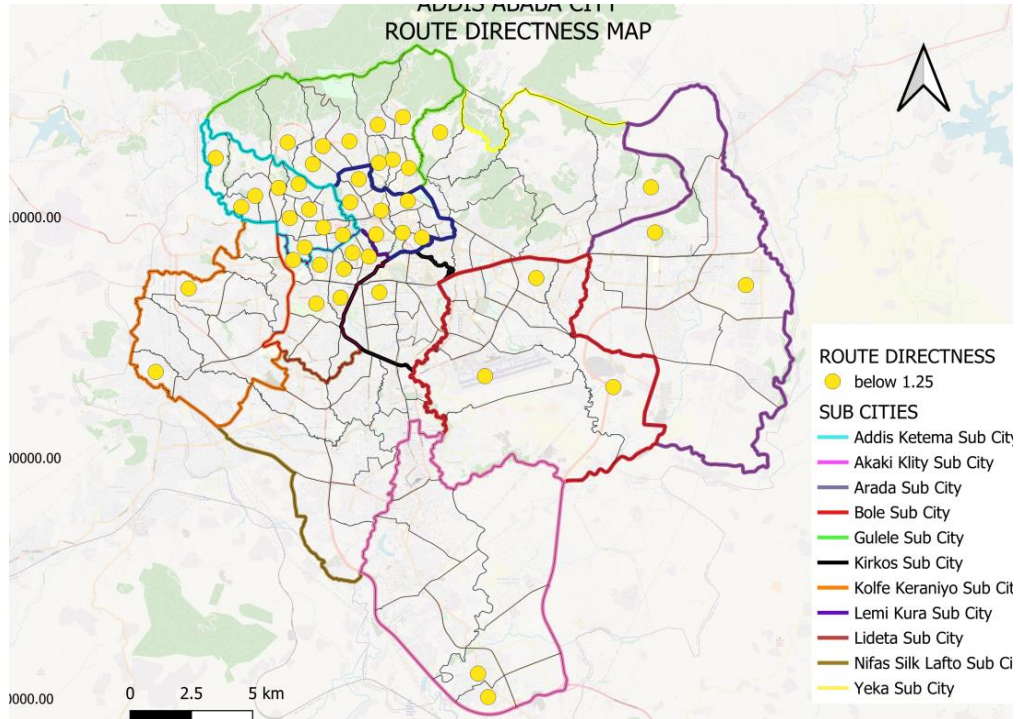


Figure 4-17 Low route directness index (Base image: openstreetmap, retrieved 1 may 2024)

## 4.5 Validation

This section presents a validation of the study by drawing comparisons with sample peak hour traffic, correlation and ANOVA testing. Mobility & accessibility of Addis Ababa zones are validated as follows.

### 4.5.1 Sample Peak Hour Traffic Congestion

Traffic was recorded around two sub cities, Kirkos (in CBD) with slow traffic, crowded roads and Nifas silk (in the peripheries) with fast traffic (see Figure 4-18 & Figure 4-19).

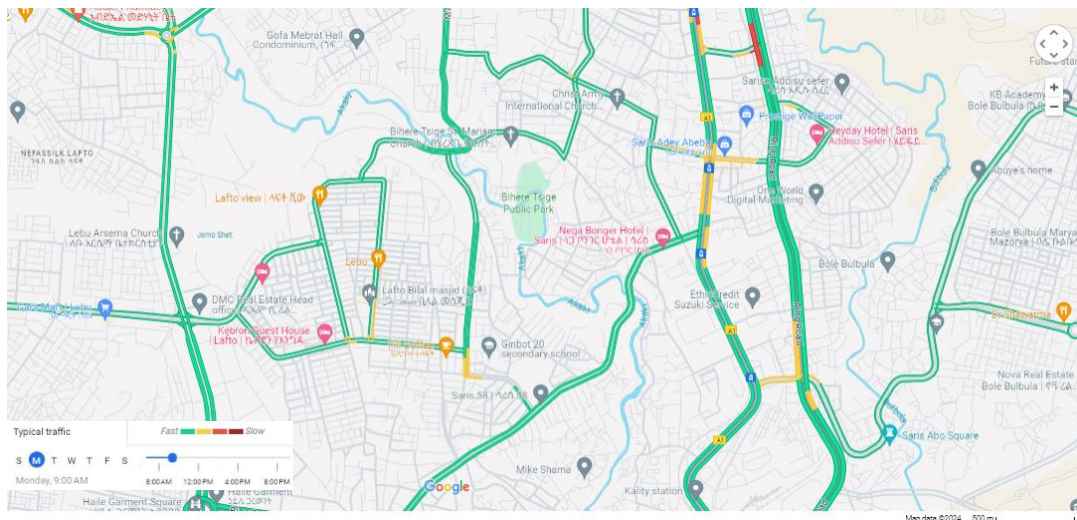


Figure 4-18 Sample traffic around nifas silk (Captioned on 17 June 2024, 9:00 AM local time)

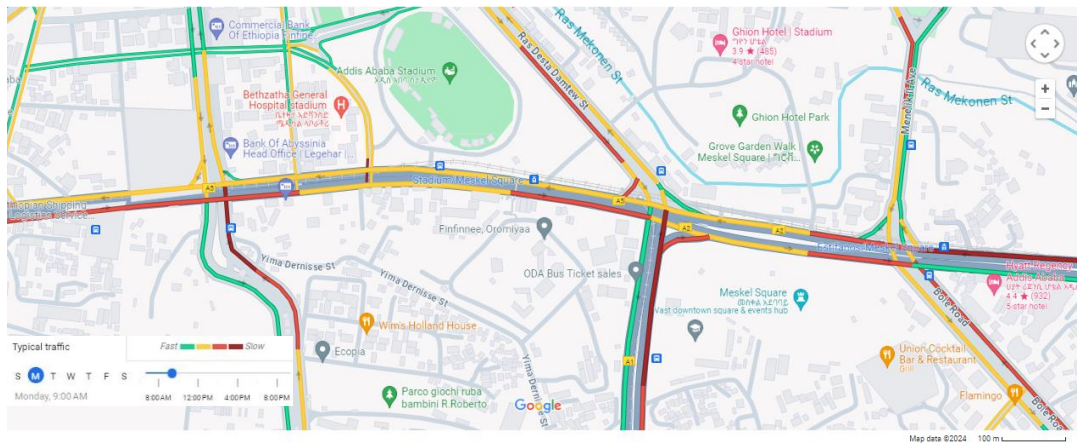


Figure 4-19 Sample traffic around kirkos (Captioned on 17 June 2024, 9:00 AM local time)

#### 4.5.2 Correlation and ANOVA Testing

A nonparametric indicator of the degree and direction of association between two variables assessed on at least an ordinal scale is the Kendall's tau-b ( $\tau_b$ ) correlation coefficient, or simply Kendall's tau-b. Whereas a score of -1 indicates that the rankings are wholly at odds, a value of +1 indicates that the two rankings are identical. The degree of association is indicated by values ranging from -1 to +1; positive values show that both variables increase together, while negative values show that one variable increases while the other falls. No association is indicated by a value of 0.

Table 4-1 Correlations between access and NMI

<b>Correlations</b>				
			access	mobility
Kendall's tau_b	access	Correlation Coefficient	1.000	.587*
		Sig. (2-tailed)	.	.012
		N	11	11
	NMI	Correlation Coefficient	.587*	1.000
		Sig. (2-tailed)	.012	.
		N	11	11
*. Correlation is significant at the 0.05 level (2-tailed).				

There is significant correlation between mobility and accessibility which means when NMI increases accessibility also increases, in another term that means worse mobility with better accessibility (see Table 4-1).

Table 4-2 ANOVA test

ANOVA						
		Sum of Squares	df	Mean Square	F	Sig.
Accessibility	Between Groups	182.675	1	182.675	5.781	.040
	Within Groups	284.409	9	31.601		
	Total	467.084	10			
NMI	Between Groups	.095	1	.095	17.351	.002
	Within Groups	.049	9	.005		
	Total	.144	10			

The test hypothesis is predicated on the idea that accessibility and mobility are correlated, meaning that limited accessibility to destinations typically accompanies good mobility and vice versa. The test showed that a significant value,  $p < 0.05$ .

#### 4.6 Discussion

This research identified the mobility and accessibility conditions in different neighborhood of Addis Ababa using the QGIS travel time plugin, basing the free flow travel time and the peak hour travel time index. Congestion is unacceptable in all the neighborhoods, which was found to be equal to and greater than 1.5, which means an Additional 50% or more of the uncongested travel time, which means if a travel initially takes 30 min in free flow, during peak hours it will take 45 min and more all over Addis Ababa zones. Although all of them are above the acceptable threshold there are still mobility inequalities between zones in Addis Ababa. There is a slight but noticeable difference between zones of different locations, in general the outer zones sub cities like Lemi Kura, Akaki Kality and Nifas Silk generally seem to have lower NMI's than zones around the CBD. While peripherals mostly experience 50% to 70% of additional delay,

zones in and around the CBD sub cities like Kirkos, Lideta, Gulele and Arada mostly experience 70% to 100% (2 times the free flow travel time).

But it's not as black and white, some of the peripheral areas experience worse congestion than the others. One cause is these areas are far away and people must travel longer times to reach their destination which in turn causes them to encounter more congestion along the way and have a higher neighborhood mobility index. Another reason is the lack of infrastructure in the peripheral areas of Addis Ababa as stated there are two types of mismatch in Addis Ababa, showing that the peripheral areas lack road infrastructure and roads in the central areas carry more than their capacity (Ayalneh, 2012). Thus it is found that the road density of Addis Ababa & Akaki kality sub city is 2.67 and 0.78 respectively (Asres, 2020). This implies that Akaki Kality being one of the peripheral areas, this means in the peripheral road density is lower than compared to the whole Addis Ababa. This is one cause of the higher traffic congestion experienced by the areas far from the CBD.

There is a clear distinction between zones and a clear relationship between location and accessibility. The inner part of the city (CBD) has the most accessibility, Sub cities like Kirkos, Lideta, Gulele and Arada, which is ability to reach more than 75% of the destination in 30 minutes. Consequently accessibility decreases as we go further from down town to peripherals, sub cities like Lemi Kura, Akaki Kality and Nifas Silk, this means that people living in the outer part of Addis Ababa have to travel more (above 30 minutes often) to reach potential destinations. Land use function of Addis Ababa indicates that most of the basic social services (universities, hospitals, big institutions etc.) all are concentrated at or around city center (Lerango, 2011); Which is the major issues causing less accessibility to peripheral residents, people who live outside the city center have to travel significantly longer to accesses this services.

A study titled "Evaluating Transport Network Structure: Case Study in Addis Ababa, Ethiopia" by Ayalneh, developed GI based indicators to evaluate road network structure in relation to potential travel demand and recommend improvement in network structure. In the CBD, Compared to production, the range of trip attraction values is far wider. As the city's primary business hubs, zones 35 and 26 (known locally as Merkato and Piazza)

have high travel attraction values. This demonstrates that the Central Business District, which surrounds the city's core and its environs, is home to the activities with high attractiveness levels, primarily employment and retail establishments. From this perspective zones in the central area with more attractive activities have a higher trip attraction and generation which in turn makes them congested. This is also true for the neighborhood mobility index, because the CBD and the north-south corridor have more congestion because of the higher trip flow in those areas. Although there is a few changes in this study, new areas in the periphery with more congestion are discovered (partial part of lemikura and bole).

In another study which the NMI is derived from, titled Development of a Neighborhood Mobility Index for Assessing Mobility Disparities in Developing Countries with Application to the Greater Cairo Area, Egypt by Wael M. ElDessouki, A case study on Greater Cairo was done using the NMI. The findings showed notable differences between the GCA neighborhoods. There is poor mobility and high traffic congestion in Cairo's central neighborhoods (ElDessouki, 2022). Despite these drawbacks, Cairo's central neighborhoods offer comparatively superior accessibility because of their close proximity to important urban hubs. This shows a similar tendency in developing nations where activities are concentrated in the central areas. However in our study results aren't as distinctive as Cairo, in Addis Ababa in addition to the entire zone being above the acceptable result some congested areas are located in the peripheries.

Comparing the mobility index and route directness map; it is not connected to living inside the CBD or the peripheral area rather it seems to be zones in the same regions experience the same results. This might be a result of geographical location and planning of roads in different neighborhoods. These being said Zones around Akaki Kality, Lemi Kura, Bole and few other parts experience less effective routes, since there are not enough roads as we go further from the CBD people are likely to take longer routes.

The results reveal that while those who live farther away must go farther in order to access activities; those who live in the center must also deal with greater traffic. However residents in the city center have a better accessibility even with the additional congestion, the accessible opportunities outweigh the additional congestion.

## CHAPTER 5 CONCLUSION AND RECOMMENDATION

This chapter is the final chapter of this research; it has two sections conclusion of the study and recommendation of appropriate practices.

### 5.1 Conclusion

This paper identified the intensity of congestion in various zones of Addis Ababa and compare it with in these zones, and analyses the relationship between location in the city and mobility using the QGIS travel time plugin I was able to gather travel time and distance, The free flow travel time and the peak hour travel time were the bases of this research. Like many urban areas, Addis Ababa also suffers from transportation issues like mobility, congestion and accessibility. To reach sustainability in transportations one of the crucial parts is having equity in mobility regardless of location or class.

As findings of this study, all zones in Addis Ababa experience unacceptable amount of delay, which is 50% and above relative to the free flow. However, zones in the inner city suffer more from congestion relative to zones further away from the CBD, although they enjoy far more accessibility of activities within the city. They are able to reach more than 75% of the destination within 30 minutes; while as we go further from downtown people have to travel more for jobs, shopping and education. From worst congestion to the least at subcity level rank as Addis ketema, arada, lideta, kirkos, bole gulele, yeka, kolfe and nifas silk, akaki kaliti and lemi kura respectively. Accessibility from good to worst is ranked as kirkos, arada, lideta, Bole, Nifas silk, Yeka, Gulele, addis ketema, kolfe keraniyo, akaki kaliti and lemi kura.

Furthermore, roads directness were analyzed, distance by physical routes were divided by distance by airline which unlike the above two analysis which showed no particular relationship between living in the city core or outside. Zones with next to each other share the same values which suggested that may be geographical location is mainly the reason behind. Nonetheless zones in the periphery had less direct roads because of the lack of transport infrastructure in these zones.

## 5.2 Recommendations

It is clear, then, that transport and urban development policies can enhance existing, and create new, inequalities in both realized everyday mobility and opportunities for such mobility. While often an unintended consequence of policy and planning, these inequalities are particularly problematic if they reinforce and/or exacerbate ‘transport poverty’ (Randal et al., 2020). A vision for sustainable mobility underlines reducing travel demand and share of private motorized trips, energy shift and technological changes will undoubtedly be part of the strategy. Reversing the trend of increasing car ownership highlights a modal shift by enhancing public transit and creating an environment that supports the growth of soft modes. Furthermore Moving away from fossil carbon fuels and toward low carbon energy sources would result in a significant reduction in transportation-related CO<sub>2</sub> emissions (O et al., 2013). Addis Ababa consumes 60% of the country’s Benzene imported and 18% of the Naphthalene, which indicates that, there are a significant number of small motorized vehicles that consumes much more fuel per passenger per kilometer (Lerango, 2011).

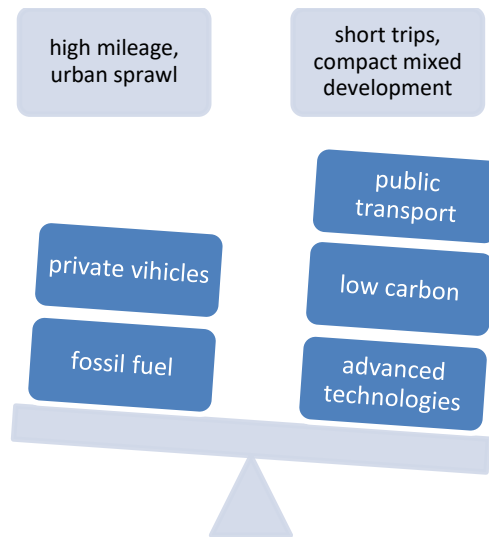


Figure 5-1 Current unsustainable tendencies and possible paths towards sustainability (Adapted from source: O et al., 2013)

The trend of income growth in developing countries drives the motorization trend causing road congestion, which in turn slows down the motorization. The congestion on the other

hand reduces the attractiveness of on-road public transport, which increases car use (in the absence of rapid transit) (Gtz, 2010; Street, 2011).

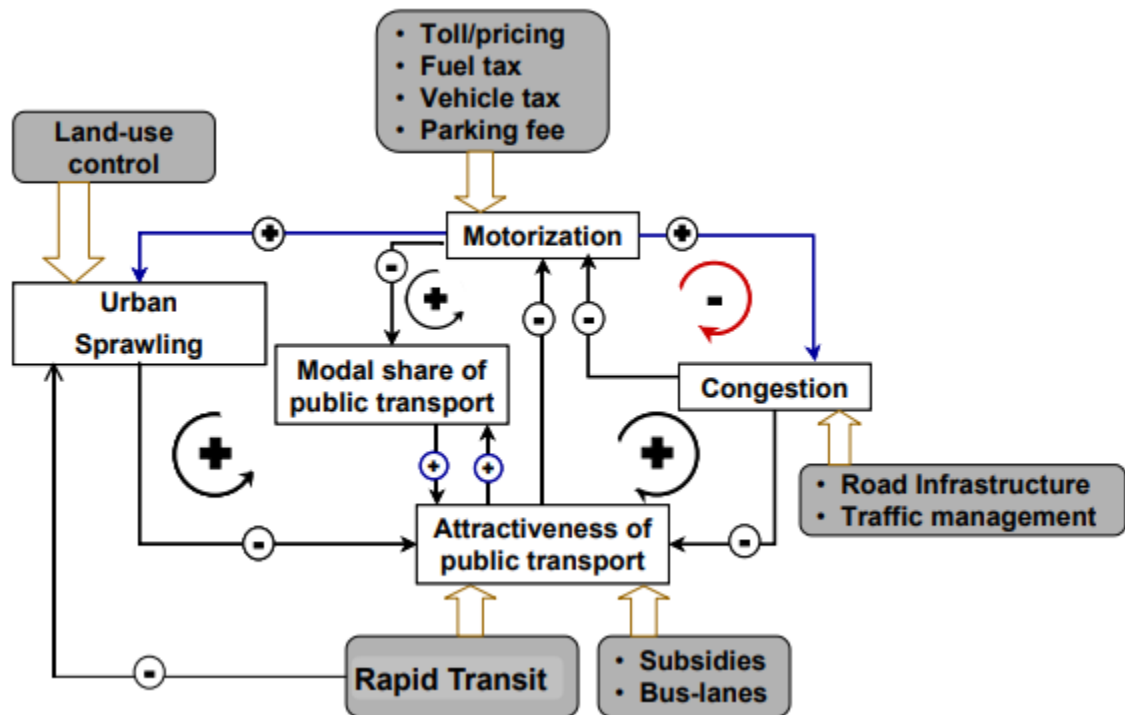


Figure 5-2 Feedback Loops Diagram (source: street, 2011, p. 4117)

As we discussed above, not one solution is gone solve all the problems rather multiple approaches that go hand in hand. Solution like compact development would reduce travel time by densification of activities in one place, and non-motorized approaches make short trips easier while they decrease our carbon emission which is good for the environment. Mass transits are also major solution that we should look into, which decreases private ownership of vehicles and increase vehicles occupancy and only building mass transit is not the end but making sure the effective use of it.

Improve public transportation since the urban poor makes up the majority of the population increasing the frequency and coverage of public transport routes especially in the peripheries is recommended. Policy challenge is how to maintain or regain the desirable modal share of public transport. One of the obvious policy options is to develop off-road rapid transit facility, which can offer high service level and thereby compete with private mode.

Infrastructure Improvements and efficiency through investing in infrastructure upgrades, such as better roads, pedestrian pathways, and bicycle lanes, to facilitate mobility, For the reason that In Addis Ababa road density is lower than the acceptable value (Ayalneh, 2012). Also Planning and design non-motorized options like Cycle lane. No only constructing these networks but maintenance and effective management is necessary.

The number of cars on the road can be decreased by policies like road pricing, carpooling encouragement, and improving safety and incident response times, which can also speed up incident clearing times and lower collision rates.

Community engagement and bottoms up approach to planning by promoting community participation in transportation planning procedures guarantees that services satisfy regional demands and preferences. By putting in place initiatives designed especially to increase mobility for vulnerable groups, like low-income citizens and those with disabilities, equity-focused programs can be implemented.

Average Daily Traffic (ADT) and Annual Average Daily Traffic (AADT), Corridor Travel Times, Vehicle Miles Traveled (VMT), and Crash Rates are important traffic metrics to assess the relative safety of various roads or intersections. Monitoring systems are used to regularly evaluate mobility and accessibility metrics. Mode Share and Peak Hour Factor (PHF) measure the percentage of individuals who utilize various modes of transportation, such as walking, bicycling, driving, public transportation, and Locating areas with inadequate or nonexistent use of alternative forms of transportation (Rasmussen, 2023).

Areas requiring further investigations include a mobility analysis that includes public transportation and if it is possible to find more information in the future; a more complex analysis of mobility condition including socioeconomic characteristics is recommended. In addition assessment on the impacts of the corridor development project which is under construction right now on mobility trends of neighborhoods in Addis Ababa will be desirable in the future.

## 6. Reference

- AACRTB, A. A. C. R. and T. B. (2016). *Ethiopia Transportation System Improvement Project. February*, 1–148.
- Addis Ababa City Government Plan and Development Commission. (2024). AA Sub City & Woreda Boundary Map & Road network map of Addis Ababa
- Addis Ababa City Roads Authority. (2010). Land use map of Addis Ababa
- Afrin, T., & Yodo, N. (2020). A survey of road traffic congestion measures towards a sustainable and resilient transportation system. *Sustainability (Switzerland)*, *12*(11), 1–23. <https://doi.org/10.3390/su12114660>
- Aftabuzzaman, M. (2007). *Measuring traffic congestion-A critical review*. <https://www.researchgate.net/publication/282780229>
- Akbar, P. A. (2018). *Mobility and congestion in urban India*.
- Anpar Research LTD. (2020). Pros And Cons Of Qualitative Research vs Quantitative Research. In *Anpar Research LTD*. <https://www.anparresearchltd.com/post/pros-and-cons-of-qualitative-research-vs-quantitative-research>
- Ashenafi, A., & Tekolla, W. (2015). *Getting the Best out of Transit Oriented Development ( TOD ) in Addis Ababa , Ethiopia : Impact of AA-LRT on Mass Transport System in Addis Ababa , challenge and possible solution Challenges of AA-LRT Public Transport Situation in Addis Ababa. September*, 1–13.
- Asres, B. (2020). *Land Use and Transportaion Demand Interactions in Addis Ababa The Interactions between Land use change and Transportation Demand in Addis Ababa , Ethiopia ( 1988-2040 ). November*, 0–16.
- Ayalneh. (2012). *Evaluating Transport Network Structure: Case Study in Addis Ababa, Ethiopia*.
- Azagew, S., & Worku, H. (2020). Accessibility of urban green infrastructure in Addis-Ababa city, Ethiopia: current status and future challenge. *Environmental Systems*

*Research*, 9(1). <https://doi.org/10.1186/s40068-020-00187-0>

- Bertini, R. L. (2005). You are the Traffic Jam: An examination of congestion measures. *85th Annual Meeting of the Transportation Research Board, January*, 17. <http://onlinelibrary.wiley.com/doi/10.1002/cbdv.200490137/abstract>
- Blanco, J., & Apaolaza, R. (2018). Socio-territorial inequality and differential mobility. Three key issues in the Buenos Aires Metropolitan Region. *Journal of Transport Geography*, 67(July 2017), 76–84. <https://doi.org/10.1016/j.jtrangeo.2017.07.008>
- Calvert, R. (2021). 20 Minute Neighbourhoods Implementing 20 minute neighbourhoods in planning policy and practice. *Royal Town Planning Institute, May 2018*, 12.
- Cascetta, E., Carteni, A., & Montanino, M. (2013). A New Measure of Accessibility based on Perceived Opportunities. *Procedia - Social and Behavioral Sciences*, 87, 117–132. <https://doi.org/10.1016/j.sbspro.2013.10.598>
- Central Stastical Service. (2024). Population Size of Addis Ababa, Area and Density by Sub City
- Chaudhary, S., Kamble, P., Honmane, B., Ingole, A., & Arangi, S. R. (2020). *Traffic Congestion in City : Causes and Solutions International Research Journal of Modernization in Engineering Technology and Science*. 06, 1234–1237.
- Cullen, S. (2019). *Causes and effects of suburban traffic dynamics: A case study in a municipality close to Munich*. July, 1–89. <http://uu.diva-portal.org/smash/record.jsf?pid=diva2%3A1337425&dswid=-1125>
- Desalegn, A., & Solomon, N. (2020). Infrastructure inequities and its effect on poverty reduction across regional states in Ethiopia. *Journal of Mega Infrastructure & Sustainable Development*, 2(3), 291–309. <https://doi.org/10.1080/24724718.2022.2122671>
- Downs, A. (2004). Why Traffic Congestion Is Here to Stay... and Will Get Worse. *Access*, 25(25), 19–25.

- ElDessouki, W. M. (2022). Development of a Neighborhood Mobility Index for Assessing Mobility Disparities in Developing Countries with Application to the Greater Cairo Area, Egypt. *Sustainability (Switzerland)*, 14(23).  
<https://doi.org/10.3390/su142315846>
- Engdasew, S. S. (2021). *Analysis of Road Traffic Congestion and its Economic Impact on Addis Ababa City : A Case Study in Yeka Sub City (A Major Intersection Along Megegnagna to Karalo)*
- Fortunati, J. (2018). Mobility doesn't mean the same thing as transportation. In *Mobility Lab*. [https://mobilitylab.org/2018/07/26/what-is-mobility/?mkt\\_tok=MjExLU5KWS0xNjUAAAF\\_Fzm91FaWliSIYXvfhf0xERVUu9KAU9Lk4KPQnZEq0sVMES\\_9OH5iHqehgzkCuS9pC2vFNZuSF5cHV5I9Ko0IcHnDvccb9oUXxxqf8IS56zkw](https://mobilitylab.org/2018/07/26/what-is-mobility/?mkt_tok=MjExLU5KWS0xNjUAAAF_Fzm91FaWliSIYXvfhf0xERVUu9KAU9Lk4KPQnZEq0sVMES_9OH5iHqehgzkCuS9pC2vFNZuSF5cHV5I9Ko0IcHnDvccb9oUXxxqf8IS56zkw)
- G. Gebre & D Van Rooijen. (2009). Institutional Repository Urban water pollution and irrigated vegetable farming in Addis Ababa. *34 Th WEDC International Conference, Addis Ababa, Ethiopia*, 166.
- Gakenheimer, R. (1999). Urban mobility in the developing world. *Transportation Research Part A: Policy and Practice*, 33(7–8), 671–689.  
[https://doi.org/10.1016/S0965-8564\(99\)00005-1](https://doi.org/10.1016/S0965-8564(99)00005-1)
- Garber, N.J. and Hoel, L. . (1996). Fundamental principles of traffic flow. *West Publishing Comp*, 213–243.
- Gtz. (2010). Challenges of urban transport in developing countries- a summary  
 Contributors to this document : Manfred Breithaupt , Armin Wagner , Carlos F . Pardo . Based on documents by Enrique Peñalosa , Lloyd Wright , Axel Friedrich , Todd Litman , Wuppertal Instit. *October, 2010(September)*, 1–76.
- Heyns, W. (2015). *Managing Traffic Congestion – The Case of Land-Use Management and Transport Planning Integration* (Vol. 86). <https://doi.org/10.2495/978-1-78466-077-2/005>

- Hidayati, I., Tan, W., & Yamu, C. (2021). Conceptualizing Mobility Inequality: Mobility and Accessibility for the Marginalized. *Journal of Planning Literature*, 36(4), 492–507. <https://doi.org/10.1177/08854122211012898>
- IvyPanda. (2022). *Descriptive Correlational Design Definition & Goals - 577 Words | Research Paper Example*. <https://ivypanada.com/essays/descriptive-statistics-and-correlational-design/>
- J. Barceló, L. Montero, X. R.-R. (2016). *ACCESSIBILITY*.
- Jamei, E., Chan, M., Chau, H. W., Gaisie, E., & Lättman, K. (2022). Perceived Accessibility and Key Influencing Factors in Transportation. *Sustainability (Switzerland)*, 14(17). <https://doi.org/10.3390/su141710806>
- Jiang, X., Wang, J., & Tang, Y. (2008). Molecular cloning and expression analysis of a novel human testis-specific gene septin 12 transcript variant 2. *Chinese Journal of Andrology*, 22(3), 6–10.
- JICA. (2008). *Technical Report 2 Transport Planning & Development PART 2 : Traffic Control and Management*. 6.1-6.74.
- Kayal, M. P., Singh, R., & Kumar, M. M. (2012). Defining Sustainable Urban Mobility. *The Energy and Resources Institute TERI-NFA Working Paper, March*, 1–12. <https://www.teriin.org/projects/nfa/2008-2013/pdf/working-paper-11-Defining-Sustainable-Urban-Mobility.pdf>
- Lerango, Z. (2011). *Sustainable transport system: Mobility and Accessibility in Addis Ababa*.
- Litman, T. (2003). Measuring transportation: Traffic, mobility and accessibility. *ITE Journal (Institute of Transportation Engineers)*, 73(10), 28–32.
- Lomax, T. J., Schrank, D. L., & Eisele, W. (2005). The Keys to Estimating Mobility in Urban Areas, Applying Definitions and Measures that Everyone Understands. *Texas Transportation Institute, The Texas A&M University System, College Station, Texas., May 2005*.

- Mekonnen, B., Hailu, A., Molla, M., & Legesse, M. (2024). Trends of higher education enrolment , graduation , and employment in Ethiopia : an empirical analysis. *Cogent Education*, 11(1). <https://doi.org/10.1080/2331186X.2024.2302623>
- Mena Kuleno, M., Debisa Denno, H., Abera, G., & Ramesh Reddy, R. (2018). Quantifying Traffic Congestion by Studying Traffic Flow Characteristics in Wolaita Sodo Town, Ethiopia. *International Journal of Scientific & Engineering Research*, 9(6), 109–120. <http://www.ijser.org>
- Meyer, M. D. (2016). Transportation Planning Handbook. In *Transportation Planning Handbook*. <https://doi.org/10.1002/9781119174660>
- Miller, E. J. (2018). Accessibility: measurement and application in transportation planning. *Transport Reviews*, 38(5), 551–555. <https://doi.org/10.1080/01441647.2018.1492778>
- Miller, E. J., & Ph, D. (2021). *TRAFFIC ANALYSIS ZONE DEFINITION : ISSUES & GUIDANCE. March*.
- Mohan Rao, A., & Ramachandra Rao, K. (2012). Measuring Urban Traffic Congestion – a Review. *International Journal for Traffic and Transport Engineering*, 2(4), 286–305. [https://doi.org/10.7708/ijtte.2012.2\(4\).01](https://doi.org/10.7708/ijtte.2012.2(4).01)
- Moran Toledo, C. (2011). *Relevance and Reliability of Area-Wide Congestion Performance Measures in Road Networks*.
- Muhammad Ali, P. J., & Faraj, R. H. (2013). *A traffic congestion problem and solutions: the road between Sawz Square and Shahidan Square in Koya city as a case study*. 125–133. <https://doi.org/10.2495/isud130151>
- O, J., H, C. N., Oliveira, P. De, & A, J. (2013). *The Sustainable Mobility- Congestion Nexus: A Co- Benefits Approach to finding Win-Win Solutions*. 82.
- Peralta-quirós, T. (2015). *Getting the Right Urban Indicator*. November.
- Randal, E., Shaw, C., Woodward, A., Howden-Chapman, P., Macmillan, A., Hosking, J.,

- Chapman, R., Waa, A. M., & Keall, M. (2020). Fairness in transport policy: A new approach to applying distributive justice theories. *Sustainability (Switzerland)*, 12(23), 1–21. <https://doi.org/10.3390/su122310102>
- Rasmussen, R. (2023). *10 Essential Transportation Metrics to Monitor*. <https://urbanlogiq.com/10-essential-transportation-metrics-to-monitor/>
- Rodrigue, J. (2021). *Transport Modes and Globalization*. January. <https://doi.org/10.1016/b978-0-08-102671-7.10403-8>
- Salazar-Ferro , Pablo, Ferdinand Boutet, J., & Allaire, M. G. M. (2023). *Topic guide Integrating land-use and urban mobility planning*.
- Savvides, A. (2013). *Equity of mobility in sustainable transportation*. 179, 1091–1101. <https://doi.org/10.2495/SC130932>
- Schrank, D. (2001). The keys to estimating mobility in urban areas. *ITE 2001 Annual Meeting and Exhibit, May 2005*. <http://trid.trb.org/view.aspx?id=709596>
- Sciences, S., Work, S., & Correspondence, U. K. (2017). *The Advantages and Disadvantages of Using Qualitative and Quantitative Approaches and Methods in Language “ Testing and Assessment ” Research : A Literature Review*. 6(1), 102–112. <https://doi.org/10.5539/jel.v6n1p102>
- Sekasi, J., & Martens, M. L. (2021). Assessing the contributions of urban light rail transit to the sustainable development of addis ababa. *Sustainability (Switzerland)*, 13(10), 1–22. <https://doi.org/10.3390/su13105667>
- Shiferraw, M. (2022). City Profile: Addis Ababa. *World Literature Today*, 96(3), 5. <https://doi.org/10.1353/wlt.2022.0101>
- Stangl, P. (2019). Overcoming flaws in permeability measures: modified route directness. *Journal of Urbanism*, 12(1), 1–14. <https://doi.org/10.1080/17549175.2017.1381143>
- Street, S. J. (2011). *Journal of the Eastern Asia Society for Transportation Studies, Vol.9, 2011*. 9, 1558–1571.

- Suarez, F. (2009). Gracias por su interés en esta publicación de la CEPAL. In *Repositorio*.
- Sub Saharan Africa Transport Policy Programme. (2018). *SSATP-Ethiopia-Sustainable Mobility and Accessibility Policy in Cities-Policies for Sustainable Accessibility and Mobility in Cities of Ethiopia*.
- Tammaru, T., Sevtsuk, A., & Witlox, F. (2023). Towards an equity-centred model of sustainable mobility: Integrating inequality and segregation challenges in the green mobility transition. *Journal of Transport Geography*, 112(June), 103686. <https://doi.org/10.1016/j.jtrangeo.2023.103686>
- Teferi, H. G. (2020). *Assessing Traffic Congestion and Cost Analysis in Addis Ababa : The Case of Megegnagna Diaspora and Lamberat Semen Bus Terminal Square , Yeka Sub – City*. 3(6).
- Thomson, I., & Bull, A. (2006). Urban traffic congestion: Its economic and social causes and consequences. *CEPAL Review*, 2002(76), 105–116. <https://doi.org/10.18356/f43aec5d-en>
- Transport policy of Addis Ababa. (2011). *Transport Policy of Addis Ababa. August*, 1–47. <https://chilot.me/wp-content/uploads/2011/08/transport-policy-of-addis-ababa.pdf>
- Transportation Land-Use Modeling & Policy. (2022). Chapter 9: Introduction to Transportation Modeling: Travel Demand Modeling and Data Collection & Chapter 13: Last Step of Four Step Modeling (Trip Assignment Models)
- UK Government. (2016). *Overall measure of accessibility of services*. 1–8. [https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment\\_data/file/742199/Overall\\_accessibility\\_measure\\_Sept\\_2018.pdf](https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/742199/Overall_accessibility_measure_Sept_2018.pdf)
- Venter, C. (2017). *Developing a common narrative on urban accessibility: A transportation perspective*. November.
- Wang, M., & Debbage, N. (2021). Urban morphology and traffic congestion:

- Longitudinal evidence from US cities. *Computers, Environment and Urban Systems*, 89(July), 101676. <https://doi.org/10.1016/j.compenvurbsys.2021.101676>
- Weisbrod, Glen, Vary, Don, and Treyz, George, Economic Implications of Congestion, NCHRP Report 463, T. research B. (2001). *Traffic Congestion and Reliability: Trends and Advanced Strategies for Congestion Mitigation: Chapter 2*. [https://ops.fhwa.dot.gov/congestion\\_report/chapter2.htm#content](https://ops.fhwa.dot.gov/congestion_report/chapter2.htm#content)
- Wen, L., Kenworthy, J., Guo, X., & Marinova, D. (2019). Solving Traffic Congestion through Street Renaissance: A Perspective from Dense Asian Cities. *Urban Science*, 3(1), 18. <https://doi.org/10.3390/urbansci3010018>
- Wondimu Tekolla, A., Segni Tulu, G., & Gebre Tarekegn, A. (2021). Evaluating the Impact of Addis Ababa Light Rail Transit on Public Transit System, Its Efficiency and Eligibility for Transit Oriented Development (TOD). *American Journal of Traffic and Transportation Engineering*, 6(6), 160. <https://doi.org/10.11648/j.ajtte.20210606.13>
- World Bank. (2014). *Federal Democratic Republic of Ethiopia Addis Ababa Urban and Metropolitan Transport and Land Use Linkages Strategy Review Note of Proposed World Bank Engagement on Urban and Metropolitan Transport and Land-use for Inclusive Green Growth in Addis Ababa*. ACS12347, 27.
- World Bank. (2020). Challenges in Urban Mobility and the Way Forward: A study of Maseru, Lusaka, and Harare Cities. *Challenges in Urban Mobility and the Way Forward*. [www.worldbank.org](http://www.worldbank.org)
- Www.vtppi.org. (2020). *5.5 Congestion*. March 2020, 1–28.

## Appendixes

### Appendix A Article

Analyzing the mobility differences between neighborhoods in Addis Ababa

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### Abstract

Addis Ababa is the principal city of Ethiopia and one of the fastest growing cities in Africa. However, in Ethiopian cities, the rate of physical urban growth has outpaced the rate of infrastructure and service provision. To make matters worse, the lack of data in Ethiopia continues to be a major obstacle to accurately identifying and analyzing challenges related to urban mobility. This study used the neighborhood mobility index and QGIS travel time plugin to determine the mobility and accessibility conditions in Addis Ababa neighborhoods. It was found that all neighborhoods were above the acceptable threshold of NMI 1.5, which means most residents in Addis Ababa travel an additional of 50% of the free flow travel time or more, and among these, zones in the CBD counter more congestion relative to zones in the peripheries. Though, it reveals that zones in the CBD enjoy far more access to major activities in the city, more than 75% of the city's major destinations are reachable within 30 minutes. Conclusively, the pragmatic finding indicate that neither people living in the city or in the peripheries have it all, Due to the concentration of social services in the center, those who live farther out must travel longer to attend activities. On the other hand, roads in the core areas are overflowing with traffic, central inhabitants must likewise contend with even more congestion. Using congestion as a mobility indicator, the study's findings will assist legislators and urban planners in identifying mobility differences among Addis Ababa's zones and in customizing future road network enhancement measures to address those problems.

**Key words:** Addis Ababa, Accessibility, Congestion, Equity, Mobility, QGIS

## 1. Introduction

The ultimate objective of transportation equity is to guarantee equal access to social and economic opportunities by ensuring fair levels of access for everyone to all locations (Savvides, 2013). It is concerned with the effectiveness of transportation, its price, and the degree of mobility of individuals (Randal et al., 2020). Equity in urban mobility for different neighborhoods within the city is a critical factor for social justice and sustainable development (ElDessouki, 2022).

The movement of people or things is referred to as mobility. It is presumptively understood that "travel" refers to person or ton miles, and "trip" refers to person or freight vehicle trips (Litman, 2003). Mobility is entwined with congestion and accessibility. An important component of measuring mobility is congestion, Congestion is the inability to reach a destination in a time and cost that are satisfactory to the traveler, when traffic is moving at speeds below the designed capacity of a roadway (Downs, 2004). While, accessibility refers to the number of places or opportunities that may be reached in a certain amount of time from a particular set of places (Hansen, 1959 ; Schrank, 2001). The idea of accessibility heavily

incorporates mobility. Three perspectives on accessibility exist: as an instrument of the effectiveness of mobility, of access to transportation, and of access to opportunities (Venter, 2017). Access requires mobility; If it takes you a long time to get somewhere, there are no secure options for transportation, and it's expensive, you don't have access because you lack mobility (Fortunati, 2018). This means that urban mobility is a means to ensuring an end, namely accessibility (J. Barceló, L. Montero, 2016).

Measuring mobility using congestion as an indicator, one can compare the travel speed under crowded conditions to the travel speed in free flow conditions (Afrin and Yodo, 2020). Congestion is a function of reduction in speeds, Therefore, the setting of a thresh old that is directly related to travel speeds is most appropriate. This is in contrast to the traditional planning use of LOS, which compares volumes with capacity and does not explicitly account for speed (Suarez, 2009). Most measures require data that is hard to find in a developing country like Ethiopia, thus the neighborhood mobility index was chosen as it uses minimum land use information and travel time from online sources.

Urban growth, poor transportation infrastructure, a lack of strong administration, gaps in transportation laws and regulations, and natural terrain all have an impact on Addis Ababa's transportation system (Lerango, 2011). The peripheral areas lack road infrastructure and roads in the central areas carry more than their capacity, since main activities, primarily jobs and shopping malls, are concentrated in the Central Business District (Ayalneh, 2012). Even though Addis Ababa has a low rate of vehicle ownership compared to global standards, people are moving more and more in that direction; as well as Lack of proper road infrastructure contributes to these issues by causing traffic jams, car emissions, and accidents in the transportation systems (Asres, 2020). The following factors have been linked to traffic congestion: Lack of effective mass transit, an imbalance between traffic volume and road capacity, traffic diversion, inadequate traffic control, a difficulty with population growth, as well as on-street parking (Engdasew, 2021).

To address growing congestion, public authorities made significant investments in the capital city of Addis Ababa over the past ten years. An LRT was built, and partnerships with significant donors were

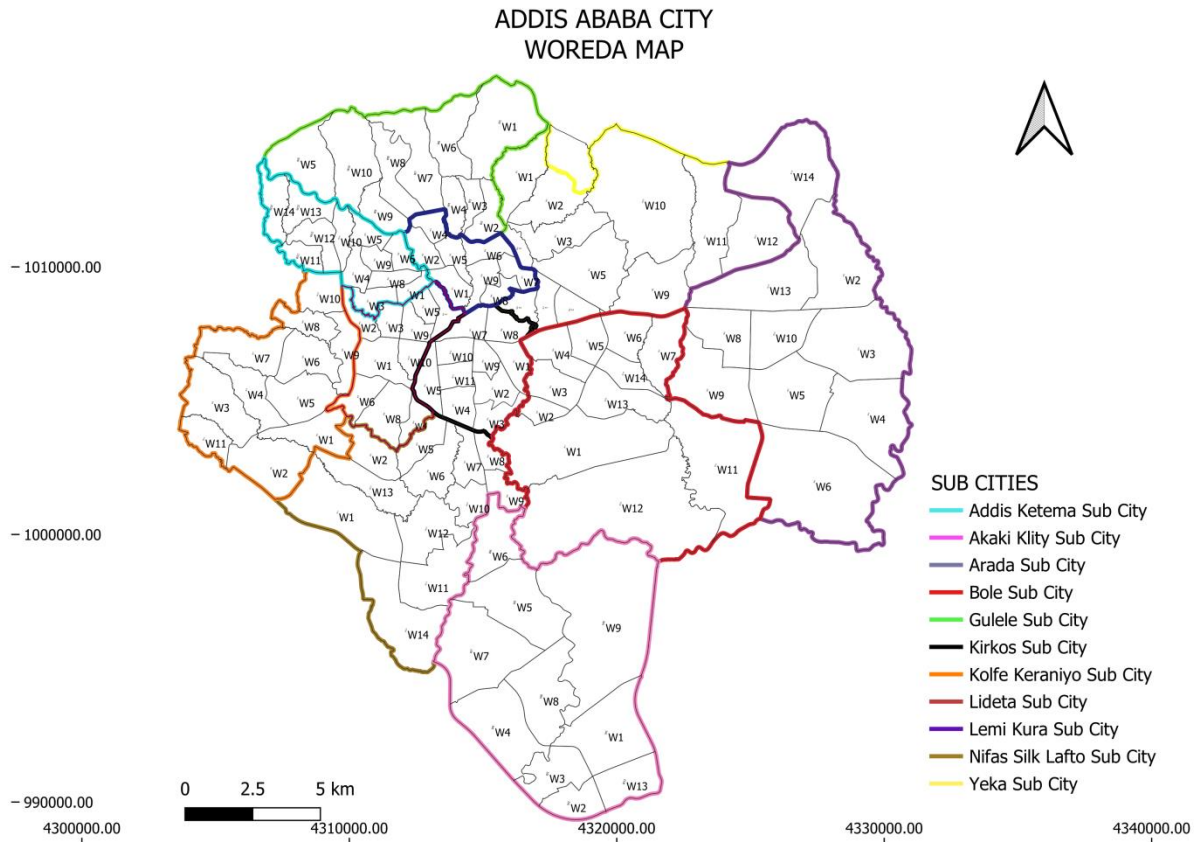
formed to enhance bus services, make investments in traffic management and infrastructure, and create a BRT system (Sekasi & Martens, 2021). Even though much has been expected from AA-LRT to alleviate the transportation problems in Addis Ababa, its mobility share among other mass transport is only 6% and it is getting lesser every day (Wondimu Tekolla et al., 2021). To make matters worse the scarce availability of data in Ethiopia remains a major impediment to identifying and precisely analyzing urban mobility challenges (Sub Saharan Africa Transport Policy Programme, 2018).

This study used the QGIS travel time plugin to identify the accessibility and mobility conditions in several Addis Ababa neighborhoods, basing on the free flow travel time and the peak hour travel time index. The study is distinctive in that it makes use of third-party travel time data and minimal land-use information to help develop an inclusive, unbiased, and trustworthy outcome. In order to target the neighborhoods who need it the most and achieve mobility equity, this research intends to assist in allocating the few funds we have based on extensive analysis.

## 2. Study area

Addis Ababa is geographically located at the heart of the nation, 9o2’N latitude and 38o45’E longitude. Its average altitude is 2,400 meter above sea level, occupying a total of 540 sq. km land area surrounded by mountainous landscape. Addis Ababa serves

as social, economic and political center for the country, about 65% of industries of the country are located in the city (G. Gebre & D Van Rooijen, 2009). It is a seat for African Union, United Nations Economic Commission for Africa, and other international organizations..



*Figure 1 Addis Ababa map with its Sub Cities and Woredas (source Addis Ababa city government plan and development commission; 2022)*

The city is divided into 11 sub-cities and 116 woredas, which are the lowest administrative units (Shiferraw, 2022) (see figure 1). Addis Ababa accounts for 25 percent of the urban population, with The

remainder roughly evenly split between the medium-sized cities of 20,000 – 500,000, and small cities of under 20,000 people (World Bank, 2014). Total population as of 2024 estimated to be 4,030,000 with an

annual growth rate of 4.4 percent (CSS, 2024) (

The population growth in the city is by far out pacing economic growth, resulting in a large slum and squatter settlements (Azagew & Worku, 2020). The physical

horizontal expansion, economic advancement and rapid population growth results in many transportation service problems like: congestion, inaccessibility and unsafe conditions for the transport users (Asres, 2020)

*Table 1 Population density by sub city based on CSS data*

Sub city	2010 pop	2024 pop	Area sq./km	Density (2010)	Density (2024)
<b>Central Area Total</b>			41.12	23,052	31,832.9
<b>Lideta</b>	214,796	296,724	9.18	23,398	32,322.8
<b>Kirkos</b>	235,441	325,502	14.62	16,104	22,264
<b>Arada</b>	225,999	311,175	9.91	22,805	31,400
<b>Addis Ketema</b>	271,444	375,568	7.41	36,659	50,683
<b>Peripheral Area total</b>			485.87	4,053	5,600.3
<b>Akaki Kality</b>	195,273	266,587	118.08	1,654	2,257.7
<b>Nifas Silk</b>	335,740	465,317	68.3	4,916	6,812.8
<b>Kolfe keraniyo</b>	456,219	630,826	61.25	7,448	9,818
<b>gulele</b>	284,865	393,631	30.18	9,439	13,042.7
<b>yeka</b>	368,418	510,064	85.98	4,285	5,932.4
<b>bole</b>	328,900	454,605	122.08	2,694	3,723.8

(Adapted from source, css, 2024)

In contrast to their area proportions most people are concentrated in the CBD sub cities such as Arada, Kirkos, Gulele and Addis ketema sub cities. These sub cities are responsible for small portion of the total area (8%) but they account for over 32 % of the city's population (see table 1)

### 3. Methods

All the necessary secondary data was gathered from Addis Ababa City Government Plan, Development Commission and ACCRA; Administration district map, Land use map and Road network map were collected. Since the

data's collected are from different sources, different format and period, unifying data, updating and checking their consistency with online sources like google satellite map and open street map was essential to obtain accurate results in later stages. Then smallest administrative unit i.e. woredas were chosen as traffic analysis zones, A Total of 116 neighborhoods. Each zone is then reduced to a single point represented by centroid. For major destinations, high density mixed residential areas, commercial areas/markets, industries and higher educational institutes were chosen, Totally 42 major destinations were chosen.

Travel time was recorded between TAZ's and major destinations from online source, the QGIS travel time plug in, and enormous data was collected using this technology otherwise not possible. The peak hour travel time was recorded at the morning peak hour and the free flow travel time was recorded at night and during Sunday and the results were exported into excel for analysis. In Addis Ababa, Monday and Friday have high traffic variation from the normal weekdays and Weekends (Saturday and Sunday) have low traffic volume. Generally classified in three classes such as:

- A. Morning Peak Period: the time from 07:00 - 10:00 AM,
- B. Inter-peak Period or Mid-day period: the lowest traffic volume from 11:00 AM - 02:00 PM and
- C. Evening Peak Period: from 04:30 PM - 07:30 PM (Teferi, 2020)

According the neighborhood mobility index formula NMI, mobility and accessibility was calculated for each of the 116 traffic analysis zones. Finally results were put back into QGIS to generate maps, such as zone mobility in Addis Ababa and Accessibility of zones in Addis Ababa. At the end results were discussed and compared with available literature.

### **3.1. Mobility disparity analysis**

A total of 116 zones and 42 destinations were created, weight of destinations was assigned based on the population data. According to Ethiopian Statistical Service (ESS): the 2022 urban bi annual employment unemployment survey, The highest proportion about 72.4 percent of the employed persons are absorbed by the total service sectors out of this wholesale and retail trades covers about 20.0 percent, accommodation art and recreation 3.9% and the rest of other service sectors 48.5% represented by other types of services. Manufacturing, mining, quarrying and

construction industry divisions are growing in urban areas together constituted 13.9 percent. the number of people enrolled in higher education was 388,186 in 2018 and forecasted to be around 500,000 in 2024 (Mekonnen et al., 2024). Accordingly the number of people who work in service sectors, manufacturing and education is given as 16:3:1. Based on this each destination was assigned a weight of the route. Travel instances which had very short trips (less than 2km) were not included; the data seem to be unreliable for short distances. The main indicators of the analysis follow the relationship between free flow travel time and peak hour travel time.

Travel time index = peak hour travel time/free flow travel time

The mobility index for a neighborhood is given as follows (ElDessouki, 2022)

$$NMI = \frac{\sum_{JED} W_{IJ} * TR_{IJ}}{\sum_{JED} W_{IJ}}$$

Where

- $\{D\}$  is the set of major attractors/destinations in the study area.
- $W_{ij}$  is the weight for the route origin (i) and destination (j),
- $TR_{ij}$  is the travel time ratio between the origin (i) and destination (j). free flow divided by peak hour travel time

The NMI reflects the average congestion residents of that neighborhood encountered daily during their trips from home to work or university. According to the NMI results we can categorize it into 4 groups.

- 1) 1.0–1.25: This category reflects the optimum situation; the congestion delay is at most 25% of the free-flow travel time.
- 2) 1.25–1.49: This category is marginal but still acceptable; where the congestion delay is between 25% to 50% of the free-flow travel time.
- 3) 1.50–1.75: This category is unacceptable because the average delay exceeds 50% of the free-flow travel time.
- 4) > 1.75: This category is considered the worst case; the congestion delay exceeds 75% of the free-flow travel time, and walking might be a better choice.

Travel time will be taken from google map during the following hours.

- The morning peak hour 8:00 of April 22 2024.
- Free flow time was taken on Sunday April 21 2024 at mid-day 2:00 pm.

These were chosen to retrieve travel matrix between origins and destinations, to avoid non reoccurring traffic future time predicted by google is used as well as

collected separately Then exported to excel format and merged together based on their Id's.

### 3.2 Accessibility Analysis

Accessibility has long been recognized as a core concept in transportation, as the vast majority of travel is undertaken for the purpose of interacting with opportunities at the destination (Venter, 2017). Many accessibility measures simply use distance (either straight-line or network path-based, with the latter being generally preferable) as the metric. For walk accessibilities, distance is a suitable measure since it readily maps into travel time and is also a direct measure of the level of effort involved in accessing a given point. Otherwise, however, travel time is generally a much better measure of perceived impedance than distance (Miller, 2018).

*Accessability oportunities*

$$= \sum \text{objective fulfillment oportunities}$$

Where travel time

$\leq$  the acceptable travel time

Data elements;

- Travel time to destination
- Distance to destination
- Land use data
- Individual characteristics

Here travel time used as the bases for determining the accessibility potential of a given zone. Accessibility was calculated for each of the 116 traffic analysis zones in contrast to 42 major destinations in the city. There for the equation was revised as follows;

$$\begin{aligned} & \text{accessability oportunitiesof a zone \%} \\ & = \frac{\sum \text{destinations} \leq 30\text{min} * 100}{\sum \text{destinations}} \end{aligned}$$

Accessibility oportunities of a zone was determined by the number of major destinations reachable from that zone within 30 min. all the destination that took more than 30 minutes to reach was deemed as inaccessible. The results were put in percentages for better understanding, which means if a zone has an accessibility of 50%; it is within 30 minutes' drive to half of the major destinations. And results we can categorize it into 4 groups.

- 1) Accessibility of oportunities of a zone to 25% of the destinations ; poor
- 2) Accessibility of oportunities of a zone between 25% - 50 % of the destinations ; average
- 3) Accessibility of oportunities of a zone between 50% - 75 % of the destinations ; good

4) Accessibility of opportunities of a zone between above 75% of the destinations very good

Another way of measuring accessibility opportunities in QGIS is by using the travel time filter, first the 42 major destinations we established are selected as destinations we want to evaluate and traffic analysis zones are then selected as a starting point. The maximum time was set 30 minutes and driving (private car) was the transportation mode selected. The morning peak hour was the time chosen. It classifies the major destinations we selected earlier into

reachable and unreachable according to the time filter we put in.

#### 4. Results

##### 4.1 Neighborhood mobility of Addis Ababa

Congestion appears to be unacceptable in all the neighborhoods, which was found to be equal to and greater than 1.5, which means an Additional 50% or more of the uncongested travel time, if a travel initially takes 30 min in free flow, during peak hours it will take 45 min and more for almost all Addis Ababa zones.

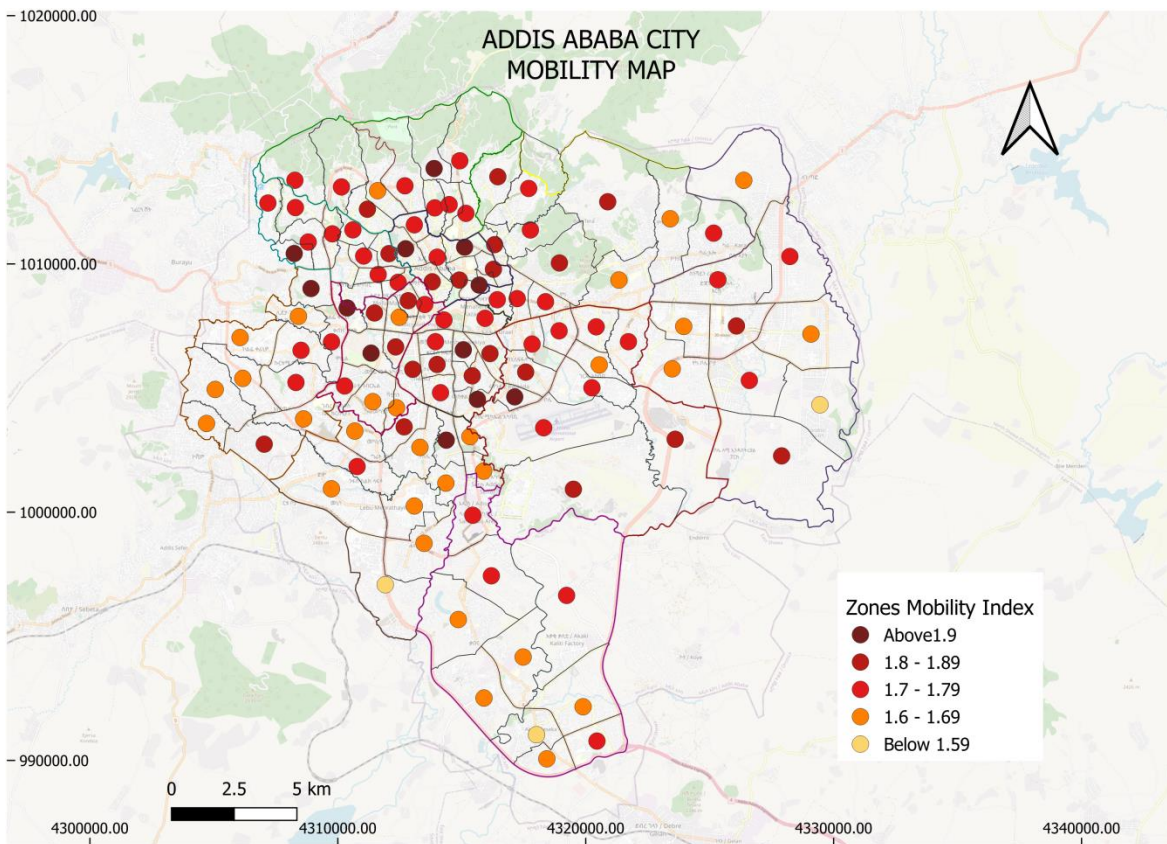


Figure 2 Addis Ababa neighborhood mobility map (Base image: openstreetmap, retrieved 1 may 2024)

Although all of them are above the acceptable threshold there are still mobility inequalities between zones in Addis Ababa. There is a slight but noticeable difference between zones of different locations, in general the outer zones sub cities like Lemi Kura, Akaki Kaliti and Nifas Silk generally have lower NMI's than zones around the CBD. While peripherals mostly experience 50% to 70% of additional delay, zones in and around the CBD sub cities like Kirkos, Lideta, Gulele and Arada mostly experience 70% to 100% (2 times the free flow travel time). The four central sub-cities are the most congested in comparisons to Peripheral Area (figure 2). Even though these areas only count for 8% of the total city area, their population accounts for 32% of the city residents. Even if they are closer to activities

it's harder to move around because residents from every corner come to the CBD for the same opportunities. Nonetheless it's not as black and white, some of the peripheral areas experience worse congestion than the others. One reason is these areas are far away and people must travel longer times to reach their destinations, which causes them to encounter more congestion along the way and have a higher neighborhood mobility index. Another reason is the lack of infrastructure in the peripheral areas of Addis Ababa as identified there are two types of mismatch in Addis Ababa, showing that the peripheral areas lack road infrastructure and roads in the central areas carry more than their capacity (Ayalneh, 2012).

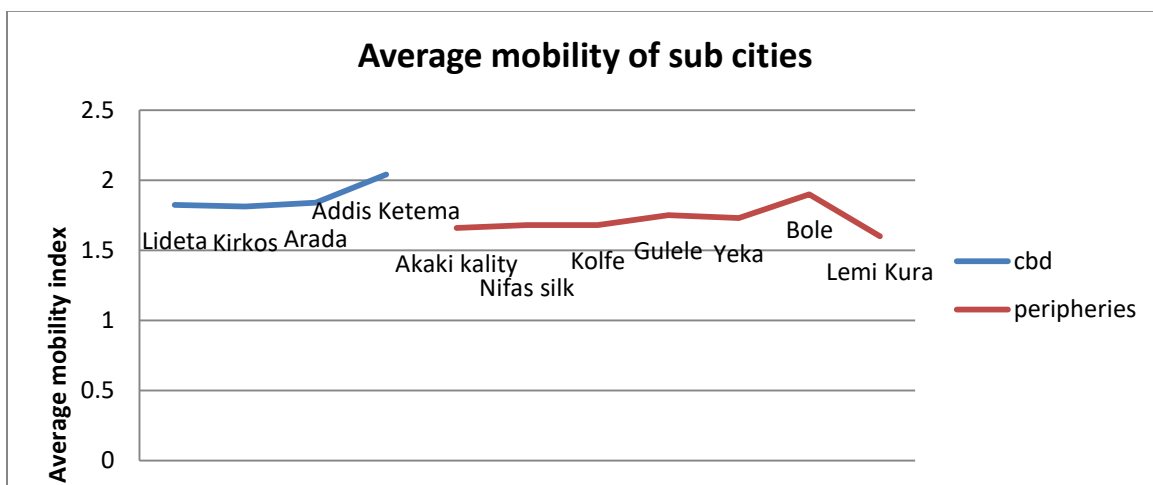


Figure 3 Average mobility indexes of zones

From worst congestion to the least at subcity level rank as Addis ketema, arada, lideta, kirkos, bole gulele, yeka, kolfe and nifas silk, akaki kality and lemi kura respectively (see figure 3).

Higher road density value implies that as there are available transport routes resulted for higher directedness and connectivity level within the networks. Thus it is found that the road density of Addis Ababa & Akaki kality sub city is 2.67 and 0.78 respectively (Asres, 2020). This implies that Akaki Kality being one of the peripheral

areas, in the peripheral road density is lower than compared to the whole Addis Ababa. This is one cause of the higher traffic congestion experienced by the areas far from the CBD.

## 5.2. Accessibility of Activities

For a more compressive view, accessibility for the 116 woredas were studied. As we discussed earlier accessibility is the end point of mobility, Accessibility opportunities of a zone was determined by the major destinations reachable from that zone within 30 min.

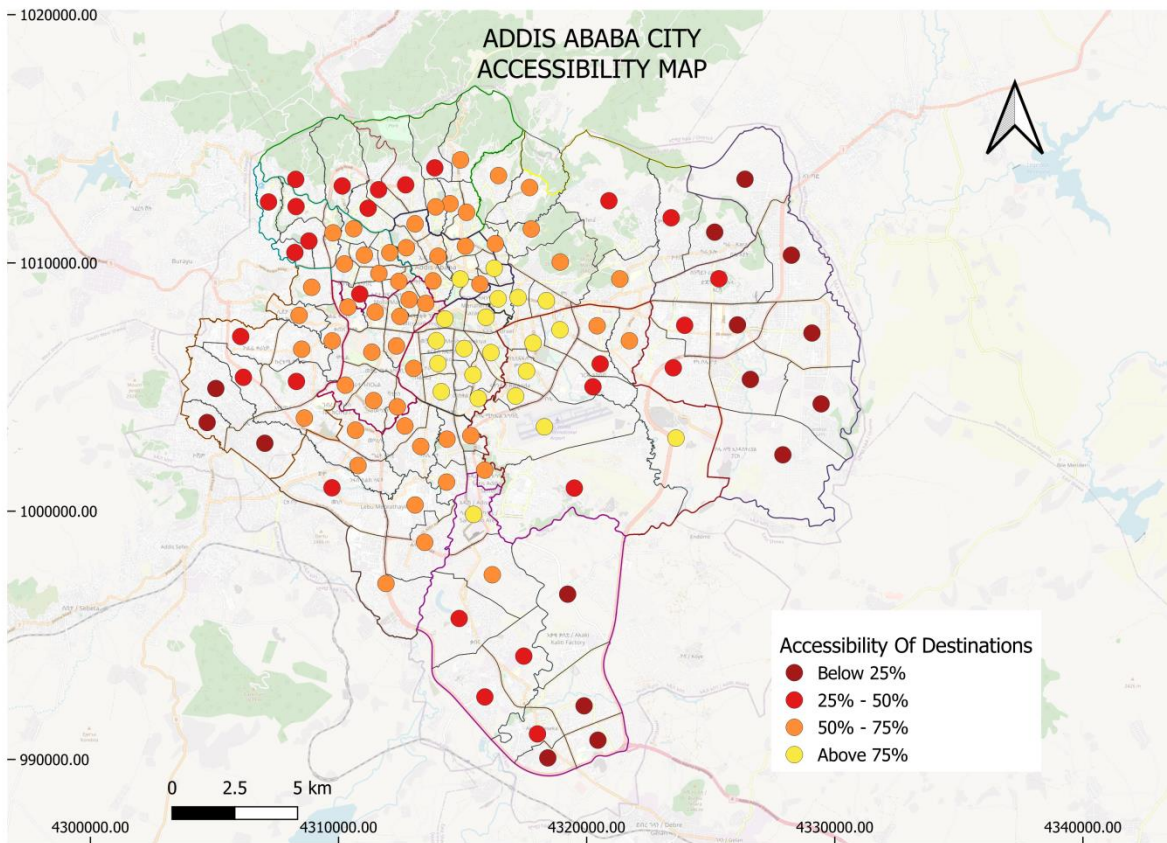


Figure 4 Addis Ababa accessibility map (Base image: openstreetmap, retrieved 1 may 2024)

All the destinations that took more than 30 minutes to reach was deemed as inaccessible. The results were put in percentages for better understanding, which means if a zone has an accessibility of 50%, it is within 30 minutes' drive to half of the major destinations. And results we can categorize it into 4 groups. the results are presented in figure 4.

As we see from figure 4, it appears that there is a clear distinction between zones and a clear relationship between location and accessibility. The inner part of the city (CBD) has the most accessibility, sub cities like Kirkos, Lideta, Gulele and Arada , which is ability to reach more than 75% of the destination in 30 minutes. Consequently

accessibility decreases as we go further from down town to peripherals, sub cities like Lemi Kura, Akaki Kality and Nifas Silk, this means that people living in the outer part of Addis Ababa have to travel more (above 30 minutes often) to reach potential destinations.

When we compare it from the mobility map earlier accessibility declines visibly from the CBD outward. It seems that the accessibility of destination and mobility are to some degree reciprocal, more access means less mobility because of the clustering of activities in one place also more mobility means more commuting time to get to major destinations (figure 4).

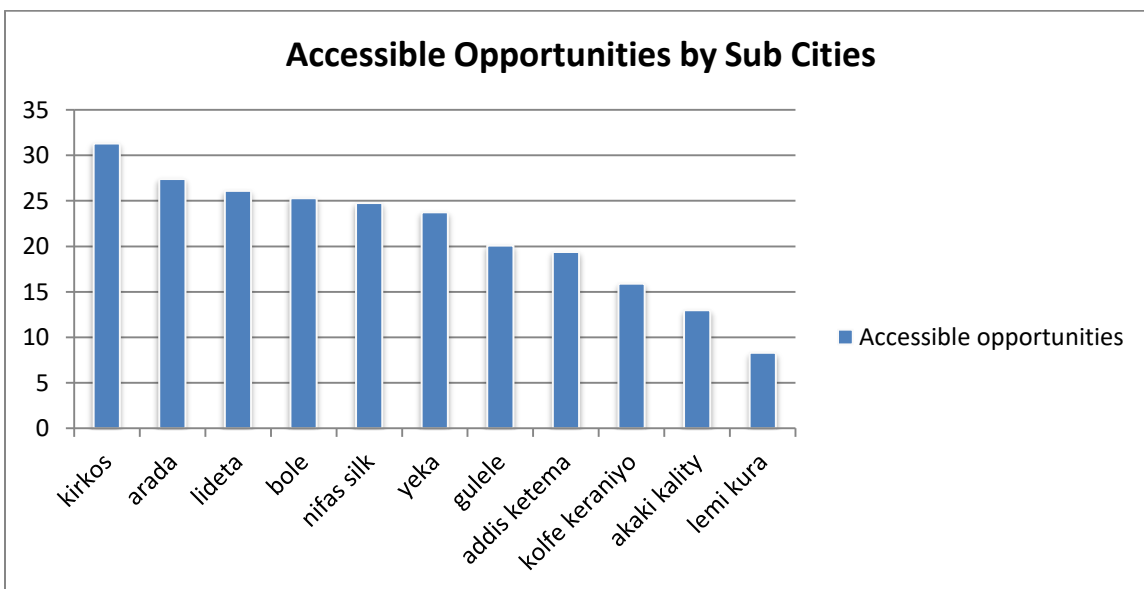


Figure 5 Average accessible opportunities by sub cities

The built-up area of Addis Ababa makes up around 54% of the total area; of this, 64% is utilized for residential purposes, while the remaining 18%, 10%, and 8% are used for commercial, industrial, and public uses, respectively. The majority of the city's inhabitants (99%) are concentrated in the built up area, with a density of roughly 7000 per km<sup>2</sup> (UN, 2000).

Land use function of Addis Ababa indicates good distribution of basic services on its plan but then again in reality most of the basic social services (universities, hospitals, big institutions) all are concentrated at or around city center (Lerango, 2011). People who live outside the city center have to travel significantly longer to access these services. Accessibility from good to worst is ranked as Kirkos, Arada, Lideta, Bole, Nifas Silk, Yeka, Gulele, Addis Ketema, Kofe Keraniyo, Akaki Kality and Lemi Kura respectively (figure 5).

## **5. Conclusion**

This research identified the mobility and accessibility conditions in different neighborhood of Addis Ababa using the QGIS travel time plugin, basing the free flow travel time and the peak hour travel time index. The findings of this study will

help urban planners and politicians identify mobility disparities between Addis Ababa's zones using congestion as a mobility indicator and will enable them to tailor upcoming road network improvement initiatives to solve those issues.

Congestion appears to be unacceptable in all the neighborhoods, which was found to be equal to and greater than 1.5, which means an Additional 50% or more of the uncongested travel time, which means if a travel initially takes 30 min in free flow, during peak hours it will take 45 min and more all over Addis Ababa zones. Although all of them are above the acceptable threshold there are still mobility inequalities between zones in Addis Ababa. There is a slight but noticeable difference between zones of different locations, in general the outer zones sub cities like Lemi Kura, Akaki Kality and Nifas Silk generally have lower NMI's than zones around the CBD. While peripherals mostly experience 50% to 70% of additional delay, zones in and around the CBD sub cities like Kirkos, Lideta, Gulele and Arada mostly experience 70% to 100% (2 times the free flow travel time). However it's not as black and white, some of the peripheral areas experience worse congestion than the others. One reason is the lack of infrastructure in the peripheral areas

of Addis Ababa as stated there are two types of mismatch in Addis Ababa, showing that the peripheral areas lack road infrastructure and roads in the central areas carry more than their capacity (Ayalneh, 2012).

On the other hand there is a clear distinction between zones and a clear relationship between location and accessibility. The inner part of the city (CBD) has the most accessibility, sub cities like Kirkos, Lideta, Gulele and Arada, which is ability to reach more than 75% of the destination in 30 minutes. Consequently accessibility decreases as we go further from down town to peripherals, sub cities like Lemi Kura, Akaki Kality and Nifas Silk, this means that people living in the outer part of Addis Ababa have to travel more (above 30 minutes often) to reach potential destinations. Land use function of Addis Ababa indicates that most of the basic social services (universities, hospitals, big institutions etc) all are concentrated at or around city center (Lerango, 2011).

The results reveal that neither those who live in the city nor those who live on the outskirts have it all and that while those who live farther away must go farther in order to access activities; those who live in the center must also deal with greater traffic. However residents in the city center have a

better accessibility even with the additional congestion, the accessible opportunities outweigh the additional congestion.

## References

- Asres, B. (2020). *Land Use and Transportaion Demand Interactions in Addis Ababa The Interactions between Land use change and Transportation Demand in Addis Ababa , Ethiopia ( 1988-2040 )*. November, 0–16.
- Ayalneh. (2012). *Evaluating Transport Network Structure: Case Study in Addis Ababa, Ethiopia*.
- Azagew, S., & Worku, H. (2020). Accessibility of urban green infrastructure in Addis-Ababa city, Ethiopia: current status and future challenge. *Environmental Systems Research*, 9(1). <https://doi.org/10.1186/s40068-020-00187-0>
- Downs, A. (2004). Why Traffic Congestion Is Here to Stay... and Will Get Worse. *Access*, 25(25), 19–25.
- ElDessouki, W. M. (2022). Development of a Neighborhood Mobility Index for Assessing Mobility Disparities in Developing Countries with Application to the Greater Cairo Area, Egypt. *Sustainability (Switzerland)*, 14(23). <https://doi.org/10.3390/su142315846>
- Engdasew, S. S. (2021). *Analysis of Road Traffic Congestion and its Economic Impact on Addis Ababa City : A Case Study in Yeka Sub City (A Major Intersection Along Megenagna to Karalo)*
- Fortunati, J. (2018). Mobility doesn't mean

- the same thing as transportation. In *Mobility Lab*.  
[https://mobilitylab.org/2018/07/26/what-is-mobility/?mkt\\_tok=MjExLU5KWS0xNjUAAAF\\_Fzm91FaWliSIYXvfhf0xE RVuwUu9KAU9Lk4KPQnZEq0sVME S\\_9OH5iHqehgzkCuS9pC2vFNZuSF5 cHV5I9Ko0IcHnDvccb9oUXxxqf8IS5 6zkw](https://mobilitylab.org/2018/07/26/what-is-mobility/?mkt_tok=MjExLU5KWS0xNjUAAAF_Fzm91FaWliSIYXvfhf0xE RVuwUu9KAU9Lk4KPQnZEq0sVME S_9OH5iHqehgzkCuS9pC2vFNZuSF5 cHV5I9Ko0IcHnDvccb9oUXxxqf8IS5 6zkw)
- G. Gebre & D Van Rooijen. (2009). Institutional Repository Urban water pollution and irrigated vegetable farming in Addis Ababa. *34 Th WEDC International Conference, Addis Ababa, Ethiopia*, 166.
- J. Barceló, L. Montero, X. R.-R. (2016). *ACCESSIBILITY*.
- Lerango, Z. (2011). *Sustainable transport system: Mobility and Accessibility in Addis Ababa*.
- Litman, T. (2003). Measuring transportation: Traffic, mobility and accessibility. *ITE Journal (Institute of Transportation Engineers)*, 73(10), 28–32.
- Mekonnen, B., Hailu, A., Molla, M., & Legesse, M. (2024). Trends of higher education enrolment , graduation , and employment in Ethiopia : an empirical analysis. *Cogent Education*, 11(1).  
<https://doi.org/10.1080/2331186X.2024.2302623>
- Miller, E. J. (2018). Accessibility: measurement and application in transportation planning. *Transport Reviews*, 38(5), 551–555.  
<https://doi.org/10.1080/01441647.2018.1492778>
- Randal, E., Shaw, C., Woodward, A., Howden-Chapman, P., Macmillan, A., Hosking, J., Chapman, R., Waa, A. M., & Keall, M. (2020). Fairness in transport policy: A new approach to applying distributive justice theories. *Sustainability (Switzerland)*, 12(23), 1–21.  
<https://doi.org/10.3390/su122310102>
- Savvides, A. (2013). *Equity of mobility in sustainable transportation*. 179, 1091–1101.  
<https://doi.org/10.2495/SC130932>
- Schrank, D. (2001). The keys to estimating mobility in urban areas. *ITE 2001 Annual Meeting and Exhibit, May 2005*.  
<http://trid.trb.org/view.aspx?id=709596>
- Sekasi, J., & Martens, M. L. (2021). Assessing the contributions of urban light rail transit to the sustainable development of addis ababa. *Sustainability (Switzerland)*, 13(10), 1–22. <https://doi.org/10.3390/su13105667>
- Shiferraw, M. (2022). City Profile: Addis Ababa. *World Literature Today*, 96(3), 5.  
<https://doi.org/10.1353/wlt.2022.0101>
- Sub Saharan Africa Transport Policy Programme. (2018). □ *SSATP-Ethiopia-Sustainable Mobility and Accessibility Policy in Cities-Policies for Sustainable Accessibility and Mobility in Cities of Ethiopia*.
- Venter, C. (2017). *Developing a common narrative on urban accessibility: A transportation perspective*. November.
- Wondimu Tekolla, A., Segni Tulu, G., & Gebre Tarekegn, A. (2021). Evaluating the Impact of Addis Ababa Light Rail Transit on Public Transit System, Its Efficiency and Eligibility for Transit Oriented Development (TOD).

*American Journal of Traffic and  
Transportation Engineering*, 6(6), 160.  
<https://doi.org/10.11648/j.ajtte.20210606.13>

World Bank. (2014). *Federal Democratic  
Republic of Ethiopia Addis Ababa*

*Urban and Metropolitan Transport and  
Land Use Linkages Strategy Review  
Note of Proposed World Bank  
Engagement on Urban and  
Metropolitan Transport and Land-use  
for Inclusive Green Growth in Addis  
Ababa. ACS12347, 27.*

## Appendix B Maps

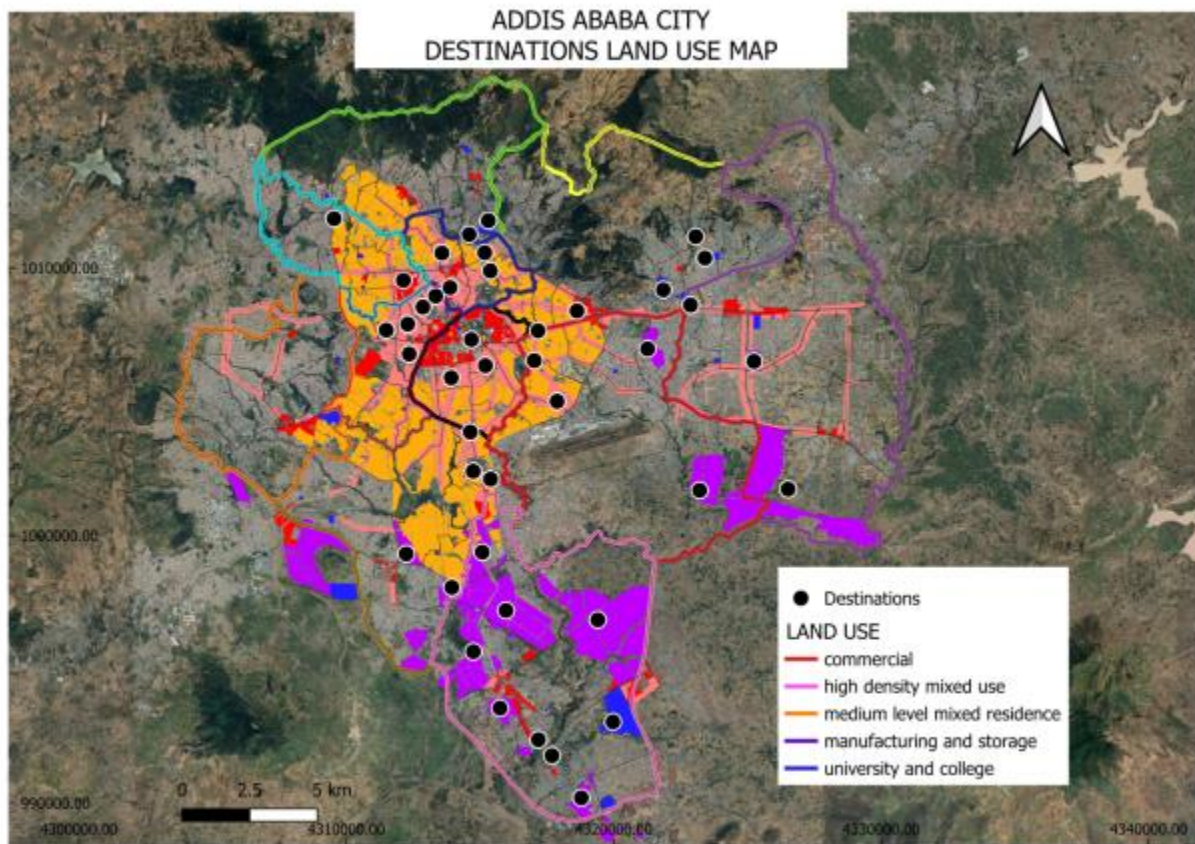


Figure 0-1 Major land use map overlapped on google satellite (adapted from source: ACCRA, 2010)

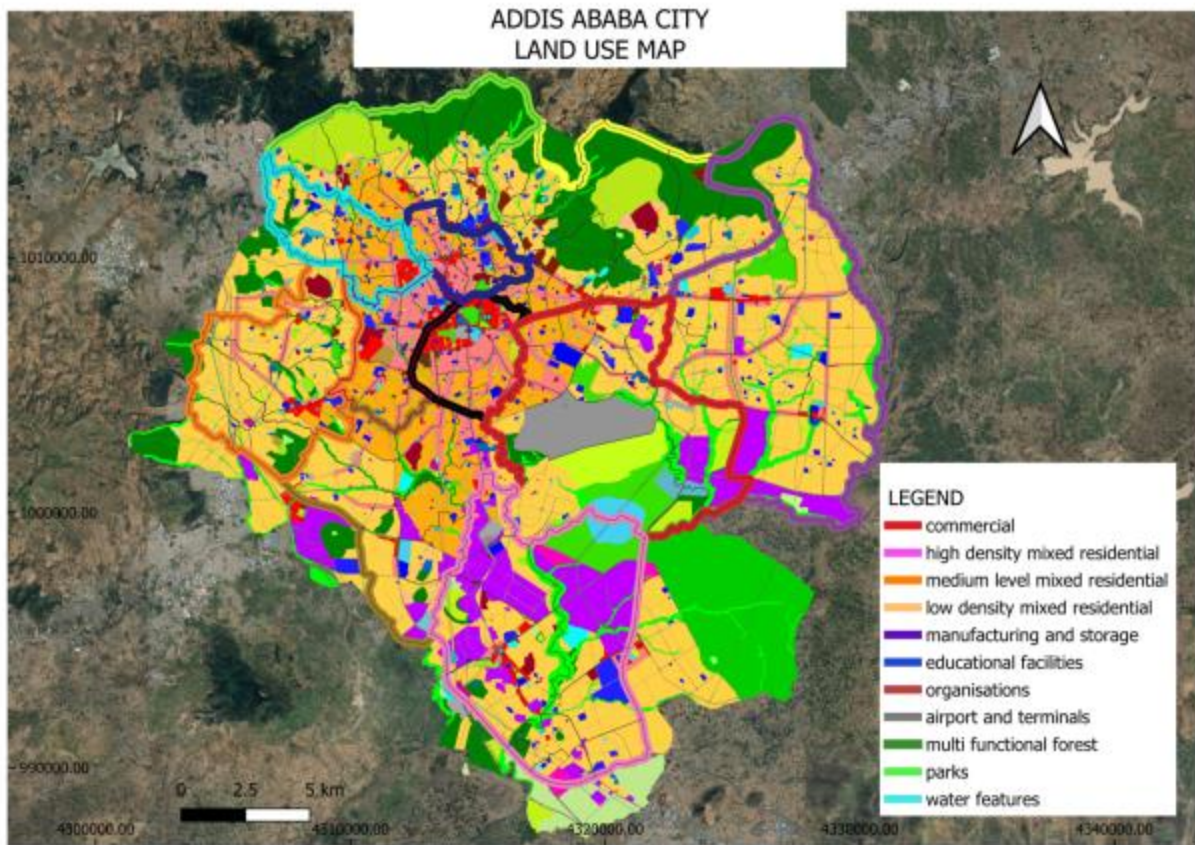


Figure 0-2 Land use map, sub city and woreda map overlapped on google satellite (adapted from source: ACCRA. 2010)

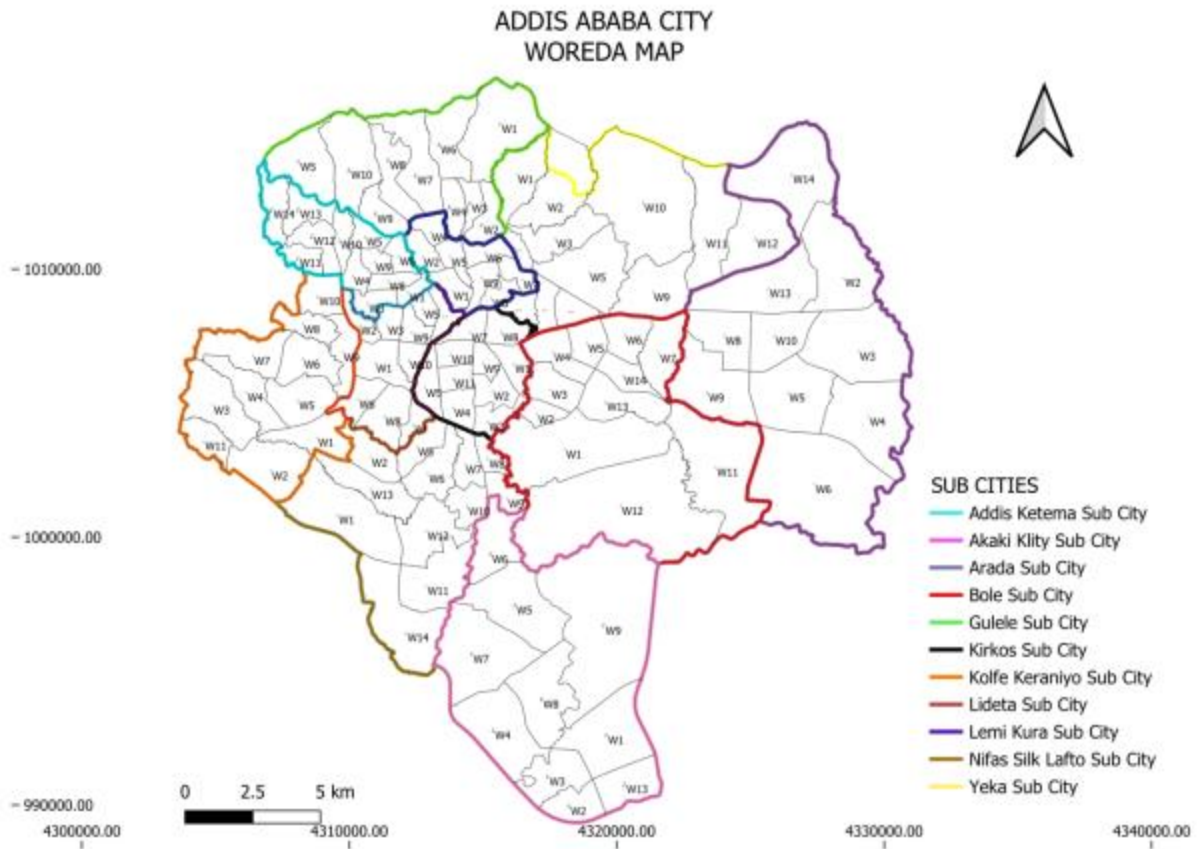


Figure 0-3 Woreda map (source: Addis Ababa City Government Plan and Development Commission)

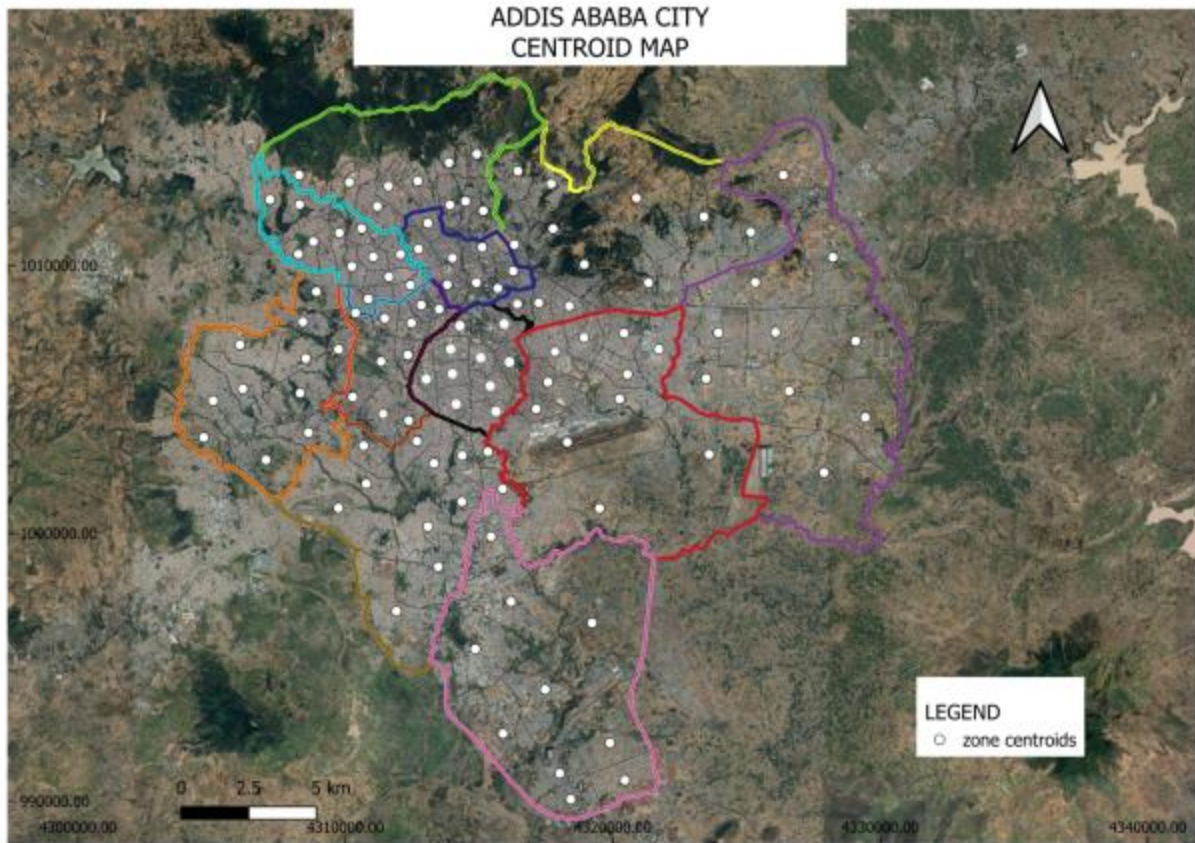


Figure 0-4 centroid map (*Base image: openstreetmap, retrieved 1 may 2024*)

## Appendix C Tables

### Addis Ketema woredas: results summary

Addis Ketema	NMI	Accessible opportunities (<=30 min)	Route directness index
W1	1.73	26	1.212487318
W3	4.614134961	16	1.245605878
W4	1.816509316	21	1.228600233
W5	1.710313486	21	1.213247408
W6	1.835511813	21	1.273964141
W8	1.76	24	1.208860139
W9	1.775326362	22	1.220321849
W10	1.768	20	1.227758588
W11	1.901144333	16	1.229445134
W12	1.748460024	19	1.229295317
W13	1.766543687	14	1.287952181
W14	1.72131174	13	1.254103368

### Akaki kaliti woredas: results summary

AKAKI KALITY	NMI	Accessible opportunities (<=30 min)	Route directness index
W1	1.6	9	1.381988609
W2	1.68	8	1.25686213
W3	1.549	11	1.208330388
W4	1.636	12	1.298350279
W5	1.76	20	1.289594894
W6	1.72	30	1.288625556

W7	1.69	14	1.302992596
w8	1.64	13	1.373622852
W9	1.77	6	1.784712963
W13	1.715	7	1.408519549

Arada woredas: results summary

Arada	NMI	Accessible opportunities (<=30 min)	Route directness index
W1	1.83	29	1.228845841
W2	1.936	22	1.222110368
W4	1.75	24	1.194462312
W5	1.79	28	1.219030752
W6	1.92	27	1.247945918
W7	1.81	30	1.267024735
W8	1.93	29	1.244479672
W9	1.868	30	1.208335662

Gulele woredas: results summary

Gulele	NMI	Accessible opportunities (<=30 min)	Route directness index
W1	1.739	21	1.198
W2	1.78	25	1.23422602
W3	1.79	24	1.210396083
W4	1.76	24	1.213182454
W5	1.737	13	1.275134081
W6	1.939	18	1.234822424

W7	1.72	19	1.227460374
W8	1.669	19	1.198940801
W9	1.8	19	1.205359163
W10	1.72	18	1.200729314

Kirkos woredas: results summary

Kirkos	NMI	Accessible opportunities (<=30 min)	Route directness index
W1	1.849222445	33	1.346509396
W2	1.863600236	32	1.304963911
W3	2.031208897	30	1.366954876
W4	1.775241607	29	1.308793277
W5	1.876459166	27	1.298858728
W7	1.775848735	30	1.285867031
W8	1.731799356	31	1.279486403
W9	1.923188265	30	1.285867031
W10	1.69138189	27	1.238363945
W11	1.822429082	31	1.285362074

Bole sub city: results summary

Bole	NMI	Accessible opportunities (<=30 min)	Route directness index
W1	1.78	32	1.244398321
W2	1.969	30	1.390958447
W3	1.869	30	1.336475503
W4	1.78	30	1.464598616

W5	1.75	30	1.403596509
W6	1.78	29	1.243784634
W7	1.71	29	1.27148214
W11	1.89	31	0.939206535
W12	1.85	10	1.675637744
W13	1.77	19	1.390316688
W14	1.687	8	1.801593642

Kolfe sub city: results summary

Kolfe Sub city	NMI	Accessible opportunities (<=30 min)	Route directness index
W1	1.65933885	22	1.334291861
W2	1.862435752	8	1.300343147
W3	1.625634081	8	1.279535752
W4	1.617715349	14	1.288895309
W5	1.784108507	15	1.335163349
W6	1.727801539	23	1.280378565
W7	1.687952628	13	1.240208248
W8	1.643550386	21	1.279464089
W9	1.78850364	25	1.261245257
W10	1.972415485	20	1.273279021
W11	1.669883325	6	1.258339369

Lemi kura sub city: results summary

Lemi Kura Sub city	NMI	Accessible opportunities (<=30 min)	Route directness index
W2	1.71687097	6	1.267141833
W3	1.638440627	9	1.250053058
W4	1.563897093	6	1.392504048
W5	1.731820832	9	1.358862212
W6	1.818926741	2	1.440043259
W8	1.655843144	18	1.26436741
W9	1.66057497	15	1.353299355
W10	2.314818504	0	1.277107452
W13	1.714847749	12	1.238032271
W14	1.666438295	6	1.334038059

Lideta sub city: results summary

Lideta Sub city	NMI	Accessible opportunities (<=30 min)	Route directness index
W1	2.28118103	25	1.237751489
W2	1.93283564	24	1.234005456
W3	1.839420574	25	1.239263292
W4	1.692968365	26	1.36544338
W5	1.805235658	27	1.241001419
W6	1.790704071	25	1.299049944
W7	1.763956764	28	1.255024523
W8	1.648376392	26	1.365416685
W9	1.688952974	28	1.252155825
W10	1.883873329	27	1.259767924

Nifas silk sub city: results summary

Nifas Silk Sub city	NMI	Accessible opportunities (<=30 min)	Route directness index
W1	1.661339132	18	1.352994609
W2	1.665227703	25	1.366895632
W5	1.840932944	26	1.3268967
W6	4.72135014	27	1.295452169
W7	2.20857581	26	1.332065156
W8	1.64853933	28	1.345527887
W9	1.677897144	28	1.340879746
W10	1.683660692	28	1.338043141
W11	1.671333565	23	1.329815521
W12	1.6509336	22	1.379202715
W13	1.713871946	23	1.31423281
W14	1.446744053	23	1.312540893

Yeka sub city: results summary

Yeka Sub city	NMI	Accessible opportunities (<=30 min)	Route directness index
W1	1.81806499	21	1.257698388
W2	1.708982377	25	1.31319392
W3	1.714208356	28	1.338944329
W4	1.869884097	29	1.26210003
W5	2.493777953	23	1.376007527
W6	1.741096628	31	1.284274665
W7	1.734073612	31	1.304789539
W8	1.706153036	31	1.286211944

W9	1.676424225	29	1.276232368
W10	1.80802644	16	1.322277898
W11	1.678362928	12	1.275015182
W12	1.756232112	12	1.223781196