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OPTIMIZING URBAN MOBILITY

EXPLORING THE GAP BETWEEN TRAVEL DEMAND AND EXISTING PUBLIC TRANSPORTATION NETWORK

THE CASE OF BISHOFTU

BY

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School of Built Environment

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Declaration

I, the undersigned, declare that this thesis is my own and original work and has not been presented for a degree in any other university, and that all sources of material used for the thesis have been duly acknowledged, following the scientific guidelines of the Institute.

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Abstract

Ethiopia's rapid urbanization has created a challenge in public transport systems of secondary cities like Bishoftu, which rely heavily on informal paratransit transport modes. This paper investigates, the mismatch between travel demand and current public transport network in Bishoftu amid growing population and physical expansion of its boundary. Using a multi criteria approach, the paper applied a Four Stage transport demand model on a block level TAZs (Traffic Analysis Zones) to analyze trip generation, distribution and optimal route assignment. Data were drawn from surveys of PT routes, road conditions and, and secondary sources including GIS data, Bishoftu Transport Authority records, and the 2019 Structure Plan Revision documents. The analysis, evaluated through four key performance indicators—accessibility, route directness, route diversity, and infrastructure condition—reveals significant gaps in service provision. Findings indicate low level of public transport accessibility with 18.6% of Bishoftu urban blocks not having access to public transport routes within a walking distance of 500m. Six, three-wheeler routes out of thirty-eight studied are found to have mobility index value higher than 1.4, indicating inefficient route assignments that should be optimized. Infrastructure limitations further constrain service, as minibuses are restricted to asphalt roads, while three-wheelers dominate on lower-quality surfaces. This study concludes that Bishoftu's current paratransit network is inadequately aligned with its mobility demand and street layout. It recommends route optimization, infrastructure upgrades, and the introduction of ring-road connections to improve accessibility and efficiency. The methodology and indicators developed are transferable for analyzing and optimizing public transport in similar Ethiopian secondary cities, contributing to the broader goal of achieving sustainable, compact urban centers by improving mobility planning. Future research should incorporate real-time travel data and explore the integration of formal mass transit systems.

Keywords: *Public transport; Network analysis; Accessibility; Paratransit; Bishoftu*

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Acronyms

PT	Public Transport
OUPI	Oromia Urban Planning Institute
CSA	Central Statistics Agency
BRT	Bus Rapid Transit
TAZ	Traffic Analysis Zone
FSM	Four Stage transport demand Modeling process
O - D	Origin destination pairs of a single trip

List of Definitions

Ganda/Kebele	lowest level administrative unit
Woreda	lowest level administrative unit similar to Ganda/Kebele
Bajaj	Three – wheeled public transportation vehicle
TAZ	Fundamental unit of geography used to represent the spatial distribution of trip origins and destinations in transportation planning

CHAPTER ONE: INTRODUCTION

Cities are an ever-evolving complex man-made organisms that require constant optimization to address contemporary challenges they face and incorporate technological advancements of the age. One component of urban settlements that is vital for their proper functioning requiring continuous improvement is public transport network. Specially in countries like Ethiopia and cities like Bishoftu, where rapid urbanization is challenging urban mobility, it is important to study public transport networks, how to optimize them and the role they play in creating better urban settlements.

1.1 **Background of the Study**

Efficiency of public transportation is an important precondition for development of cities, flourishing of economic activities and social inclusion (UN-HABITAT, 2011). Research shows that mobility and accessibility are major determinants of lifestyle and prosperity (Bell and Iida, 1997). United nations sustainable development goals (SDGs) 11.2 highlights the importance of providing safe, affordable, accessible and sustainable public transportation systems as part of SDG 11 of creating sustainable cities and human settlements.

Rapidly urbanizing countries like Ethiopia, face multiple challenges in public transportation because of rapid population growth, limited infrastructure investment, and urban sprawl (UN-HABITAT, 2011). Investment in public transportation can improve the lives of people living in poverty and contribute towards fostering equity (Rodriguez *et al.*, 2016; Kreindler *et al.*, 2023). In contrast to using private transportation modes, using public modes of transport help to reduction of pollution, reduce road accidents and manage urban spaces efficiently (Ortuzar and Willumsen, 2011). National transport policy of Ethiopia also emphasizes the importance of public transport in fostering rapid urban development (Ethiopian Ministry of Transport, 2020).

Public transport networks are complex systems because of the constituting variables that need to be managed. Ortuzar and Willumsen state, "*Public Transport networks are more complex than road networks*", because they require matching road networks and PT routes, identification of stops, interchange management, frequency assignment, temporal changes, fare and timetable calculations etc. In addition PT network could be independent of road networks as many cases of rail transport use a dedicated routes not aligning with road networks of cities (Ortuzar and Willumsen, 2011).

According to van Nes, Hamerslag and Immers (1988) and Barabino (2009), the problem of transport network design can be stated as: "*which routes and which frequencies should be offered to fulfil the demand for public transport as well as possible, given a certain available budget*?" (van Nes, Hamerslag and Immers, 1988) (Barabino, 2009). Abreha (2007) also states: "*providing equitable and efficient public transport for the ever-increasing demand with the limited resource available is a challenge in the developing world*" (Abreha, 2007). The framing of the problem by both studies indicates components of transportation network design that could be addressed individual or all together at once include: the network, frequency of transportation modes, mobility demand, quality of service and budget.

1.2 Public transport, rapid urbanization and compact cities

A measure of how functional public transports are in cities is their capacity to serve more people per resource invested (Bell and Iida, 1997). It is for this reason that transport studies promote compact cities and compact urban form as essential when planning for public transport solutions that are sustainable (UN-HABITAT, 2011). But looking at the trend of how the population of cities is increasing globally and comparing it to the rate of land consumption, we observe a rather counter intuitive reality. A study of 681 cities between 1990 and 2020 concluded that physical expansion of cities was much higher than their population growth (United-Nation-HLPF, 2023). From 2000 – 2010, average annual land consumption was 2% while population growth of cities was 1.6%. Similarly, from 2010 – 2020 average land consumption was 1.5% but population growth was only 1.2% (United-Nation-HLPF, 2023).

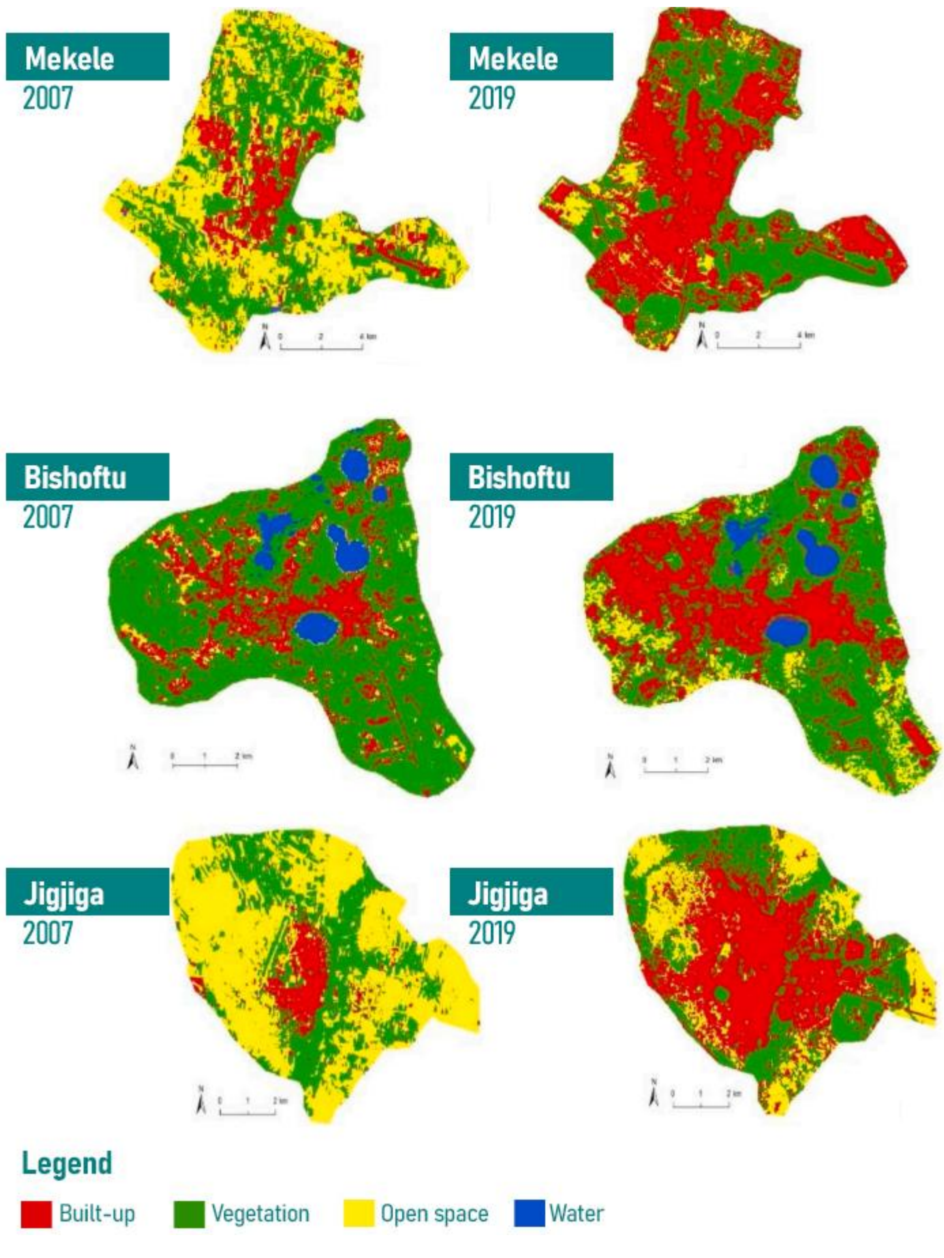

Figure 1.1 Built up area expansion in Ethiopian cities. (Koroso, Lengoiboni and Zevenbergen, 2021)

A 2021 study on Urban Land Use Efficiency (ULUE) in 16 Ethiopian cities confirmed that global trend of sprawling urban settlements was also evident in Ethiopia (Koroso, Lengoiboni and Zevenbergen, 2021).

70% of the cities studied had a ratio of land consumption rate to the population growth rate greater than one. This indicates that Ethiopian cities are expanding (represented by red color on Figure 1.1) faster than their population is growing. These sprawling periphery areas in cities like Bishoftu have low public transport coverage making connection to facilities such as work and leisure a challenge (Debas, 2019). Bishoftu not only suffers from lack of accessibility but also low transport network density (Gezahegn, 2019).

1.3 Statement of the problem

A 2014 world Bank study shows, public transport problems in Ethiopian cities are not only related to lack of infrastructure and adequate investment, but also to the lack of transport authorities capacity to efficiently design and manage for public transport based on public needs (World Bank, 2014). A data from 2022 shows, only 51.6 % of world urban population has access to convenient public transport (United-Nation-HLPF, 2023); The problem is even more severe in rapidly urbanizing countries like Ethiopia because of underlying economic realities such as poverty limited availability of finances (UN-HABITAT, 2011).

Demand for public transportation growing by the day in Ethiopian Cities. Transportation networks are the main component of transportation infrastructure through which public mobility occurs. But public transportation in cities is challenged by low accessibility, lack of connectivity, poor transportation network, inadequate transport network density(Gezahegn, 2019). Efficient public transportation network planning and optimization is thus needed to address these challenges.

Bishoftu like many Ethiopian Cities is challenged by lack of accessible public transport, efficient public transport connectivity and lack of infrastructure(Gezahegn, 2019). But there is little study available that shows the level of problem based on indicators that could be used for assessment and future interventions.

1.4 Objective of the study

The general objective of the study is to investigate the performance of Bishoftu city public transport network in relation to current mobility demand of its residents and settlement characteristics of the city contributing to future interventions and improvements in public transport.

1.4.1 Specific objectives

- To assess the gap between existing modes of Public Transportation (PT) networks and mobility demand of Bishoftu based on TAZs (Traffic Analysis Zones) studied
- To assess the level of public transport accessibility and connectivity of the Bishoftu
- To forward research based public transport network improvement measures for the city of Bishoftu.

1.5 Research Question

- What is the gap between existing mobility demand and available public transport network in Bishoftu?
- How much accessible is the city of Bishoftu by using available public transport modes?
- Which indicators can be used to evaluate public transportation networks in Bishoftu?

- What kind of interventions are needed to align mobility demand in Bishoftu with public transportation network infrastructure?

1.6 Significance of the study

Bishoftu is one of many secondary cities in Ethiopia sharing similar challenges in public transportation. The output and recommendations of this study can be used as an input towards studying and formulating better public transport systems in other Ethiopian cities. Policy makers can use the study to justify public transport optimization approaches based on practical methodologies stated in the document.

The study helps to support a general direction indicated on transport policy documents of Ethiopia, that emphasize the need for planning compact cities that have public transportation infrastructure supporting rapid urbanization. The output of the study can be used to make a case for how efficient public transport planning can address the challenges of urban sprawl, inefficient land use practice and rapid urbanization at the same time. The private sector planning to invest in providing public transport service can use the study to make informed decision regarding the gap between supply and demand of public transport components and contribute towards creating more livable cities.

1.7 Scope of the Study

The study is focused on the city of Bishoftu and its 16 '*Gendas*' i.e., administrative boundaries also referred as '*woredas*' or '*kebeles*' and different public transportation modes used for mobility. While there is a current restructuring of physical boundary of Bishoftu that include the neighboring towns underway, the study is conducted based on the 2019 revised structure plan of the city taking boundary, road network and land use as an input.

Thematically, this study is scoped to the analysis of Bishoftu's public transport network performance against resident mobility demand. It focuses specifically on measuring accessibility gaps, route efficiency, network connectivity, and infrastructure adequacy to formulate optimization strategies for the city's PT system. Demography and population data used for the study are based on projection of 2007 census and documents provided by the city administration of Bishoftu. Transport data was collected from Bishoftu transport authority on three modes of transport, ‘*bajaj*’ (three-wheelers), mini-bus taxis, and buses operating in the city together with their routes of operation and frequency. The study used individual city blocks to study mobility demand of Bishoftu and compared it to current public transport service provision using indicators developed based on literature.

1.8 Limitations of the study

Transport studies depend highly on recent data to model accurate mobility behavior of people. Available population, demography and settlement data in Bishoftu was not accurate since it was based on projections of the 2007 census. There was no recent census data that could be used as an input affecting the accuracy of the study. There was financial and time limitation to collect accurate trip generation and distribution data. For this reason, transport data of Bishoftu from 2019 structural plan revision document was used. The document only considered the administrative woredas as traffic analysis zones (TAZs) which are very different in size and few in number, affecting accuracy of the study.

1.9 Organization of the Paper

This thesis is organized into six chapters. Chapter 1 introduces the research problem, objectives, and significance, framing the study within the context of rapid urbanization and public transport challenges in Ethiopian cities. Chapter 2 presents a literature review, establishing the theoretical foundation for public transport network analysis and optimization. Chapter 3 details the study area, Bishoftu, covering its historical, demographic, and morphological context. Chapter 4 outlines the methodology, including data sources, the Four-Stage Modeling approach, and the performance indicators used for analysis. Chapter 5 presents and discusses the results of the demand modeling and network evaluation. Finally, Chapter 6 summarizes the conclusions and provides recommendations for optimizing Bishoftu’s public transport network, and future research areas.

CHAPTER TWO: LITERATURE REVIEW

2.1 Definition of Key terms

The literature review discusses public transport networks, reviews relevant optimization models and performance indicators, and examines characteristics of public transport in Ethiopia. Local and international cases are discussed to identify research gaps and to formulate methodological approach to studying Bishoftu. Important words based on the contextual meaning of their use are defined below.

Public Transport Networks: components of a urban transport system characterized by routes, frequencies, and temporal service levels based on time, season, settlement patterns land use etc. (Abreha, 2007)..

Paratransit: A mode of public transportation characterized by private vehicle ownership, demand-responsiveness, and service that complements conventional mass transit. In the Ethiopian context (e.g., Bishoftu), paratransit (e.g., three-wheelers, minibuses) is the predominant form of public transport, even in high-density areas (Lave & Mathias, 2000) (Gezahegn, 2019).

Network Optimization Models: a framework used to determine the most efficient configuration of transport routes and frequencies to meet demand within given constraints. They range from simplified analytical models to complex computational models that simultaneously determine routes and frequencies (Van Nes, Hamerslag and Immers, 1988).

Four-Stage Transport Demand Modeling (FSM): A widely used framework for forecasting travel demand. The model estimates the number of trips that will occur between origin and destination zones and their relation to transport routes and modes. (Hensher and Button, 2000)

2.2 Theoretical Review

2.2.1 Public transport and urban development

Efficient public transportation networks are a good indicator of how well a city is functioning economically, environmentally and socially. According to Kalpana, Jayasinghe and Abenayake (a2020),transport networks dictate urban development and growth and access to such infrastructure "*predict and plays a role in navigation future development potentials and the urban movement in investment and resource allocation*"(Kalpana, Jayasinghe and Abenayake, 2020). Public transportation reduces greenhouse emissions and traffic congestion; and promote equity due to its affordable nature (United-Nation-HLPF, 2023). Rapidly urbanizing countries like Ethiopia are also faced with the task of creating a good urban form that responds to economic social and economic constraints. Characteristics and challenges of public transportation are everchanging depending on the current developmental and geospatial context of cities (Gkiotsalitis, 2022). When it comes to developing countries, these challenges can be characterized by the lack of investment in infrastructure, urban sprawl, informal modes of transportation that are hard to manage and lack of coordination of planning between different modes of PT (Bogale, 2012). The city of Bishoftu faces similar challenges (Gezahegn, 2019). Optimization of Public transportation network and its components in cities like Bishoftu will ensure the development of a good urban form that is livable, economically vibrant and environmentally sustainable.

2.2.2 Public Transport Networks

Public transport networks are dynamic components of cities with an ever-changing characteristic based on time of the day, season, settlement patterns, land use etc. (Abreha, 2007). Mobility demand and characteristics of cities also change rapidly which requires authorities working on public transportation to proactively manage routing and frequency of public transport (Silman, Barzily and Passy, 1974; van Nes, Hamerslag and Immers, 1988). D.L. Van et al states, the cost of rerouting public transport modes within a network requires little investment but can radically improve the total performance of systems (van Nes, Hamerslag and Immers, 1988).

2.3 Conceptual review

2.3.1 Public transport network equilibrium

Economic concepts of supply and demand also apply to transport economics. Transport demand is a derived demand based on the need of people to engage in various activities. This is to say that people travel not just because they want to travel but also because they want to engage in activities taking place in other locations than where they are (Hensher and Button, 2000). Public transportation is possible not only through the existence of infrastructures like roads, it also requires vehicles to mobilize people and goods. While the demand side is the derived mobility need for travel, the supply side will be provisions such as transport networks, road infrastructure and vehicles availability (Bell and Iida, 1997). An important component of the supply side, i.e., public transport networks, is the basis upon which other components are built since it deals with first and foremost with accessibility and spatial distribution of public transport infrastructure (Girão, Pereira and Fernandes, 2017). Transport planners accept actual equilibrium between supply and demand may never happen as the transport system is under constant change influenced by land use, socio-economic realities, technology etc. (Ortuzar and Willumsen, 2011). But the ability to forecast, model and plan mobility as closely as possible to reality remains a contributing factor to quality of urban settlements. Managing public transport will not only address mobility concerns, but also has the ability to address economic inequality by providing equitable physical access to economic opportunities cities have to offer (Kreindler *et al.*, 2023).

2.3.2 Analysis of public transportation networks

Analysis parameters for public transport networks can vary significantly depending on the objective set to achieve. And often these parameters are not uniform or comprehensive. Jafino, Kwakkel and Verbraeck, 2020, state "Despite the wide variety of transport network criticality metrics, little guidance is available on selecting metrics that are fit for the specific purpose of a study." (Jafino, Kwakkel and Verbraeck, 2020). The study tried to hierarchically categorize 17 transportation network criticality metrics after reviewing almost 400 articles. The metrics were evaluated in three conceptual categories of functionality, underlying ethical principles and their nature of spatial aggregation. Functionality refers to the contribution of the component studied in terms of "maintaining connectivity, reducing travel cost, or improving accessibility". While the ethical principles of utilitarianism vs egalitarianism were the second conceptual evaluation categories. The third category of the nature of spatial aggregation deals with whether the metrics studied dealt with network-wide aggregation or localized issues.

Research putting emphasis on connectivity of streets to measure and study transportation networks focus on metrics like connectivity index, intersection index and street density. Knight & Marshall (2015) analyzed the level of consistency these metrics provide in predicting network characteristics. The study output indicates there are inconsistencies when dealing with network of smaller size and it is better to analyze wider networks using these metrics (Knight and Marshall, 2015).

Public transport network analysis can also be done based on graph theory (van Nes and Yamu, 2021; Sadek and Al-Sadimy, 2024). Indices such as alpha index (ratio of actual number of circuits in a network to a maximum possible number of circuits), Beta index (ratio of total area of a network to total number of nodes), Gamma index (ratio of number of observed links to number of possible links) have been proposed and used by different transport network studies (Sadek and Al-Sadimy, 2024). A route detour index, route factor (Barthelemy, 2010) or referred by other studies as mobility index (Bogale, 2012) is used by different studies to analyzes the ratio between an Euclidean distance and actual route from origin to destination to study efficiency of transportation networks. Different studies propose to use a combination of indicators based on their research objective and advice others to do the same.

2.3.3 Public Transport network Optimization models

Theoretical grounds of transportation modeling have been established starting from 1950s and continue to mature in an evolutionary way to include more details and complexities over time (Hensher and Button, 2000). Large bodies of work in the field of transportation research and advancement in the power of computing starting from 1970 also contributed to the span of variables that can be modeled and analyzed currently. The models and frameworks also expanded to address economic theories coherently. Approaches on how to address the question of PT network optimization vary on how studies solve the question of network design and frequency assignment. Van Nes, Hamerslag and Immers (1988), frame the question of PT network optimization as follows: “Which routes and which frequencies should be offered to fulfil the demand for public transport as well as possible, given a certain available budget.” Their study categorized approaches used for optimization of public transportation networks in six groups, which are:

1. analytical models – models using simplified network characteristics such as route spacing

2. models analyzing which links to be used to build PT routes

3. Models that determine only routes without addressing frequency

4. Models taking given routes as input and assign frequencies

5. Models that determine PT routes first and later assign frequencies and,

6. Models that determine set of routes and their frequencies simultaneously (van Nes, Hamerslag and Immers, 1988).

While the general approach of addressing routes and frequencies remains the same, contemporary PT modeling approaches try to take advantage of the computational power of modern computers and data clouds to study public transport. Ortuzar & Willumsen (2011) discuss activity (agent) based mobility modeling where the approach is based on individual travel behavior of people, using big data and computational capacity (Ortuzar and Willumsen, 2011).

2.4 Contextual review

2.4.1 Public Transport policies in Ethiopia

Ethiopian ministry of transport and logistics has developed a transport master plan that will serve until 2025 (Lin, 2017)(Minister of Transport and Logistics, 2022). The document objectives include,

• Making transport responsive to the real passenger demand in terms of capacity, performance and safety & security

• Integration of different modes of transport for an effective, efficient, and reliable transport

- Integrating land use and transport planning, where the transport system has to respond to proposed land use developments, population growth, economic realities and social welfare in the country
- Create a transport system supported by updated and appropriate technologies

The document gives emphasis on the importance of planning using the available resource and contributing towards creating a resilient middle-income economy (Minister of Transport and Logistics, 2022).

Ethiopian has set a direction of promoting non-motorized and public transport in cities as much as possible (Institute for Transport & Development Policy, 2020). To achieve this goal the ministry of transport and logistics has prepared another document outlining measures to be taken including prioritization of public transport. The document states "*Transport investments will prioritize modes used by lower income groups, including walking, cycling, and public transport*" (Institute for Transport & Development Policy, 2020). The document further states a 10-year target where "Public transport and paratransit constitute 80% of all motorized trips". Measures included in the document to help optimize public transportation include:

- fine-grained street network to improves access to public transportation
- Land use policies encouraging transit-oriented development (TOD) and
- mass rapid transit lines within walking distance of 500 m

2.4.2 Paratransit Nature of Public Transport in Ethiopia

It is important to understand the predominant paratransit nature of public transport in Ethiopian cities while addressing public transport networks. According to Lave & Mathias (2000), Paratransit PT modes are characterized by their nature of private ownership, demand responsivity and complementarity to conventional mass transit.

Their use being highly relevant to users in areas of low-density land use and demand, which are areas not served cost-effectively by conventional transit (Lave and Mathias, 2000). But in Ethiopia, paratransit PT mode is predominant in many high-density settlements. There are few large companies and many private paratransit public transport providers in Ethiopia (Minister of Transport and Logistics, 2022). In Bishoftu, All PT modes are paratransit with the largest modal share of 70.5% being Three-wheelers (Bajajs) (Bishoftu Transport authority, 2019)(Gezahegn, 2019). While they are free to work on their own schedule (frequency), transport authority of Bishoftu assigns routes to paratransit providers individually. The transport authority tries to manage frequency of different PT modes indirectly by assigning more vehicles on routes that are assumed to be busier.

2.5 Case studies

2.5.1 International Case studies

While PT network design and optimization is an iterative process that is expected to run perpetually, there are cases where cities conducted restructuring of major components of the PT system yielding better results. The city of Bogota, Colombia, introduced BRT (rapid bus transit system) in 2000 and conducted a large-scale formalization and restructuring of its public transport system in 2010 (Rodriguez *et al.*, 2016). By redesigning its bus routes, regulating fares, upgrading infrastructure and integrating with (BRT), the city improved accessibility and affordability and safety of the overall public transport experience.

Similarly, the city of Jakarta, Indonesia, first introduced a BRT system in 2004 and currently has more than 251 km BRT routes, the largest in the world (Kreindler *et al.*, 2023). In addition, a system of micro-bus feeders was introduced to cover about 88% of the sprawling suburbs and ingrate public transport provision.

According to Gezahegn (2019), The city of Bishoftu has a plan to upgrade its public transport by introducing BRT public transport modes and services.

2.5.2 Local Cases of Public Transport Network study

Different local studies tried to develop various ways of conceptualizing public transport network studies depending on specific objectives. Bogale (2012), Studied the mismatch between public transport network demand and available infrastructure in Addis Ababa. The research focused its objective in studying accessibility, equity and efficiency, by using road density, mobility index and proximity indices as indicators (Bogale, 2012). The study further utilized a commonly used Four stage transport demand modeling approach to study the network demand of Addis Ababa city (Hensher and Button, 2000). Analysis done using the indicators show, there is inadequate infrastructure in peripheral parts of the city while road networks in central parts of the city suffer from capacity limitations.

A more detailed study on Addis-Ketema sub-city, Addis Ababa, was conducted by Sadek & Al-Sadimy (2024), (Sadek and Al-Sadimy, 2024) with the objective of evaluating the connectivity level of road network segments. The study used connectivity metrics such as alpha, beta gamma, degree of connectivity, node density and link density. The findings indicate the outskirts of the sub city still need better connections with other parts of the city (Sadek and Al-Sadimy, 2024).

Debas (2019), studied the mismatch between PT network and condominium housing in Addis Ababa using transit capacity, frequency and service coverage as indicators. The study developed a summed up aggregated index called transit availability index for all woredas in the city based on the three indicators. Besides bringing to attention the lack of data in some woredas of the city, the study identified there is a positive relationship between socio-economic status and availability of transit. Bringing to light the need for optimizing equity when it comes to public transport provision.

Similarly, Abraha (2007), emphasizes providing equitable and efficient public transportation in the context of ever-increasing demand within the constraints of limited resource is the main challenge of developing countries like Ethiopia. The study suggests optimal levels of public transportation output should be achieved by monitoring resources and service distribution (Abreha, 2007).

Other studies such as by Fenta (2014), studied factors that contribute to public transport demand in Addis Ababa, using descriptive research method. The study analyzed the rate of increase in population increase and the physical expansion of city as having an impact by increasing the demand for public transportation (Fenta, 2014). The study is complementary with the study by Koroso, Lengoiboni and Zevenbergen (2021), in its identification that cities are physically expanding in faster rate than their population are by taking Addis Ababa as a case (Koroso, Lengoiboni and Zevenbergen, 2021).

A study on three-wheeled vehicles and congestion in Bishoftu by Abebe & Garuno (2022), considers, time, cost and safety as parameters that indicate the best route between two points. The study adds a unique perspective of drivers' behavior into the discussion of public transport traffic flow (Abebe and Garuno, 2022). Gezagegn (2019) also studied public transportation in Bishoftu as part of the structural revision of the city with an objective of assessing road network and public transportation using travel demand modeling, considering safety and flow patterns on major segments. The findings indicate unsafe public transportation, high congestion and low accessibility.

CHAPTER THREE: RESEARCH METHODS AND MATERIALS

3.1 Description of the study area

3.1.1 Study area selection

The only city hosting more than a few hundred thousand people in Ethiopia is the capital city Addis Ababa. Projections based on the 2007 census data indicate that, the population of cities that have a population of more than 100,000 inhabitants all combined is proportional to the population of Addis Ababa. Most efforts spent trying to address urban issues such as public transport provision are concentrated in Addis Ababa. This is indicated by the fact that Addis Ababa has public transportation provider agencies such as ‘Anbesa’ city bus and ‘Sheger’ City bus in Addition to paratransit transportation service providers. In contrast, no other city in Ethiopia has an organized comprehensive public transport provider and are dependent on paratransit services. By taking Bishoftu as a case, the study tries to contribute to the discussion of developing public transportation systems that are optimized according the economic, social, environmental and morphological context of Ethiopian secondary Cities.

Bishoftu shares similar characteristics with many secondary cities of Ethiopia in terms of population and economic activities shaping mobility. By selecting Bishoftu as a case, the study tries to contribute to the discussion of optimizing public transport in other Ethiopian cities of similar characteristics.

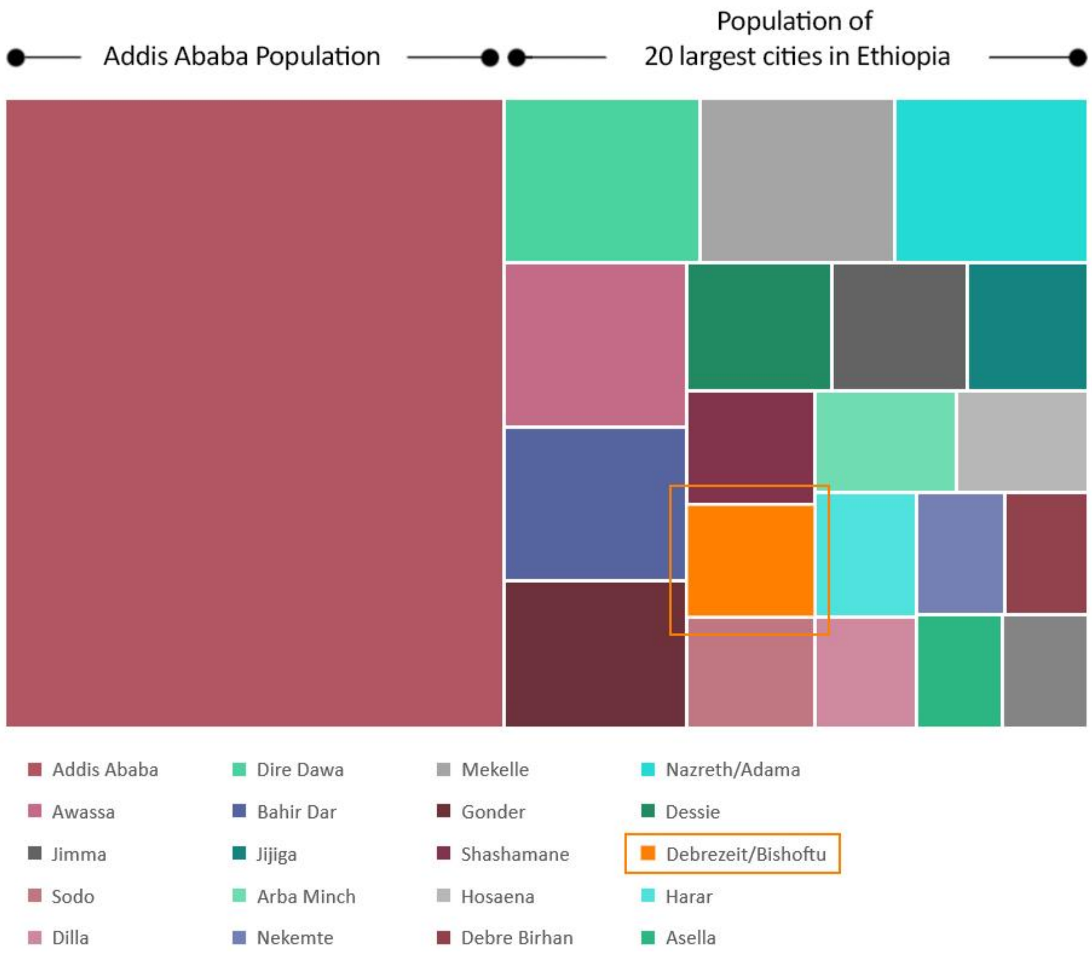

Figure 3.1 Ethiopian cities population distribution

3.1.2 Location of Bishoftu

Bishoftu is a city located 47 km South-East of Ethiopian capital city Addis Ababa. Located in Oromia region, East Shewa zone with an average altitude of 1920m. The city is organized into Four sub cities each having four '*Gendas'* (Administrative zones) (Oromia Urban Planning Institute, OUPI, 2019).

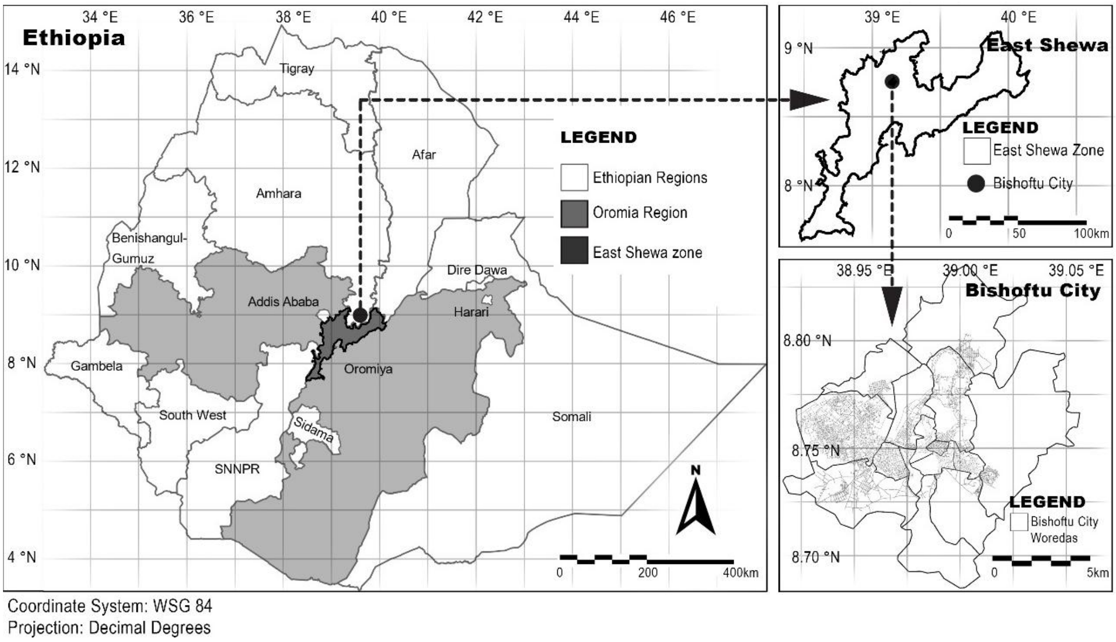

Figure 3.2 Location map of Bishoftu according to 2019 structure plan revision

The formation of the city is directly related to the construction Ethio-Djibouti rail way between 1894 – 1917. Being located along the rail way and a major trade and import-export route shaped the development of the city (Zewde, 1991; Gudina, 2019). Bishoftu is also a popular recreation resort town that hosts a number of volcanic lakes attracting local and international tourists. The city hosts a number of industries, manufacturing plants and facilities. As of 2018, there were about one hundred thirty-nine active industries in Bishoftu providing employment opportunities for more than twenty thousand people (Gadisa, 2019).

Bishoftu used to be called a Debre Zeit from 1955 up to 1990. But since 1990 the city regained its former name and is officially known as Bishoftu while the name Debre Zeit is also sometimes used to refer the city in public circles. It is commonly accepted that, the name Bishoftu means a place of water derived from an '*Afan Oromo'* language where *'Bishaan'* means water, reflecting abundance of lakes and water resources around the land.

3.1.3 History and Urbanization of Bishoftu

According to Gudina and Pankhurst, the Ethio-Djibouti railway construction reached Bishoftu in 1913 and a rail station was set up, and by 1925, Bishoftu was already acknowledged as an urban center with a settlement around two nuclei. The first one was around the present day Mandube hospital where the seat of the governor, market place, land lords and notable farmers settled. While the second center was located around an area known as 'Circle' today. This was where people working for the rail way company and merchants settled, close to the rail way station (Pankhurst, 1985; Gudina, 2019).

During Italian occupation that lasted from 1936 – 1941, Bishoftu experienced an investment of infrastructure. These included the introduction of postal service, installation of electrified street lamps on major streets and construction of a main route connecting Addis Ababa with the eastern part of the country passing through Bishoftu (Zewde, 1991; Gudina, 2019). This main road corridor coupled with construction of internal roads contributed to how the town grew in the later decades.

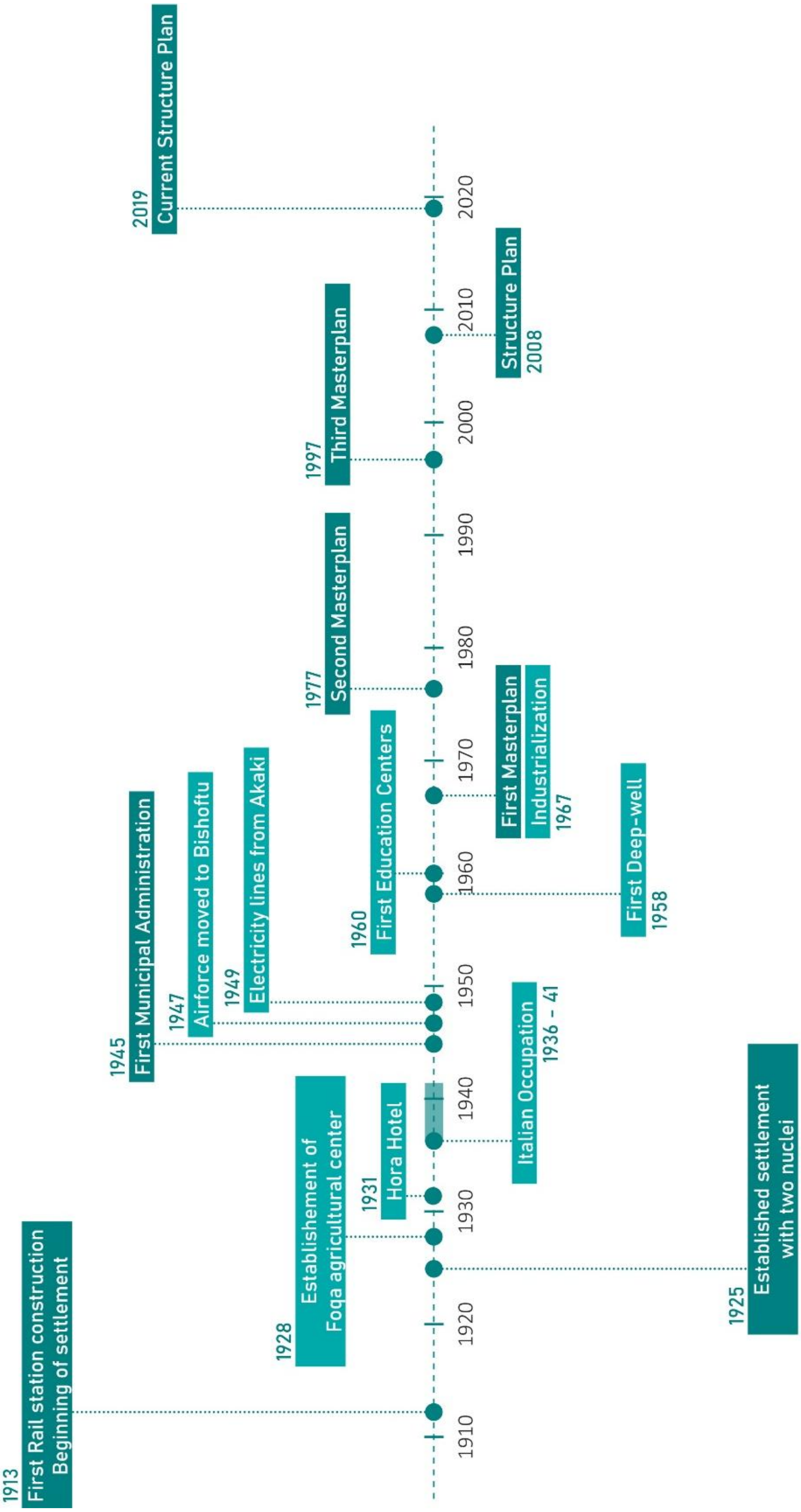

Figure 3.3 Bishoftu development timeline

It was in 1949, after Italian occupation, Bishoftu received it first power line from Akaki covering wider parts of the city and later in 1960 from '*Qoqa*' power plant. By 1970 most of the town had an electricity coverage (Zewde, 1991; Gudina, 2019). The first water well was constructed in a place called '*Foqa'* together with the construction of the railway. And in 1958 deep well was constructed providing water to the town. By 1974, most of the town had access to a water pipe line. Municipal documents show, according to Gudina (2019), by 1967 there were about thirty industrial establishments, seven hotels and number of manufacturing plants built.

Bishoftu hosts one of the most important military establishments in the country, the Ethiopian Air force. In 1947 after the Italian occupation, the Imperial Air Force was moved from Addis Ababa to Bishoftu. The Air Force shaped the development of the city, land use and settlement pattern (Zewde, 1991; Gudina, 2019). Post-Italian restructuring of urban centers granted Bishoftu a municipal administration in 1945. The population of the town was estimated to be around three hundred at this time. From 1945 to 1966 the town experienced growth in population reaching twenty thousand inhabitants.

Bishoftu got its first masterplan in 1967 but was not implemented and another master plan was developed for the city in 1977 by the ministry of work and urban development. A third masterplan was developed twenty years later in 1997 by National urban planning institute. In 2008 a structural plan was developed for Bishoftu by OUPI (Oromia urban planning institute). The current revised version of the structure plan was produced in 2019 by OUPI and is in use now.

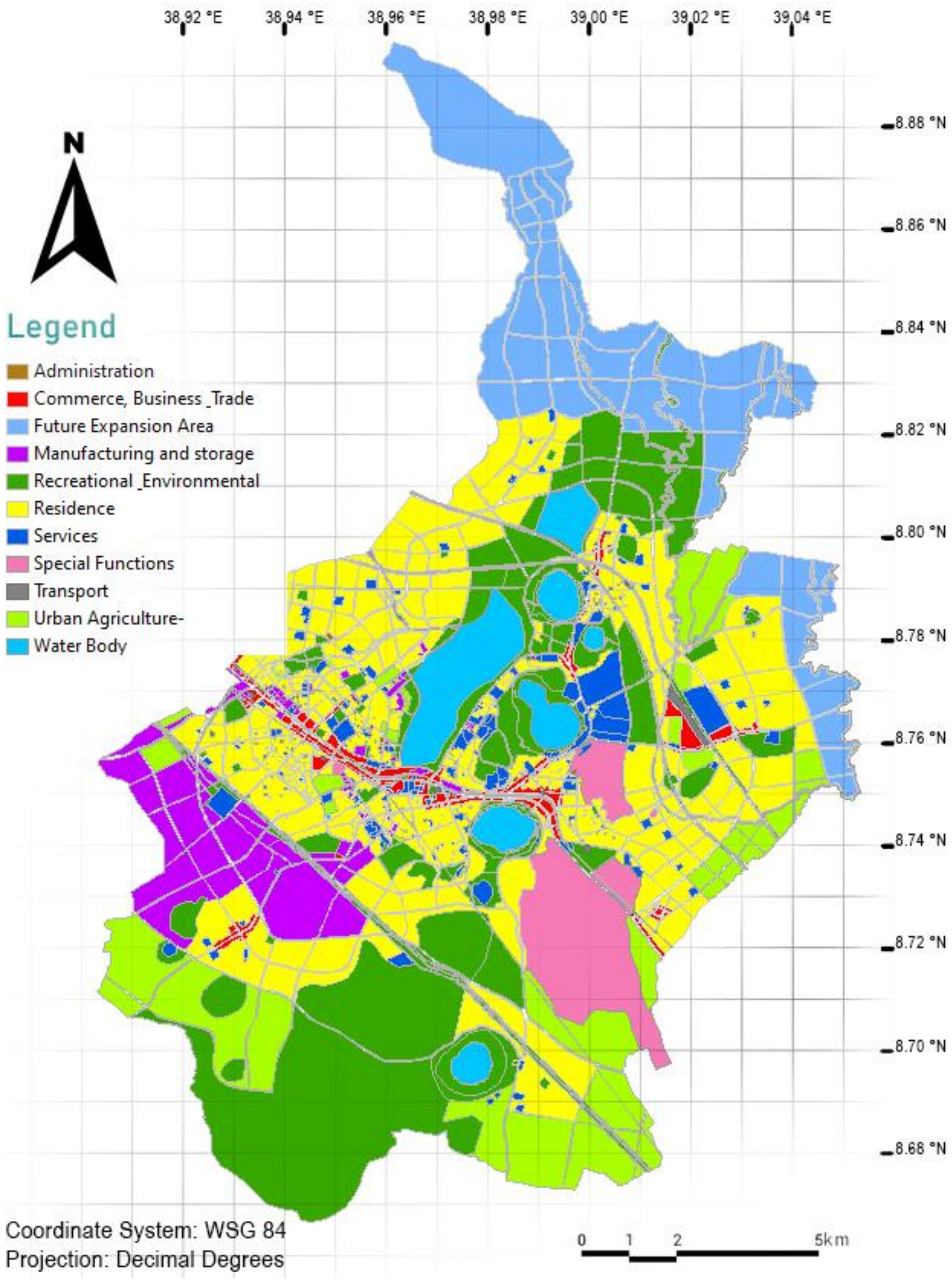

Figure 3.4 Bishoftu Structure Plan, OUPI 2019

After analyzing the development along the Addis Ababa – Bishoftu economic corridor, Tanku and Woldetensae (2023) concluded that, Bishoftu's proximity to Addis Ababa has "*contributed to the urbanization process and urban corridor formation through* *investment expansion"*. The study also shows how the urban centers from Addis Ababa to Gelan to Dukem up to Bishoftu are merging by changing the land use from agriculture to built-up urban area.

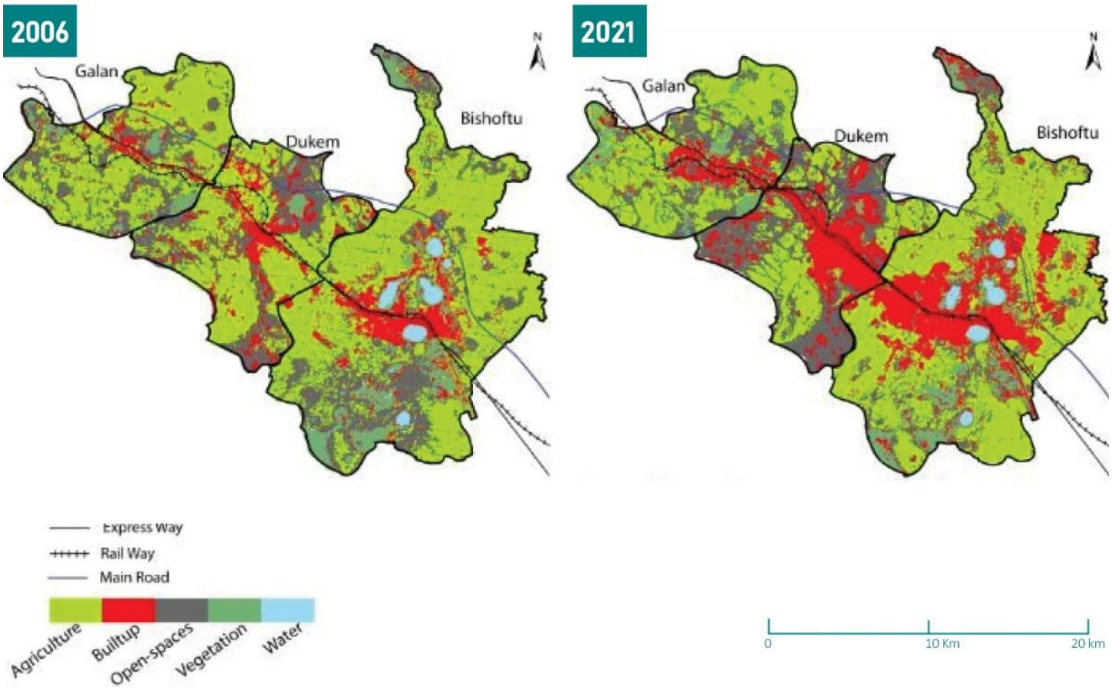

Figure 3.5 Expansion and merging of Gelan, Dukem and Bishoftu urban centers (Tanku and Woldetensae, 2023)

Oromia regional government announced in February 2023, restructuring of major cities and creation of new administrative districts and zonal units. As part of the restructuring, a plan was announced merging Bishoftu city with '*Dukem'*, *'Ude Dhankaka' 'Hidi'* and *'Dirre'* towns. The city will be upgraded into a Regio-polis and divided into three sub-cities and 10 city-districts (Addis Standard, 2023). Figure 3.5 shows how in a span of 15 years, urban centers of Gelan, Dukem and Bishoftu grew to become a one continuous industrial and residential settlements.

Table 3.1 Land use change in Bishoftu, (Tanku and Woldetensae, 2023)

Land use	**2006** (Area in Ha)	**%**	**2021** (Area in Ha)	**%**
Agriculture	10523	51	10047	49
Built-up	2616	13	5061	25
Open pace	4822	23	2971	14
Vegetation	2079	10	1960	10
Water Body	529	3	529	3

Table 3.1 & Figure 3.5 shows how the city of Bishoftu built-up area grew from 13 % in 2006 to 25 % in 2021 by taking up agricultural area and opens paces. While the loss of open space was 38%, built-up area increased by 94% in just 15 years.

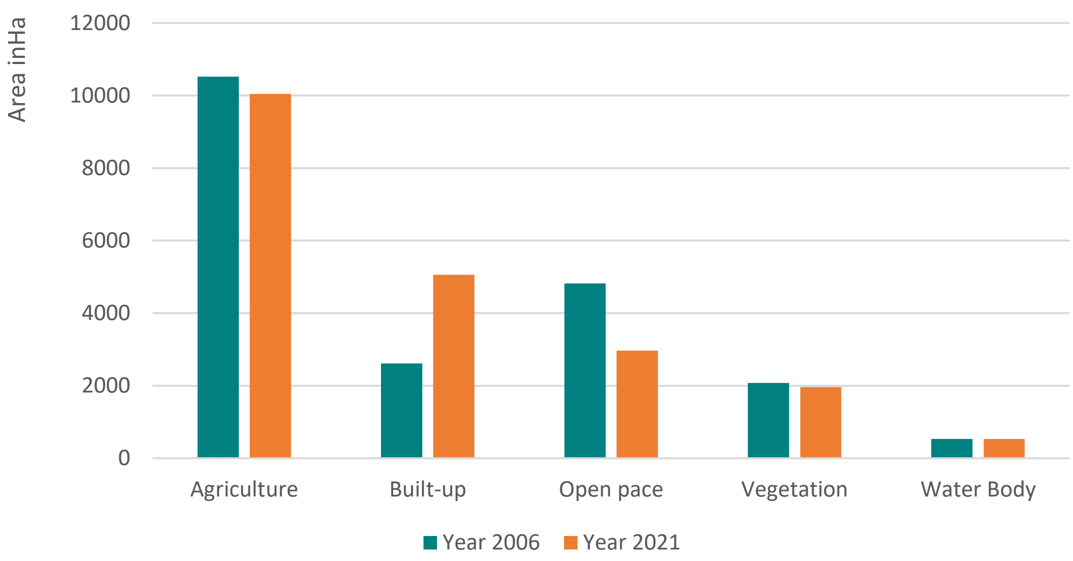

Figure 3.6 Land use change in Bishoftu, (Tanku and Woldetensae, 2023)

Similarly, Tsehay (2024) studied land use change from 1990 to 2020 in the city of Bishoftu. The findings show that, built up area increased from 6% in 1990 to 22.8% by 2020.

3.1.4 Demography

CSA sample survey in 1967 and 1970 indicates that, the population of the city of Bishoftu was 21,220 and 27,747 respectively. In 1994 the population of the city increased to 73,372 people indicating a substantial population increasing rate of 5.36%. According to the census data of 2007, the population of Bishoftu was 100,114 people (CSA 2007)(Gadisa, 2019).

Table 3.2 Bishoftu population based on sample studies conducted and projections based on 2007 census data (Gadisa, 2019), (OUPI), (CSA 2007)

Year	Male	Female	Total
1967	9,090	12,130	21,220
1970	12,730	15,017	27,747
1984	25,764	29,891	55,655
1994	35,058	38,314	73,372
2007	47,860	52,068	99,928
2009	51,282	55,555	106,837
2015	69803	77261	174,710
2017	100,899	104,958	205,858
2019	113,794	112,140	225,796

Population growth of Bishoftu has accelerated in recent years (See Figure 3.7). Gadisa (2019) states that, this can be partly justified because five more rural kebeles were incorporated under the city administration of Bishoftu in 2015. The other major factor contributing to the rapid population growth is high rate of migration from rural areas (Gadisa, 2019).

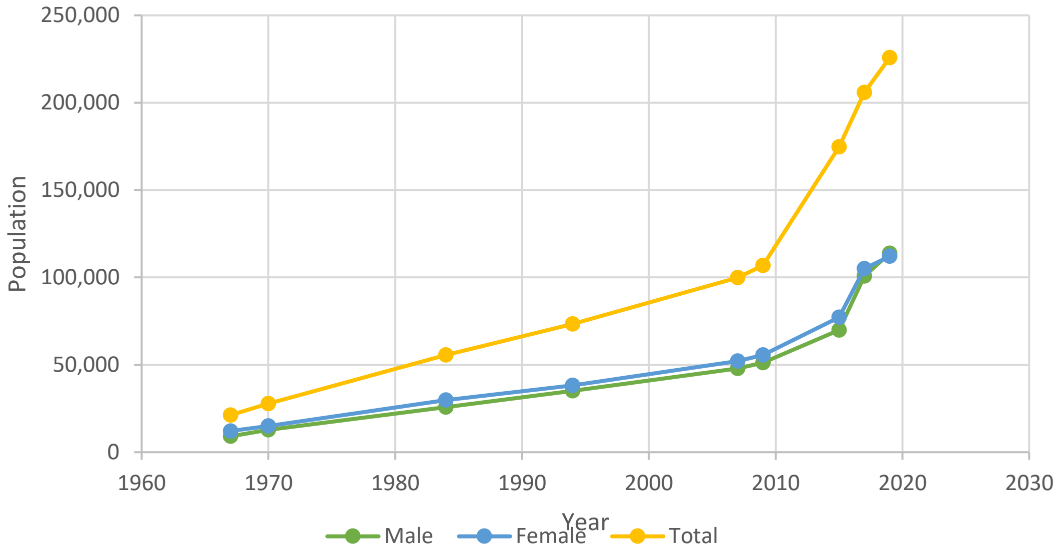

Figure 3.7 Bishoftu population growth rate (Gadisa, 2019), (OUPI), (CSA 2007)

Current, 2025, population of Bishoftu can be estimated to be **314,075** by using a population projection formula

$$P_t = P_o e^{rt}$$

Where:

P_t = Population size after ‘t’ years

P_0= Initial population size

r = Population Growth rate and

t = Projection period (years)

at and estimated growth rate of 5.5%,

Table 3.3 Bishoftu population by kebele (Gadisa, 2019), (OUPI, 2019)

	Gandas / Kebeles	Population (2019)	No of households	Average family size
1	Dirre Jitu	53,443	15,218	3.5
2	Kudada	21,235	5,402	3.9
3	Udaada	9,532	2,818	3.4
4	Dabbaso	5,645	1,709	3.3
5	Calalaqa	16,577	4,624	3.6
6	Filtu	8,004	2,005	4.0
7	Biftu	18,011	4,745	3.8
8	Katta	10,070	2,130	4.7
9	Birbirsa Foqa	26,800	5,752	4.7
10	Qalitti	12,088	8,279	2.0
11	Gorba	8,109	2,003	4.1
12	Hora Haadhoo	8,000	1,116	7.2
13	Qurqura Dambi	19,229	7,893	2.4
14	Qajima	9,191	1,409	6.5
	Total	**225,796**	**65,103**	**4.0**

Most of the population of Bishoftu is concentrated in four Gandas, *Dirre Jitu*, *Kudada, Birbirsa Foqa and Danbi*. Bishoftu has a large young and youth population. 28 % of the population is under 15 years old, while the youth population (age between 15 and 29) make up 29% of the population (OUPI, 2019). There are about 160 schools in the city. 70 Kindergartens, 75 primary schools, 10 high schools and 5 preparatory schools.

Current, 2025, population of Bishoftu can be estimated to be **314,075** by using a population projection formula

$$P_t = P_o e^{rt}$$

at growth rate of 5.5%, where P_t = Population after't' years, P_0= Initial population size, r= Growth rate, and t= Projection period (year).

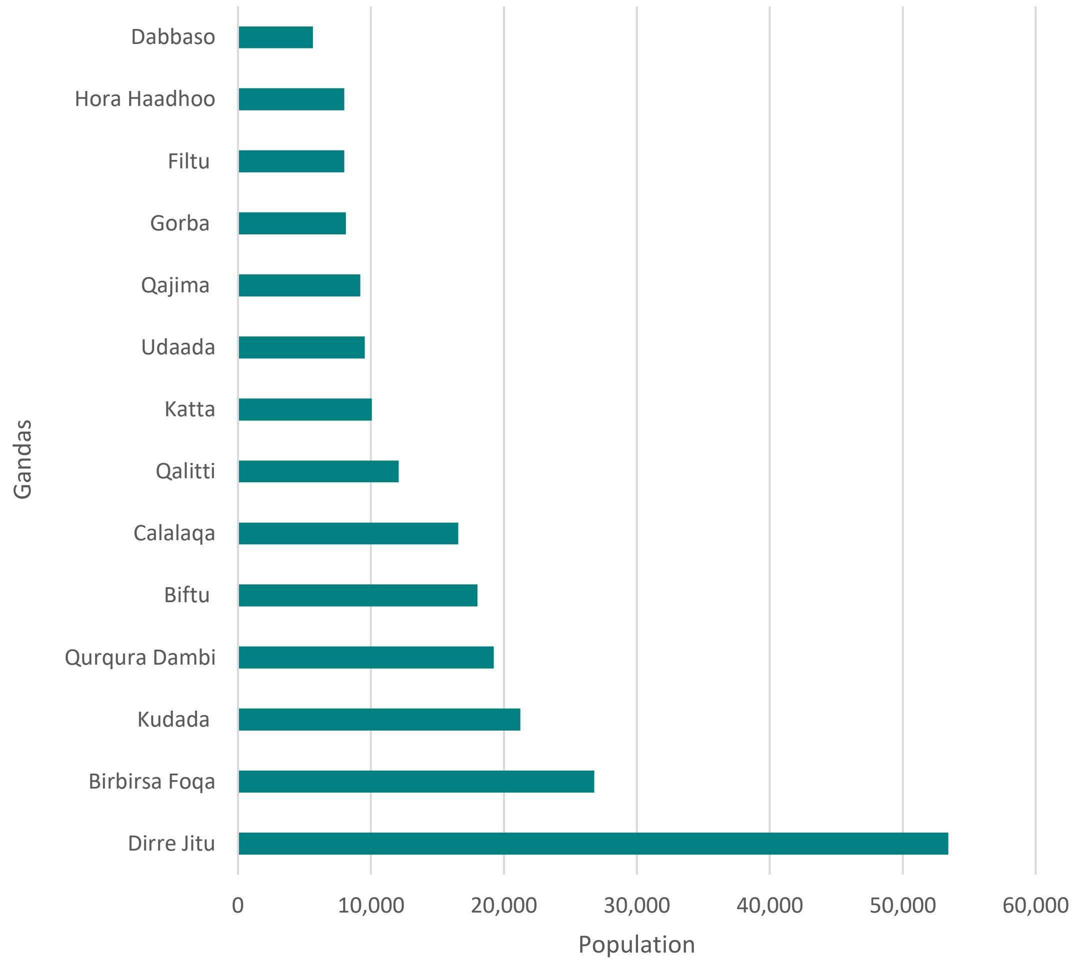

Figure 3.8 Bishoftu population comparison by kebele (Gadisa, 2019), (OUPI, 2019)

3.1.5 Road Network and public transport in Bishoftu

As of 2019 according to Bishoftu city infrastructure asset inventory, there was a total of 540.36 km of road that is 7m or wider (Gezahegn, 2019). Among these roads, only

20.7% of it is asphalt road and accessible by all modes of public transport (Gezahegn, 2019).

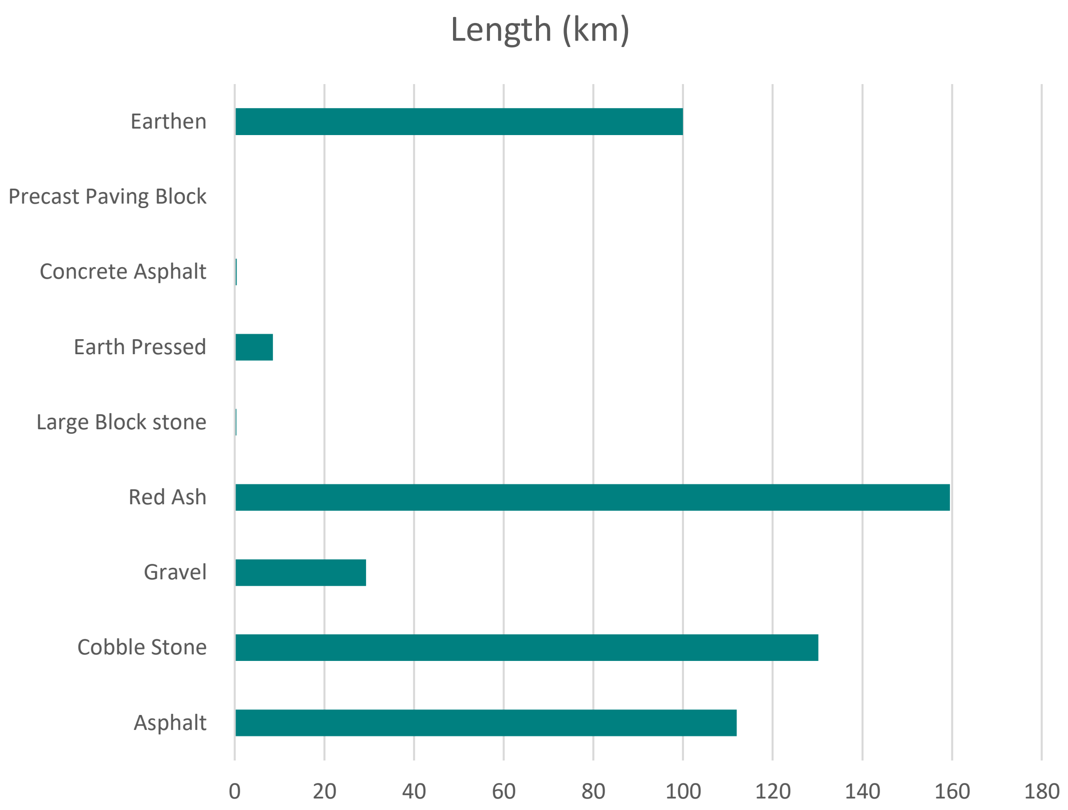

Figure 3.9 Road material cover in km Bishoftu (Gezahegn, 2019)

According to Bishoftu transport authority in 2019, Bishoftu has one major regional public transport hub that serves as departure and destination point for buses and mini-buses. The terminal gives service to seven major destinations namely, *Qalitti, Adama, Modjo, Asalla, Chaffee, Dirre* and *Adulala*. The most important destination being to Qalitti (46% mobility) because it is the major link to the capital city Addis Ababa.

The two main public transport modes in Bishoftu are Bajaj (three-wheeler) and mini-buses. The three- wheelers operate on 34 routes and has a PT modal share of 70.5% while minibus taxis have 29.5%. Mini-bus taxis operate on asphalted roads and operate on eight routes (Bishoftu transport Authority, 2019).

Bishoftu has a diverse road network structure. Some areas have road network that developed naturally following informal settlement patterns (*Fig 3.9 - d),* while other areas are well structured and planned *(Fig 3.9 - j)*. Areas that developed informally exhibit a road network characteristic that are not well connected and dominated by dead-end nodes, *(Fig 3.9 - k).*

Figure 3.10 Bishoftu road network structure samples - extracted by the author from Google maps, Airbus/Landsat satellite imagery 2025

3.1.6 Morphology of Bishoftu

Morphology of Bishoftu is highly affected by the natural features of the city. The mountainous terrain and existence of many lakes gave the city its current shape. Mobility and road network in Bishoftu is also shaped by these natural features (Abebe and Garuno, 2022).

One can analyze the settlement pattern of Bishoftu based on the morphology map and understand the sprawling nature of the city. One factor is because of the land features, lakes and wet lands. The second major factor is the influence of Addis Ababa - Adama highway, acting as an attractor for settlements to stretch along the major east-west transport corridor. The fact that the city is not compact can be a challenge to urban mobility.

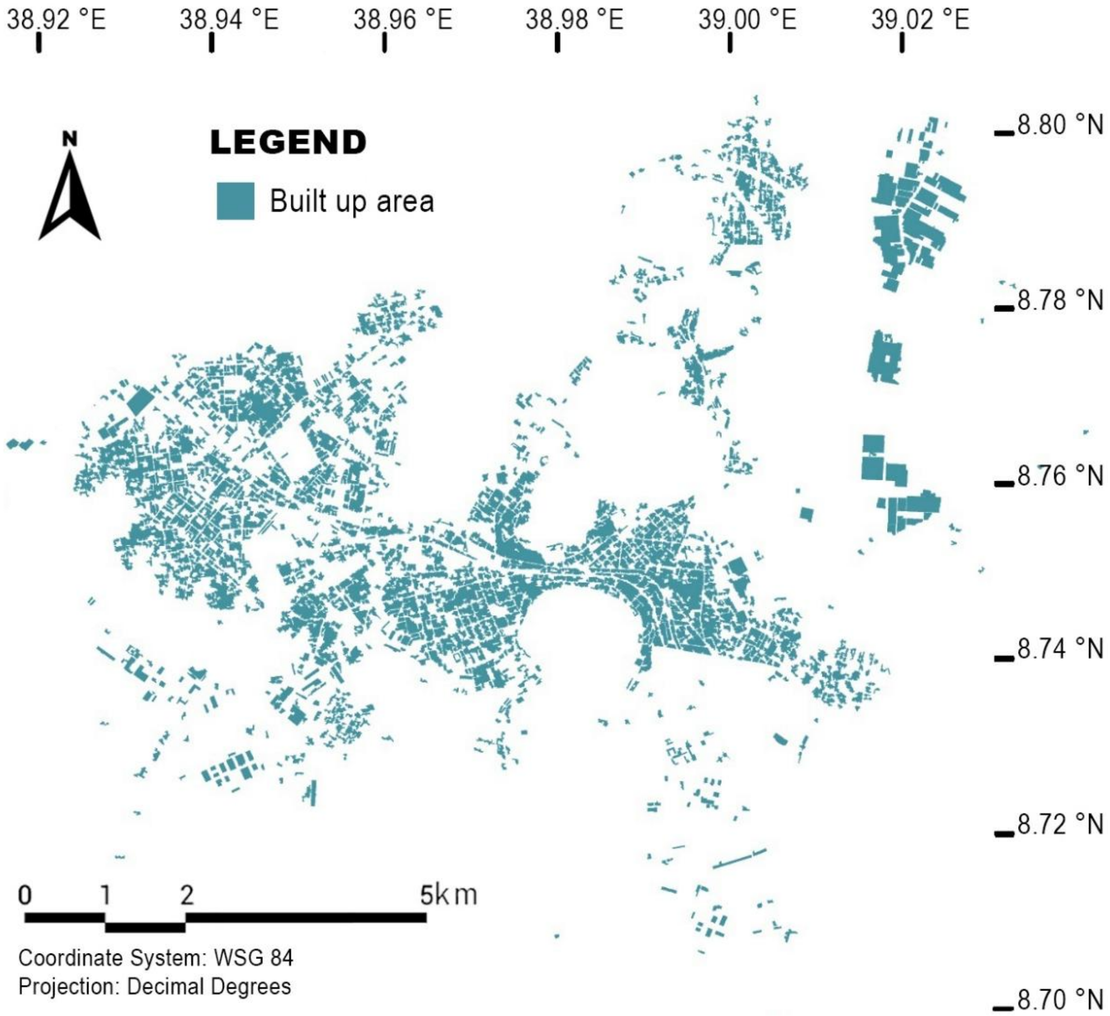

Figure 3.11 Figure Ground map of Bishoftu, built up area extracted by the author from Google maps, Airbus/Landsat satellite imagery 2025

3.2 Research Design

The study employed a mixed-methods research approach, integrating quantitative spatial and statistical modeling with qualitative contextual analysis. The methodology is focused on an empirical, data-driven modeling exercise using the Four-Stage Transport Demand Model (FSM) and Geographic Information Systems (GIS) to quantitatively analyze travel patterns and network performance. The quantitative analysis is supplemented by a qualitative review of policy documents, local case studies, and field observations, ensuring study captures the contextual realities of Bishoftu's public transport system. The research is developed around the idea that transport planning is an iterative process whereby the result has to be optimized continuously. This process invites for design-based research where the output has to be a tangible component that can be re-evaluated in addition to simple recommendations.

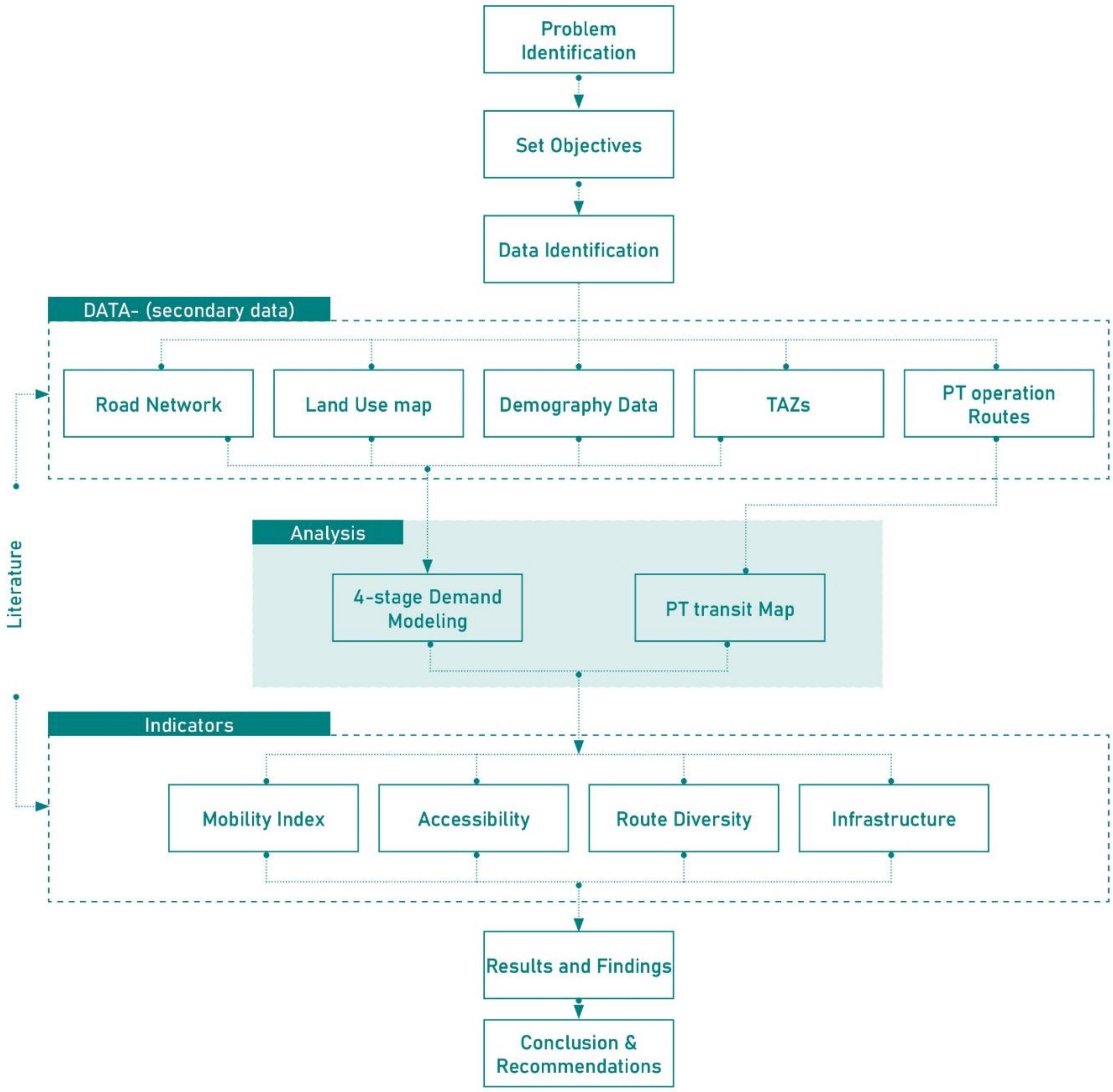

Figure 3.12 Research Design

To address the objective of the study, GIS data, Road network, road surface material, Land use, Demography and documents collected from administration and government bodies were used.

Analysis methods for the study are selected based on indicators used to study public transport network of Bishoftu, which in turn are based on literature, contextual analysis and available data.

3.3 Data sampling and collection Methods

Data collection for the study involved field surveys to geolocate public transport routes, origins, and destinations, as well as to record road surface conditions along these corridors. 38 PT routes and their origin and destination points were surveyed for the study. Road material finish of all 38 routes were was surveyed on site. Physical study of PT routes was supplemented by direct engagement with the Bishoftu City Transport Authority to obtain official records on route assignments, vehicle frequencies, and modal shares for minibuses and three-wheelers. Additional secondary data collection comprised acquiring GIS datasets, including road networks and building footprints from OpenStreetMap. Demographic data, land use, and existing trip generation data is extracted from key documents, such as the Bishoftu Structure Plan Revision (2019) and national census projections.

3.4 Data Sources and Type

The study utilized secondary data collected from local and regional administrative bodies on mobility pattern and public transport network components and verified the data on the ground. Primary data on the road material of routes used by different public transport modes was collected by the author. Additional documents from central statics agency of Ethiopia and satellite imageries are used to study the relationship between the topography of Bishoftu, its settlement pattern and urban mobility.

Table 3.4 Data Sources and Type

Data Type	Data
Transport Data	• Route and number of three-wheelers and mini-buses assigned on specific routes – Bishoftu city Transport Authority 2019
Demography	• Population data, Projected from 2007 census data - CSA
GIS Data	• Road Network, Road condition, Building footprint – open street map 2024 • Public transport origin and destination points – Bishoftu city transport authority - Locations surveyed on site • Administrative zones of Bishoftu, boundary, structure plan, Land use map – Bishoftu structure plan revision 2019
Documents	• Ethiopian Transport masterplan - 2020 • Bishoftu urban transport planning and traffic management study- 2019
Road material	• Primary data collected on the road surface material along routes used by different public transport modes - 2024

Secondary data collected from documents are verified by making on site studies and conducting systematic verification of data used as input. These include field work assessment of:

- Road network
- Transport routes (three-wheelers and mini-buses)
- Origin and destination of different public transportation mods
- Road condition
- Flow of traffic

3.5 Data Preparation and processing methods

Transport network analysis is primarily a geo-spatial analysis of mobility patters. To ensure the relevance of collected data which vast part of it was in tabular and text format, the following steps were taken.

Digitization into GIS compatible format

Data collected in a form of spreadsheet and text such as transport routes and points of origin and destination were digitized and georeferenced. This step ensures the usability of the data in spatial analysis tool such as ArcGIS and Rhino. Emphasis was given towards maintaining the format consistency so that other data such as population and land use can be added to the feature classes yielding reliable output.

Extracting and cleaning OpenStreetMap data

OpenStreetMap was used because of its rich set of data sets that can be used for different purposes. Detail building footprint and road network data are extracted for the purpose of the study. But it was important to avoid non-relevant data, reference it to match other data sources and feature classes.

Synchronize different data sources

Land use data, Road network data, Population Data, Road condition data, transport modes and routes data, etc. all come from different studies in different formats. In order to create a realistic understanding of the relationship between these different components, data from each was categorized and synchronized. E.g., Creating a land use map that is population weighted to understand trip generation and trip attraction.

Geo-referencing origin and destination points for different public transportation modes

This step is critical since the data acquired from the Bishoftu transport authority does not have accompanying spatial data on the where abouts of the origins and destination points of different public transport modes. These nodes throughout the city were manually located.

3.5.1 Software used

Software used for the study were selected based on their capacity to accommodate varied data sets and high level of customization. Public transport modeling is computation intensive task and a software capable of handling complex geo-spatial data was required. 3D modeling software, Rhino and Grasshopper with an added Decoding spaces for urban analysis plugin, were used for the study. The tools provide parametric capabilities both for modeling and analyzing various components of transportation networks dynamically.

3.6 Data Analysis Methods

3.6.1 Selection of mobility optimization models

Public transport network optimization models studied are concerned on how they approach route assignment and frequency assignment of a given system. The study suggests using optimization approach that determines routes first and then assign frequencies later (van Nes, Hamerslag and Immers, 1988) for future studies, once accurate trip generation and distribution data is available and PT modes such as public buses are introduced.

This is because the data required for frequency assignment is neither complete nor reliable, and paratransit nature of PT in Bishoftu means, frequency is the sum of individual PT providers and cannot be assigned by the transport authority.

The Four stage transport modeling method is used to study PT network demand of Bishoftu city and by comparing it with current PT network provision, the gap (mismatch) of routes is studied. Furthermore, additional indicators**:**

- mobility index,
- accessibility,
- route diversity and
- infrastructure assessments are studied based on input from the literature.

These analysis methods and indicators are discussed further.

3.6.2 Four stage Demand Modeling

The most widely applicable generalized form of transportation modeling approach called the 'four-stage model' is used to study travel demand of Bishoftu. The model studies how many trips will be made, from where to where, by which mode of transport and on which routes (Hensher and Button, 2000). The model's accuracy is dependent on the level of available data. It can be expanded to include more detail travel behaviors or scaled down based on available data. The four steps of the four-stage demand modeling are: Trip Generation, Trip Distribution, Modal Choice & Route Assignment.

The model is improvised to work for the case of Bishoftu based on available data in the following way.

Table 3.5 Summary of the Four Stage Demand Modeling (FSM) used

Stage	Data needed	Data available	Customized
Trip Generation	Trip production of TAZs based on survey of trip purpose and frequency, socio-economic characteristics and structure of TAZs	• Land-use • Trip data from OUPI • Blocks Population Data	Blocks used as TAZs, Demographic data distributed to Blocks based on their size and land use
Trip Distribution	Origin Destination (O-D) data surveyed (activity system between TAZs), impedance of travel between TAZs (cost, time, distance etc.),	• Land-use • Trip data from OUPI • Blocks • Population Data	Gravity model using land-use as attractor of activity (trip production and attraction) and distance between blocks as impedance, every blocks as origin and destination based on factor using land use
Modal Choice	• Characteristics of travelers (car ownership, income household structure etc.), • Characteristics of journey (time of day, purpose etc.), • travel facility (waiting time, travel time, availability, reliability, comfort, safety etc.)	• paratransit O-D modes with frequencies • Comfort based on road infrastructure but not used for mode choice	• All modes are considered to be paratransit public transportation modes
Route Assignment	• Network Data • Time it takes between O-D • Cost (fares, comfort etc.)	• Network Data • Distance between O-D	• Shortest route (Time and distance) within the network

Trip Generation

The first stage in the FSM deals with defining the total daily trip that occurs in the system(Bell and Iida, 1997). This can be generated for areas (TAZs) as small as household level or wide spatial zones depending on the purpose of trips. The trip generation stage assumes activities (schools, work, shopping, etc.) produce trips that have two ends. The trip production end and the trip attraction end. Trip production is an estimation of travel generated within a TAZ, while, trip attraction is the magnitude of trips that end inside the TAZ. Factors such as income, vehicle ownership, employment status, household size, population density, and accessibility of the TAZ zone affect the magnitude of trip generation.

Two separate equations are used for the estimation of Trip production and attraction for each purpose of trip. Trip production $f_P^p(A)$ and a trip attraction $f_A^p(A)$ are used where p is the purpose of each trip and A is the activity system (Mcnally, 2000). Activity system is defined as the spatial distributions of land use and/or economic activities that take place in those areas.

$P_i^p = f_P^p$ (activity system characteristics P) &

$A_i^p = f_A^p$ (activity system characteristics A)

The study employs land use as an indicator or activity system coupled with mobility data from OUPI. Different land use are assigned production and attraction values based on literature study to get realist understanding of the trip generated from each TAZs and later refined during trip-distribution stage.

Trip Distribution

The trip distribution (TD) stage addresses the question of which trips go where by combining production and attraction information from all the TAZs. In this stage potential trips ends for each purpose of travel are recombined into trips by pairing them with the trip production ends. Trip distribution is also called a destination choice model and is represented by a matrix or table $\mathbf{T_{ij}}$. The representation form for the second stage of the FSM is:

$$T_{ij} = f_{TD} (A, t_{ij})$$

$$= f_{TD} (P_i, A_j, t_{ij})$$

Where $\mathbf{t_{ij}}$ is the impedance of travel (cost and/or time) between the traffic analysis zones (TAZs) *i* & *j*. Activity system **A** is a function of the trip production $\mathbf{P_i}$ and trip attraction $\mathbf{A_j}$.

The most commonly used model for analyzing the relationship between different zones called the gravity model is used for the study. It states that the interaction between two zones is directly proportional to the level of activity (trip Production and attraction) and inversely proportional to the amount of cost (time, distance, etc.) between them (Mcnally, 2000). The trip distribution gravity model is represented as:

$$T_{ij} = a_i\, b_j\, P_i\, A_j\, f(t_{ij})$$

$$a_i = \frac{1}{\sum_j b_j A_j\, \mathrm{f}(t_{ij})} \text{ and } b_j = \frac{1}{\sum_i b_i A_i\, \mathrm{f}(t_{ij})}$$

Where:

T_{ij} = Trips from origin i to destinatio *j*

T_i = Trips originating from *i*

T_j = Trips destined to *i*

t_{ij} = travel cost from *i* to *j*

ai , bj = iteratively solved balancing factors

f = distance decay factor

The study uses land use, distance between TAZs and data collected from city transport authority of Bishoftu to calculate trip distribution.

Modal Choice

The third step in transportation demand modeling is the estimation of the transportation modes used. When people decide to go somewhere they will evaluate different options they have to get to that place. This step uses the trip distribution table produced by trip distribution stage and generate mode-specific table of travel.

Three groups of factors exist that influence choice of transportation mode (Ortuzar and Willumsen, 2011).

- Characteristics of travelers: this includes car ownership, household structure, income, residential density etc.
- Characteristics of the journey: considers the purpose of the trip, time of the day and group travel options
- Characteristics of travel facility: these are quantitative and qualitative factors such as travel time, waiting time, availability of infrastructure, reliability, frequency, comfort, safety etc.

The study assumes all trips are made using paratransit public transport. This assumption is based on data where Bishoftu has insignificant private car ownership and the rest of PT modes share the characteristics of being paratransit. It has also assumed that all trips are doubly constrained, because significant majority of trips begin and end at home (Ortuzar and Willumsen, 2011).

Route assignment

The route assignment stage addresses equilibrium in a transportation network by analyzing a transport system's demand and supply side. The demand side is the number of trips made by various modes of travel and the supply side is composed of *transport network* ***S(L,C)*** where ***L*** are links (including associated nodes) and ***C*** is their specific cost (Ortuzar and Willumsen, 2011). The most simplified approach is taken by the study to take into account two important variables, time and cost. Cost is assumed to be proportional to travel distance. The weighted sum of time and cost yields a generalized cost output which will be used to evaluate route choice (Ortuzar and Willumsen, 2011).

The study uses the output of the FSM and compare it to the existing transport network to find mismatches in the network.

3.6.3 TAZs (Traffic analysis zones)

Main unit of analysis for transport studies are TAZs. Data acquired from Bishoftu transport authority uses the woredas and their boundary as TAZs. There are nine urban core woredas used for generating TAZs. Using only six TAZs will not reflect accurate transport characteristic. Block size TAZ is generated by using street network, building footprint and population data. The building foot print is used to approximate population distribution of each block. The higher the built-up area, the higher the population will be. Base data for a single meter square population density is generated by dividing total population of Bishoftu City to all Built up area.

3.7 Transport network performance Indicators

In addition to identifying mismatch between the PT network demand and supply, the study identified important network criticality metrics important for optimizing PT network based on literature study. The following four indicators are used to further study Bishoftu PT network based on objective of the study and available data.

3.7.1 Accessibility

According to Bhat et al., “accessibility is a measure of the ease to pursue an activity of a desired type, at a desired location, by a desired mode, and at a desired time” (Bhat *et al.*, 2000)

The study measures how much an individual has to travel on foot to access the closest public transportation route within the study area. Studies reviewed suggest using bus stops as points of reference for calculating distance from nearest public transport hub. But the paratransit nature of transport mode in Bishoftu indicates anyone can access PT once they have access to the routes with PT access. Studies also show PT nodes should be available at maximum distance of 500m – 700m in urban areas. Ethiopian transport authority developed a guideline as part of promoting non-motorized transport in cities stating that, public transit lines should be accessible within a walking distance of 500m (Institute for Transport & Development Policy, 2020). The study uses the suggested distance of 500m to draw conclusion regarding accessibility of PT network in Bishoftu city.

3.7.2 mobility index / Route directness

Mobility index compares the distance it takes to travel from a point of origin to a destination with a direct airline distance (Euclidean distance).

$$Mobility\ index = \frac{\text{PT Network Route distance}}{Airline\ distance}$$

The value is used to identify PT routes that should be optimized to reduce distance and travel time. According to Bogale (2012), referencing Suggestions from Network Study for Ethiopia (2000/2001), PT routes that have a mobility index value more than 1.4 should be optimized. This value is justifiable mathematically by assuming arrangement of urban blocks in a simple grid layout and calculating the maximum Euclidean to Longest route ratio, which is the square root of 2 = 1.41. The study assumes PT routes that have a mobility index more than 1.4 require optimization.

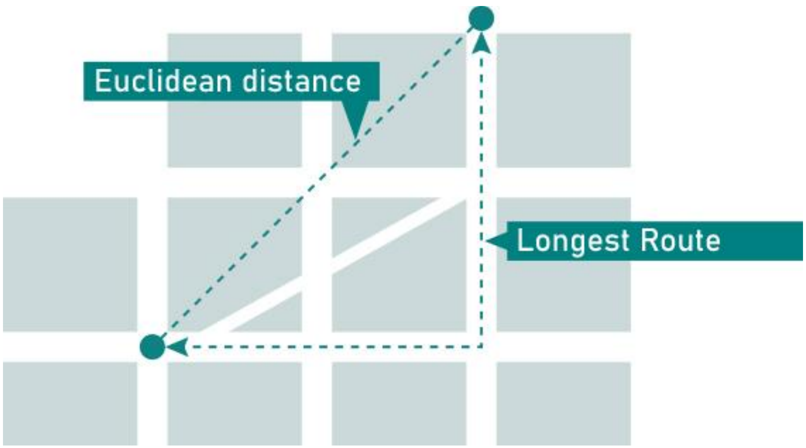

Figure 3.13 Mobility index / route-directness calculation

3.7.3 Infrastructure / Road pavement materials

Various indicators can be used to study road infrastructure. Of these indicators, road pavement material is selected because of its direct relationship with the transport networks. The type of road pavement material determines the speed of vehicles moving within the PT network and the level of comfort experienced by commuters. There are roads that are covered with asphalt, coble stone and dirt, giving service as public transport routes in Bishoftu. The study identifies routes that are and should be used for PT and recommends the level of optimization and upgrading required.

3.7.4 Route Diversity

The study identifies robustness of the transport network by surveying possibility of multiple PT routes to same destination (Barthelemy, 2010). Optimization suggestions are developed to increase the level of resilience of the transportation network based on findings of the study.

3.7.5 Public transport transit map

The study developed public transport transit map of Bishoftu (Chapter 4, Fig 4.29) and used it to study:

- Network coverage
- Connectivity and interchange points
- Route density and efficiency
- Overlapping routes etc.

The map is used as a tool to study the existing nature of PT network of Bishoftu and also a modified version is developed as an output to show optimization suggestions.

CHAPTER FOUR: RESULTS AND DISCUSSION

4.1 Introduction

This chapter deals with results based on FSM demand modeling approach, indicators and developed analysis methodologies. First Traffic Analysis Zones (TAZs) are prepared on a block level and data sets were added to them to derive PT routes and study accessibility. The results are compared with the existing PT routes and mismatch between accessibility and route directness are analyzed. A PT transit map representing existing PT modes and routes is prepared to help analyze performance of current PT networks. Current PT routes are also analyzed in terms of infrastructure and comfort by taking road material as an indicator. Possible design improvements in PT Networks are suggested to help mitigate findings of the research.

4.2 Bishoftu Public Transport demand modeling

Using the widely used four stage transport demand modeling approach as described in in chapter 4, PT routes and frequencies are determined.

4.2.1 Defining TAZs

The first step was identifying manageable TAZs and preparing data sets. A digital map of blocks in Bishoftu was extracted from a road network data acquired from *OpenStreetMap (OSM)*, a free online open-source platform making digital maps and datasets available for the wider public to use. The blocks were then mapped into Bishoftu kebeles map to create the possibility of transferring transport data sorted by kebeles into the Blocks, i.e., TAZs. The transportations data was acquired from Bishoftu transport authority and is aggregated according to 14 kebele boundaries. The administrative boundaries of the kebeles include less populated rural farmlands of

Bishoftu, which do not contribute to the urban mobility. For this reason, only dense settlements are extracted as contributing to urban mobility and thus studied as TAZs.

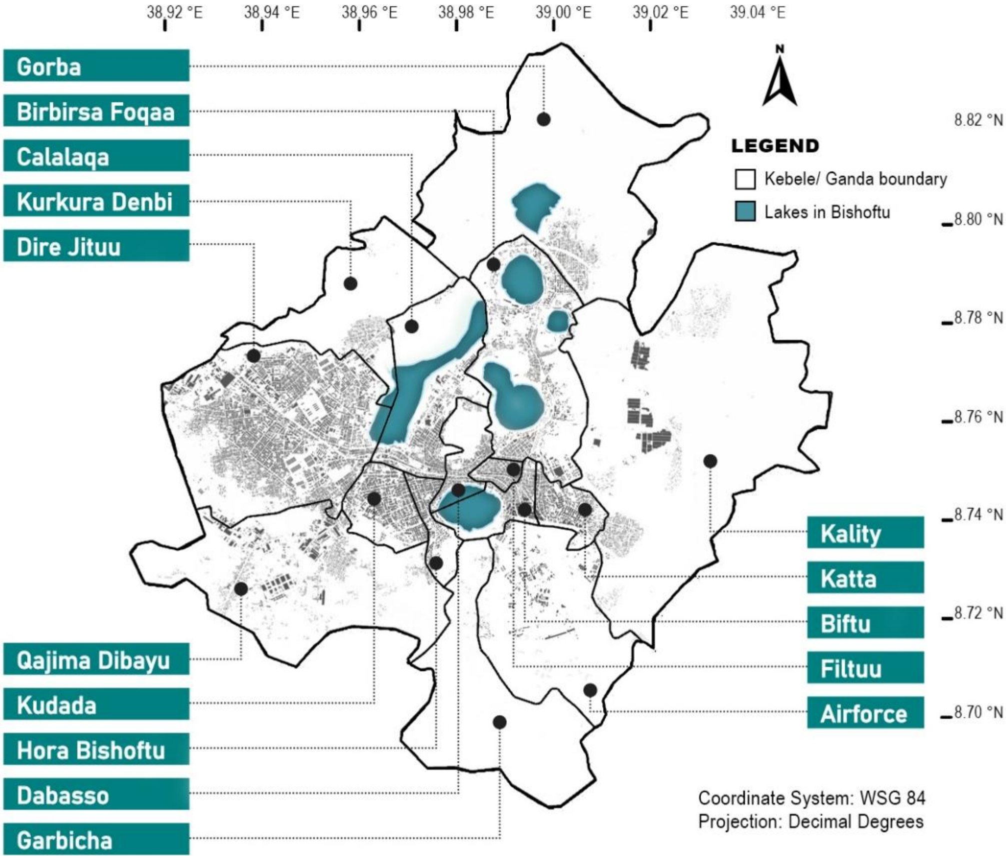

Figure 4.1 Gandas/Kebeles and Settlement distribution in Bishoftu

In order to produce a block level TAZ, first, road network segments are extracted that are part of the dense urban settlement. The network data is cleaned by removing dead-end roads that do not contribute to the mobility of the block as a whole. Then block geometries are then generated from street networks segments and used as TAZs. Data from OUPI providing trip data of nine Gandas is disaggregated in to 2157 block level TAZs.

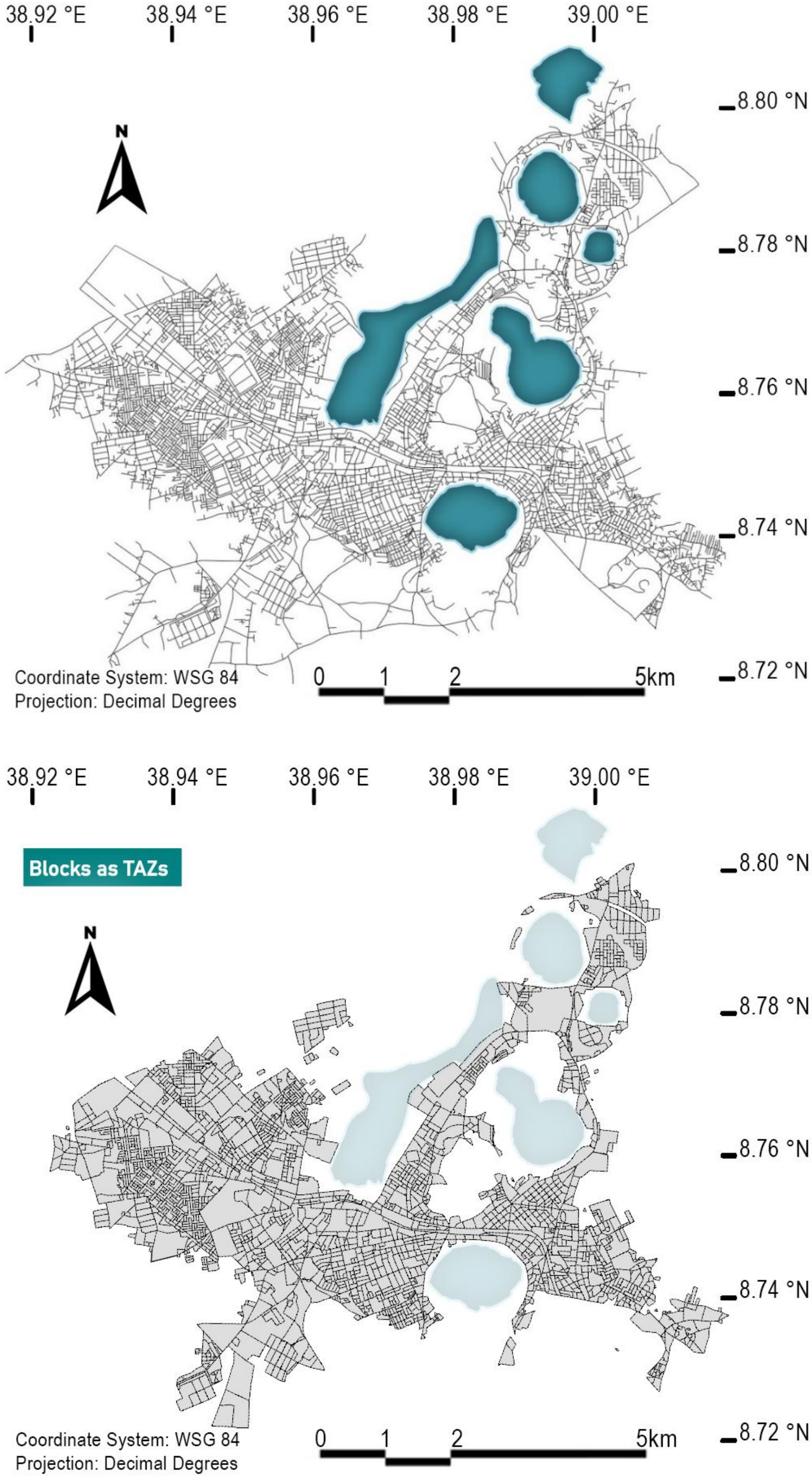

Figure 4.2 Preparing Urban Blocks as TAZs based on street network (Top - street network) (bottom – Blocks as TAZs)

After TAZs are generated, trip generation, distribution, modal split and route assignment were studied using the TAZs as the main analysis unit.

Data from 2019 structure plan revision of Bishoftu, by Oromia Urban Planning Institute is used to study trip generation and trip distribution (Gezahegn, 2019). The model used three main trip generation factors, population, building footprint floor area and employment level of the area based on land use. While the available data from OUPI was useful on its own, there were discrepancies that had to be addressed not to compromise the accuracy of the study. These include, large discrepancy between trip production & attraction and lack of consistency of areas that the TAZs represent. Problems regarding TAZ size was addressed by reprojecting data into block level TAZs produced by the study yielding better approximation, while trip production and attraction figures were better approximated during the trip distribution stage using the gravity model.

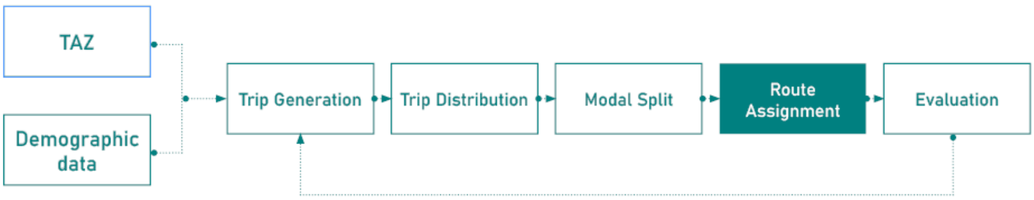

Figure 4.3 Four Stage Demand Modeling Method

4.2.2 Trip Generation

Trip generation quantifies how many trips are going out of a TAZ (production) and how many are made into a TAZ (attraction). This study used mobility data generated by Oromia urban planning institute, for the projection of 2029. The data is based on sectoral & land use studies and aggregated only for 9 urban Kebeles/Gandas.

Table 4.1 Trip production by OUPI, based on sector report and existing land use analysis (Gezahegn, 2019)

No	Ganda / Kebele	Population 2019	Number of Employee	Population 2029	Trip Production	Trip Attraction
1	Dirre Jiitu	39,631	4634	68691	205572	942229
2	Kudada	29,700	400	51478	153933	192300
3	Burqa Hora Bishoftu	11,000	150	19066	56697	41321
4	Dabbaso	12,168	1000	21090	62771	163771
5	Calalaqa	16,393	2363	28413	84740	475704
6	Filtu	8,994	1500	15589	46267	69856
7	Biftuu	22,336	500	38714	115642	79083
8	Katta	8,885	120	15400	45700	40926
9	Birbirsa Foqa	17,889	650	31006	92518	650720
	Total	166,996	11317	289446	863839	2655909

Table 4.1 shows relationship of trip generation data with number of population and employment data of Gandas for the projected year of 2029. As expected, trip generation counts are proportional to the population of each Ganda.

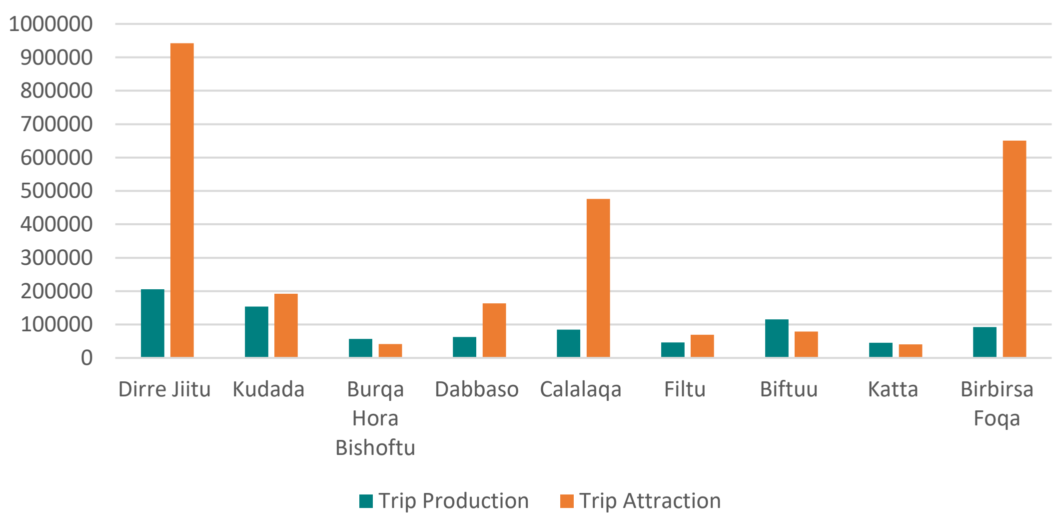

Figure 4.4 Bishoftu Trip generation data per Gandas

The data shows Gandas ‘*Dirre Jittu’*, *‘Kudada’* and *‘Biftuu’* as having the highest trip production and Gandas ‘*Dirre Jittu’*, ‘*Birbirsa Foqa’* and ‘*Calalaqa’* as having highest trip attraction count.

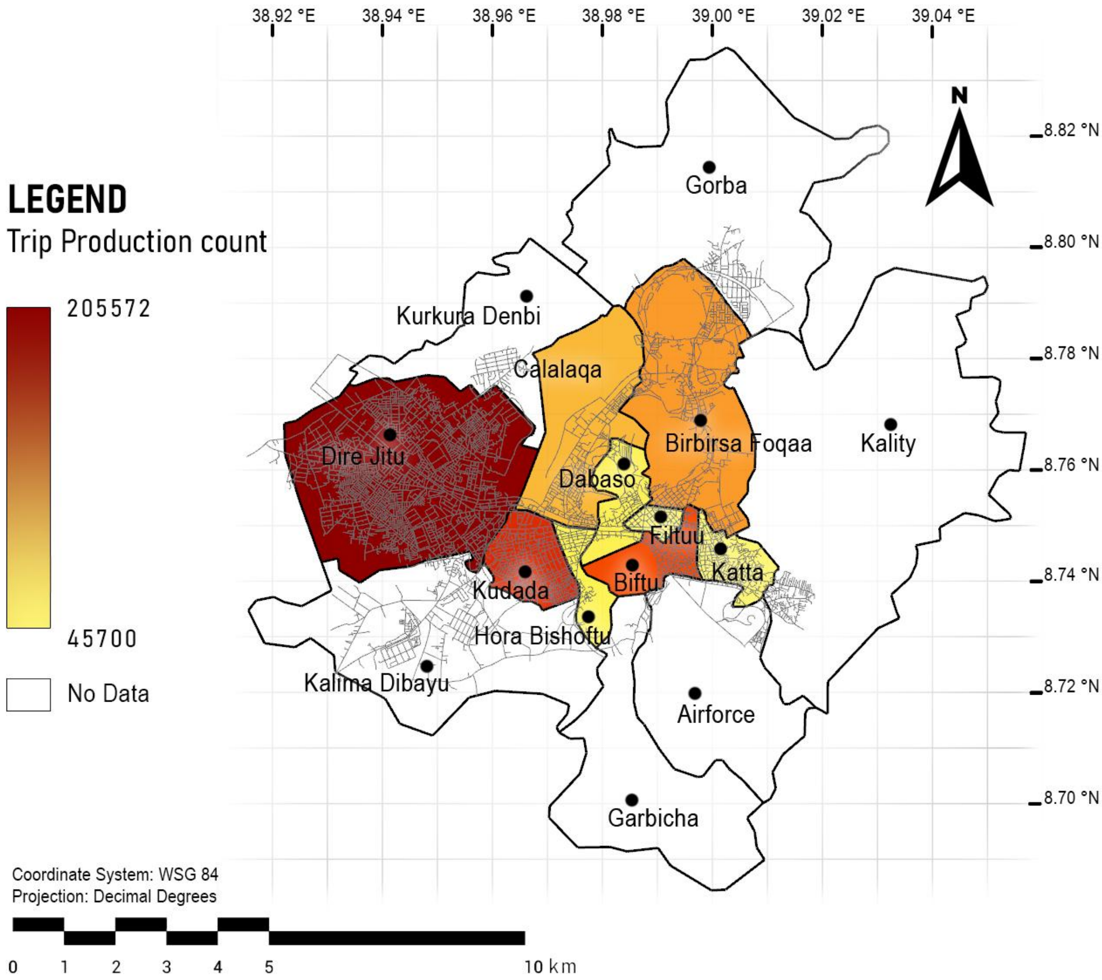

Figure 4.5 Bishoftu Trip Production per Ganda

Figure 4.5 shows aggregated trip production of 9 urban Gandas. Ganda ‘*Dirre Jiitu’* produces 205572 trips per year, and is the highest contributor to mobility. Ganda ‘Katta’ produces 45700 trips and is the lowest among all. The large trip production of Ganda ‘*Dirre Jiitu’* can be explained based on the large area and corresponding population that the Ganda has. Gandas like ‘*Calalaqa*’ and ‘*Birbirsa Foqa’*, while having large area, produce less trip because much of their land is covered by water bodies and hosts less people.

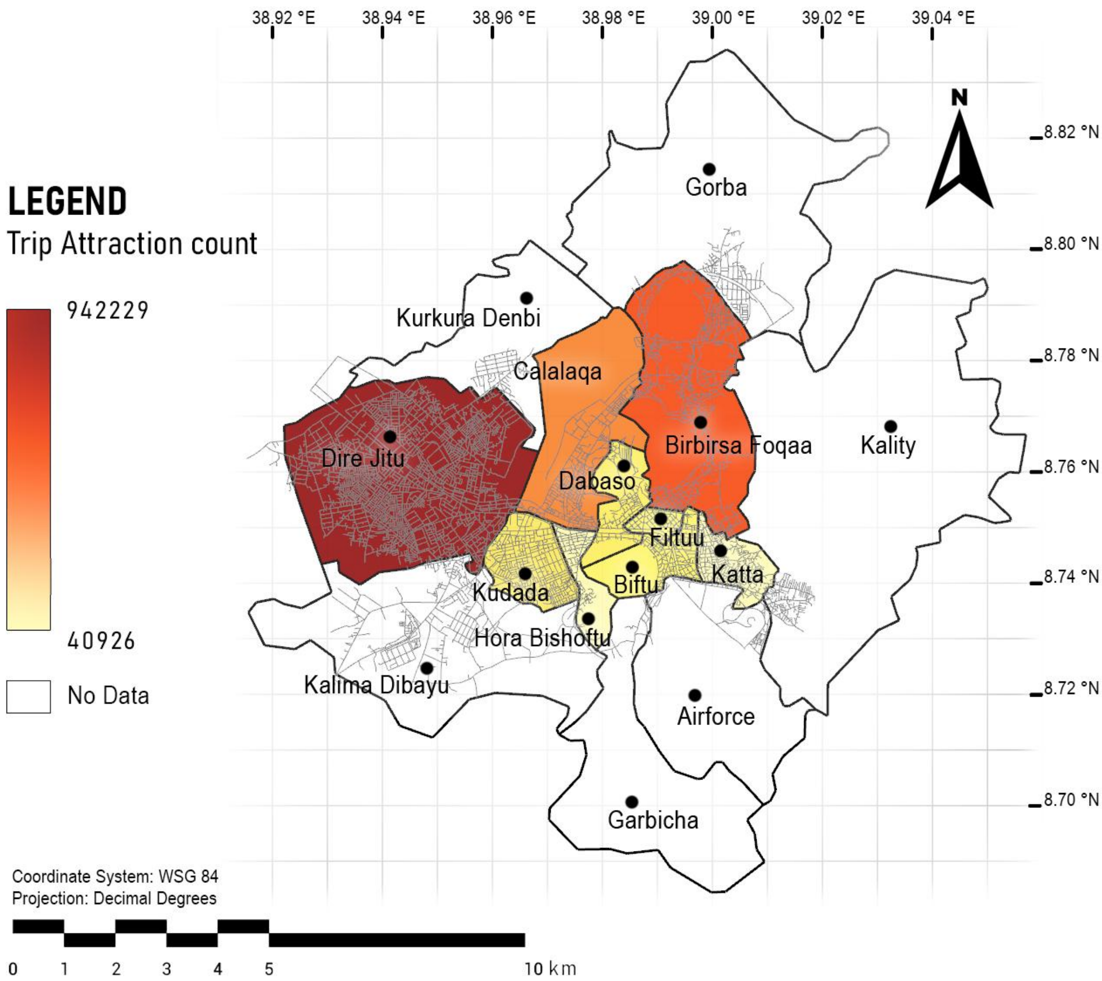

Figure 4.6 Bishoftu Trip Attraction per Ganda

Figure 4.6 shows the level of trip attraction each Ganda has. Similar to the trip production data, Ganda '*Dire Jiitu'* draws more mobility to it by attracting 942229 trips per year and Ganda 'Katta' draws less mobility by attracting 40926 trips. Gandas 'Hora Bishoftu' and *'Biftu'* have a higher trip production count than their trip attraction count. Gandas '*Dirre Jiitu', 'Dabbaso', 'Calalaqa', 'Filtu'* and '*Birbirsa Foqa'* attract more trip than they produce. Gandas *'Katta'* and '*Kudada*' have a fairly balanced trip production to attraction proportion (See Table 4.1 & Figure 4.4).

In order to get a realistic mobility demand of Bishoftu, Trip production and attraction data is adjusted based on the area that the Ganda has. This is done by dividing trip production and attraction data by the area that the Ganda covers.

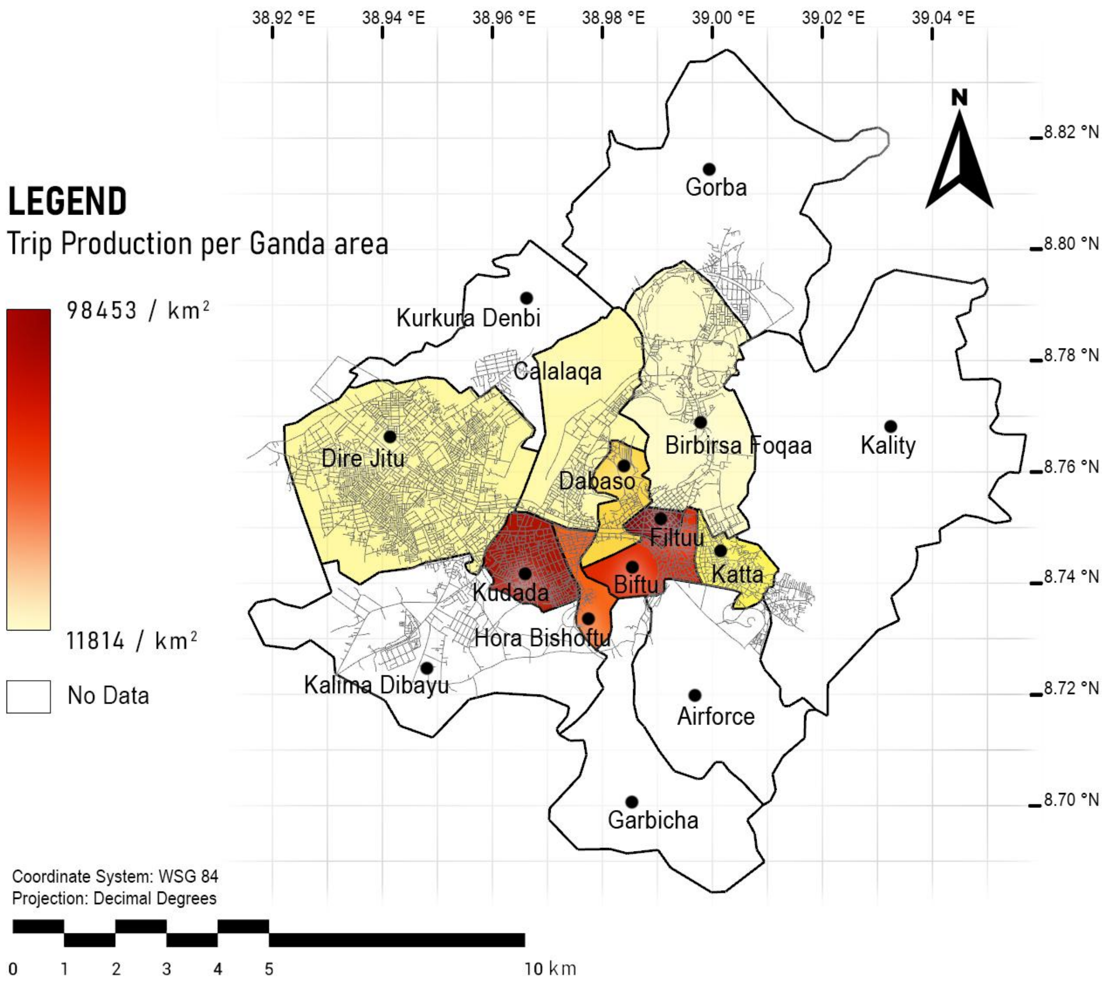

Figure 4.7 Trip production per km² per year of Ganda area

By dividing the trip generation data according to kebele area, it is possible to understand the density of mobility demand of the city. High density of trip is produced from Gandas '*Filtuu'* and *'kudada'*, having 98453 trips per km^2 per year, and 96571 trips per km^2 per year produced respectively. High trip production from Ganda '*Kudada*' can be understood as the area has higher settlement density. Ganda '*Filtuu'* is a commercial market center and despite observing high mobility going into and out of the area, it cannot be concluded that all trips are originated from the area. This is because people coming to the area could have their origin from a residential neighborhood, and once they are done with shopping activities, they will leave to their homes. Thus, the observed high trip production from '*Filtuu*' could be a result of high traffic influence during data collection where the origin of travel was not sorted properly. Further data collection is required to confirm accuracy of trip production for the Ganda of '*Filtuu*'. Ganda 'Birbirsa Foqaa' has the lowest trip production count of 11814 per km^2 per year, reflecting the abundance of area covered by water bodies and terraneous landscape, resulting in less dense settlements.

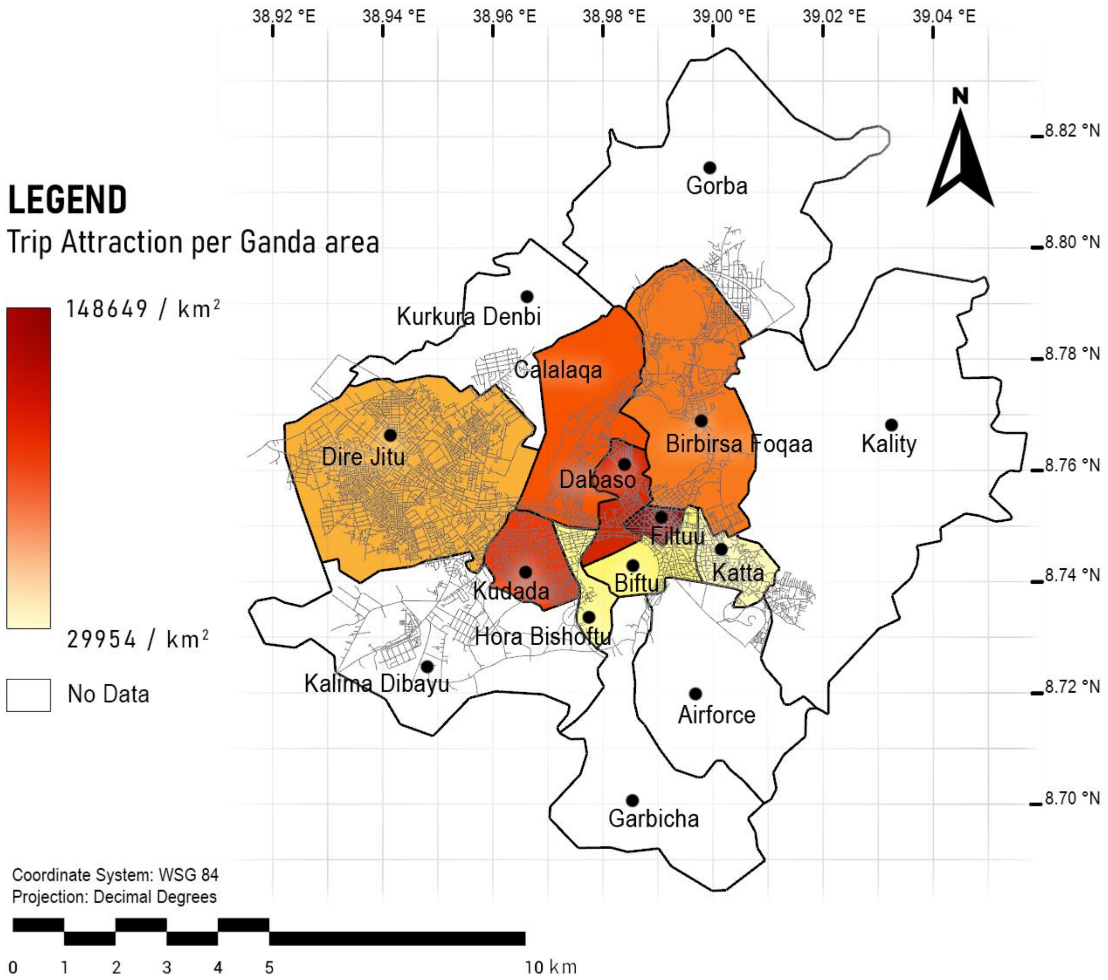

Figure 4.8 Trip attraction per km^2 per year of Ganda area

Figure 4.8 shows Ganda '*Filtuu*' has a high trip attraction count of 148649per km^2 per year. '*Filtuu*' is a place where a big market exists with a potential to attract intense commerce-based mobility, explaining observed high attraction count. In contrast, 'Katta' is an area with least trip attraction count of 29954 / km^2 per year. This can be understood based on the fact that 'Katta' is far from the city center and is also located slightly away from the '*Bishoftu -Mojo'* high way corridor, reducing its connection with the rest of neighboring settlements.

There are still discrepancies if trip data used are only adjusted by area of the Gandas. There are open spaces, farms, low density land use plots and water bodies within the Gendas that do not contribute to trip production or attraction. But their areas are still accounted for calculating trip data. The trip generation data becomes more accurate as it is further distributed to plots based on their building footprint area.

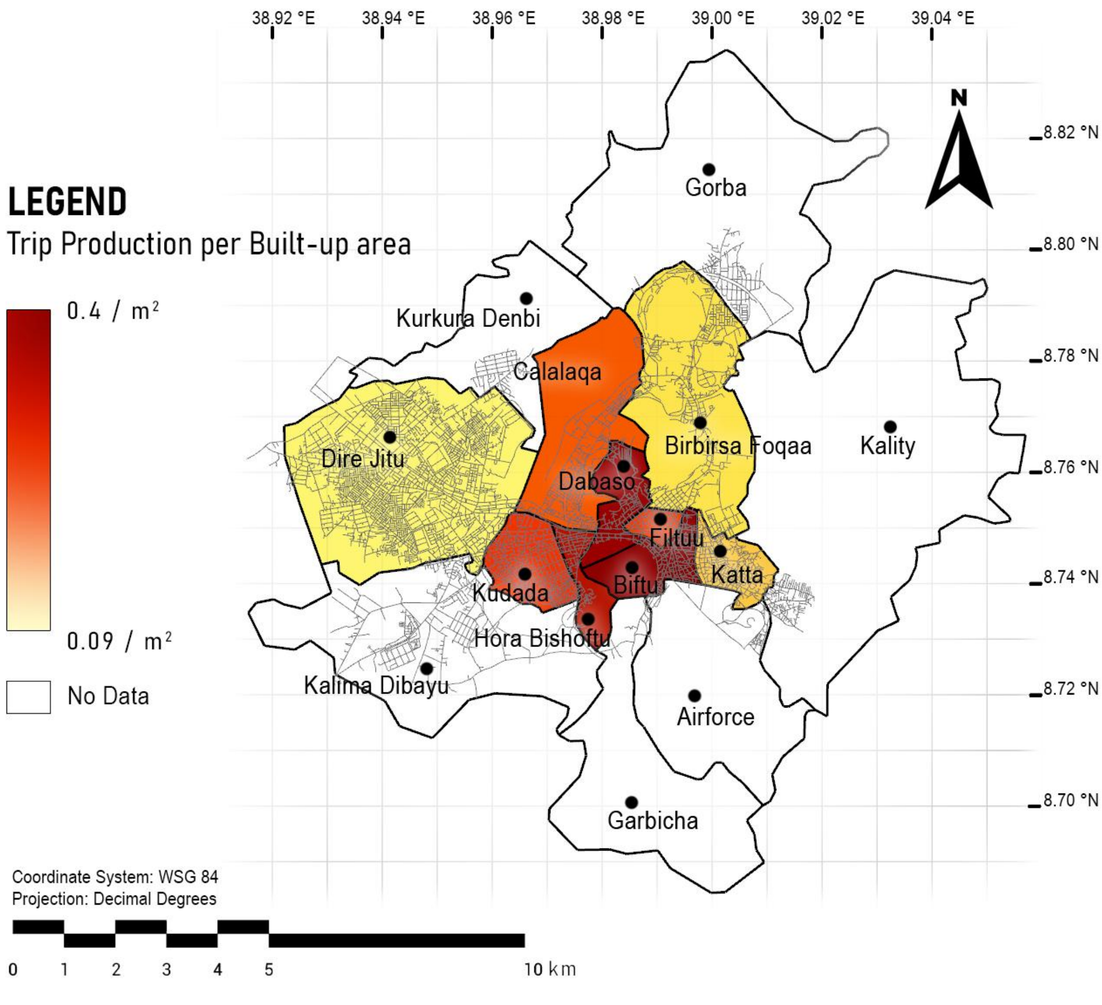

Figure 4.9 Trip production per m² of Built-up area of Gandas

Trip production per built-up area shows, central Gandas, *'Biftu'*, '*Dabassoo*' and '*Hora Bishoftu'* generate high mobility at 0.4, 0.37 and 0.34 trips per m2 respectively. This can be attributed to the compact settlement pattern found in the Gandas. Ganda '*Katta*', '*Bisrbirsa Foqaa'*, and '*Dire Jituu*' have the lowest trip production values of 0.17, 0.15 and 0.09 trips per m^2 respectively (see Figure 4.9).

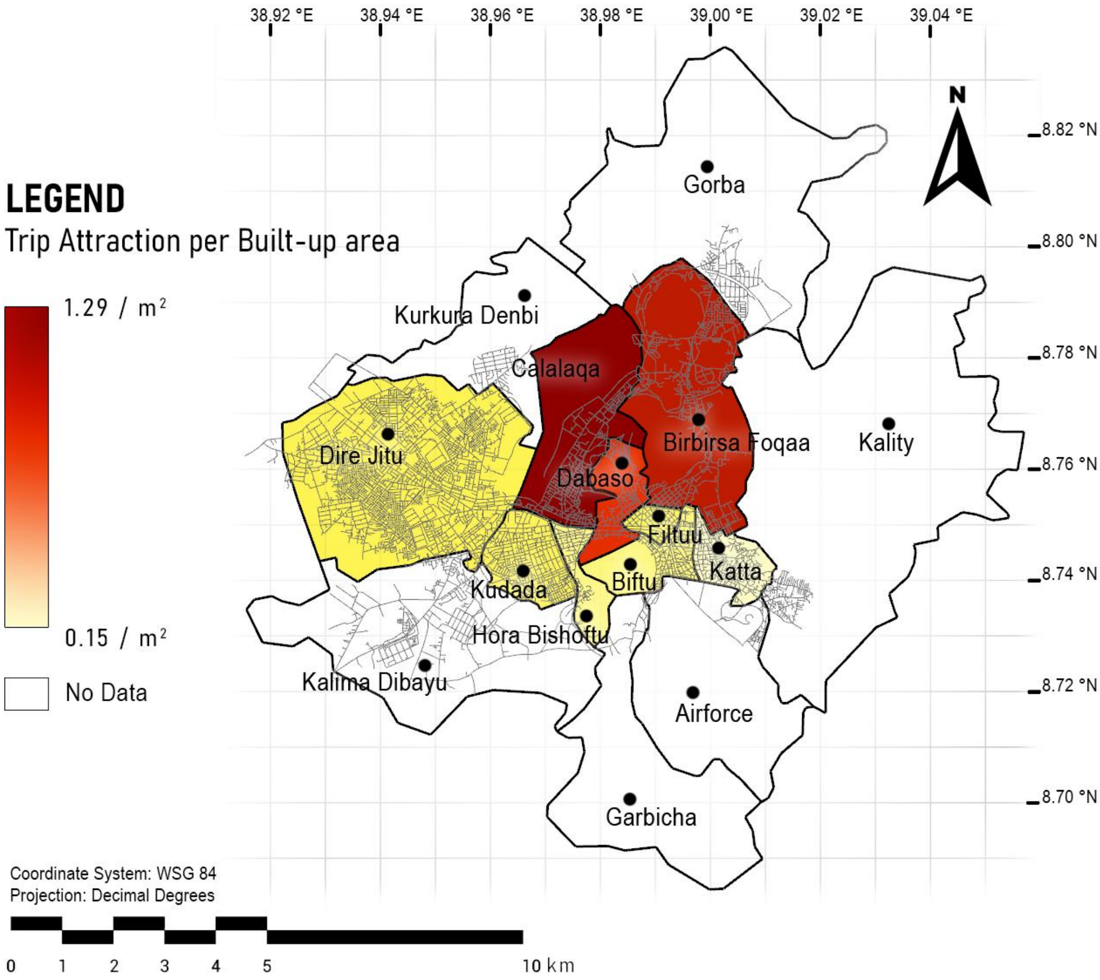

Figure 4.10 Trip Attraction per m^2 of Built-up area of Gandas

Figure 4.10 shows that, when the trip attraction data is disaggregated according to built-up area, Gandas '*Birbirsa Foqaa'* and '*Calalaqa*' appears to have higher count of 1.29 and 1.07 trips per m^2 respectively. This could be explained based on the fact that there are many institutions offering employment options in this Gandas. The concentration of resorts and tourist attractions in areas such as '*Babogaya*' lake can also be taken as contributing factors. People living in the rural Ganda of '*Gorba*' have to pass through 'Birbirsa Foqaa', possibly contributing to the perceived higher trip attraction. While it usually explains well what is observed on site, there are reasonable doubts to question the accuracy of the trip attraction provided by OUPI. Lack of available data in dense settlements within rural Gandas, discrepancy between number of trip production and attraction and level of aggregation can affect accuracy of the study outputs. One such observation is, trip attraction per built-up area of ‘Filtuu’ which appears to be low at 0.38 trips per m^2, despite having a vibrant market that attracts traffic. Data regarding mobility from and towards the market is discussed further in the following chapters.

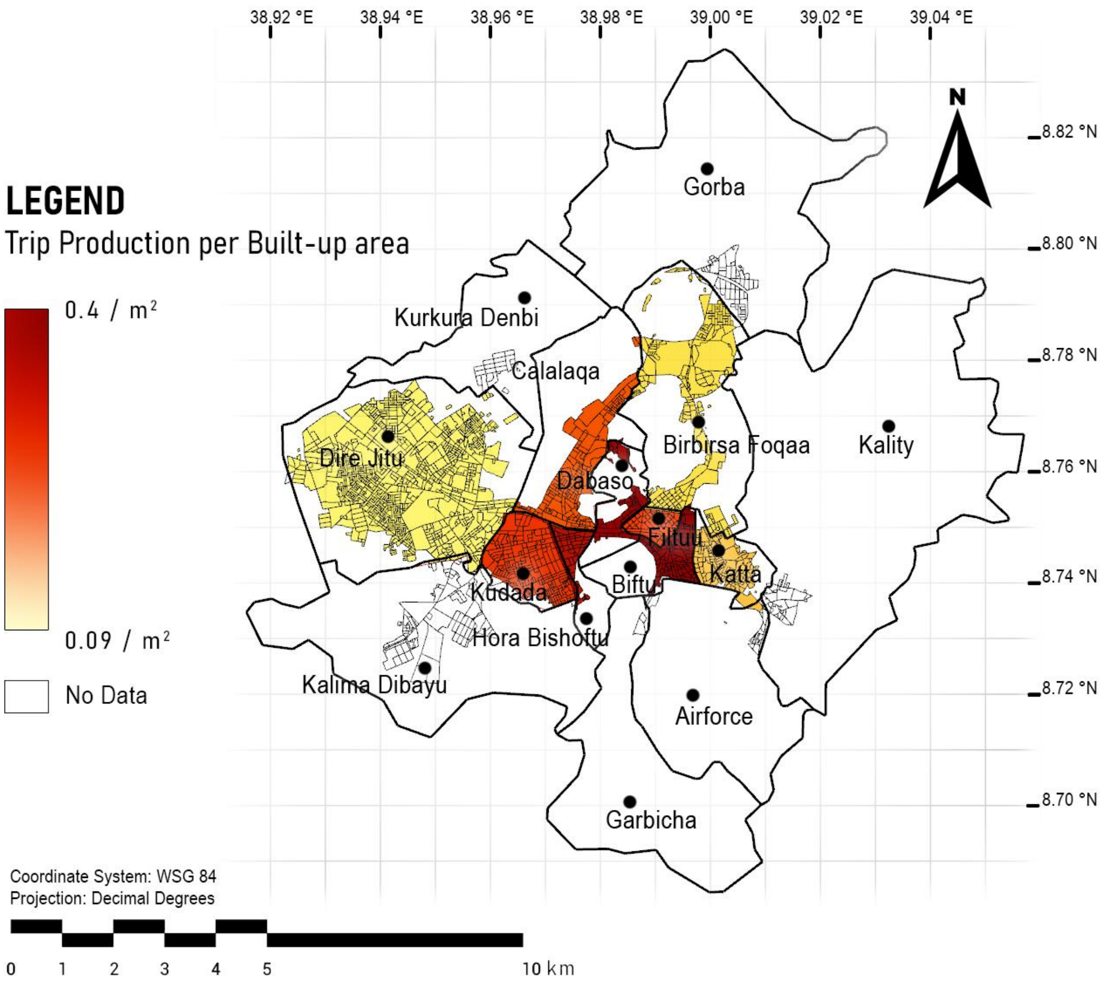

Figure 4.11 Trip production per built-up area projected onto TAZs (Block level)

The next step performed during trip generation stage was mapping trip production and attraction data into block level TAZs. Figures 4.11 and 4.12 show how working on block level TAZs give us a better understanding of the relationship between settlement pattern and mobility behavior.

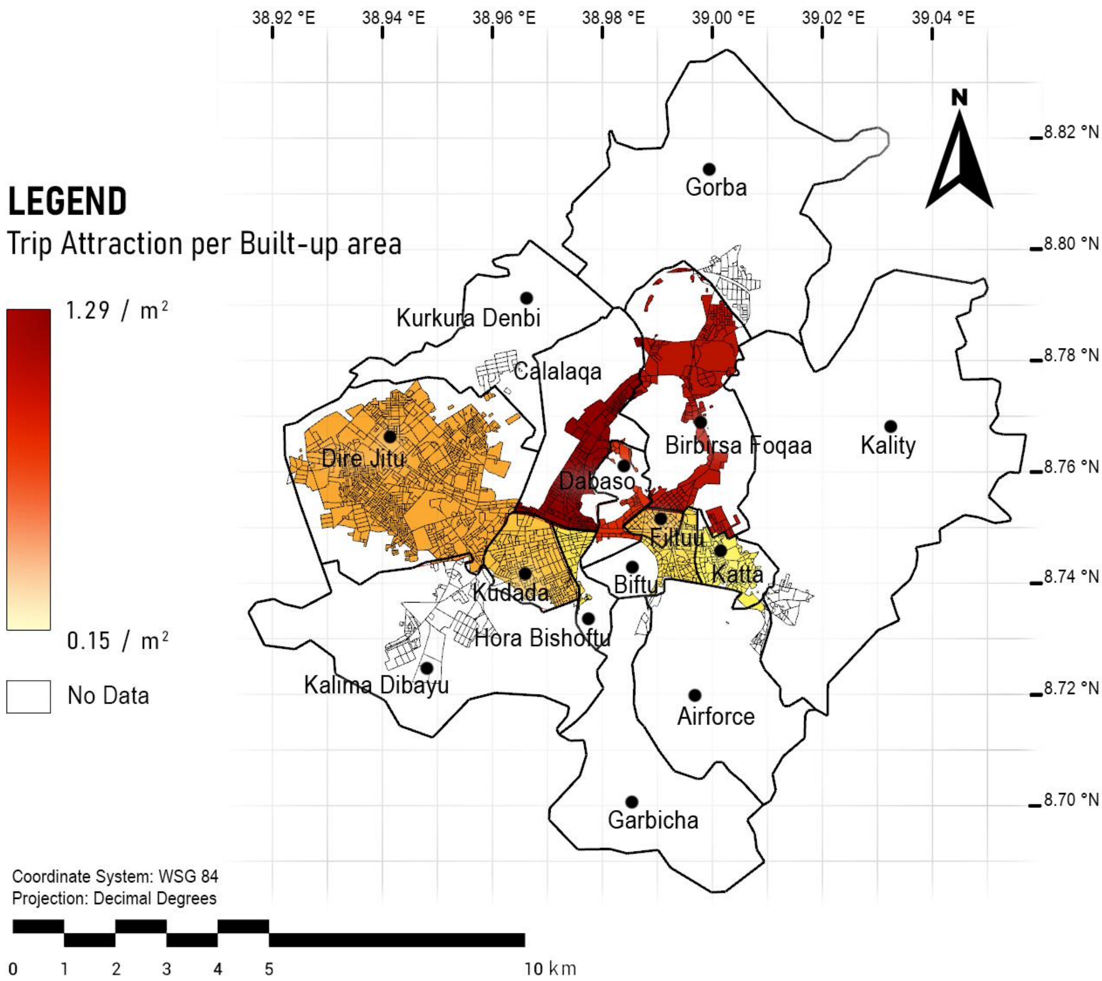

Figure 4.12 Trip Attraction per built-up area projected onto TAZs (Block level)

Table 4.2 Average Trip production & attraction per m^2 of built-up area per Gandas, for projected year of 2029, derived from (Gezahegn, 2019)

No	Ganda / Kebele	Trip-production Per m2	Trip-attraction Per m2
1	Kataa	0.17	0.15
2	Calalaqa	0.23	1.29
3	Filtuu	0.25	0.38
4	Birbirsa Foqaa	0.15	1.08
5	Dabassoo	0.37	0.96
6	Biftuu	0.40	0.27
7	Hora Bishoftu	0.34	0.25
8	Kudadaa	0.28	0.36
9	Dire Jituu	0.09	0.42

Trip data from OUPI aggregated by kebele/Ganda level was divided by combined area of buildings within each Ganda to get final block level TAZ trip production and attraction data and presented on Table 4.2.

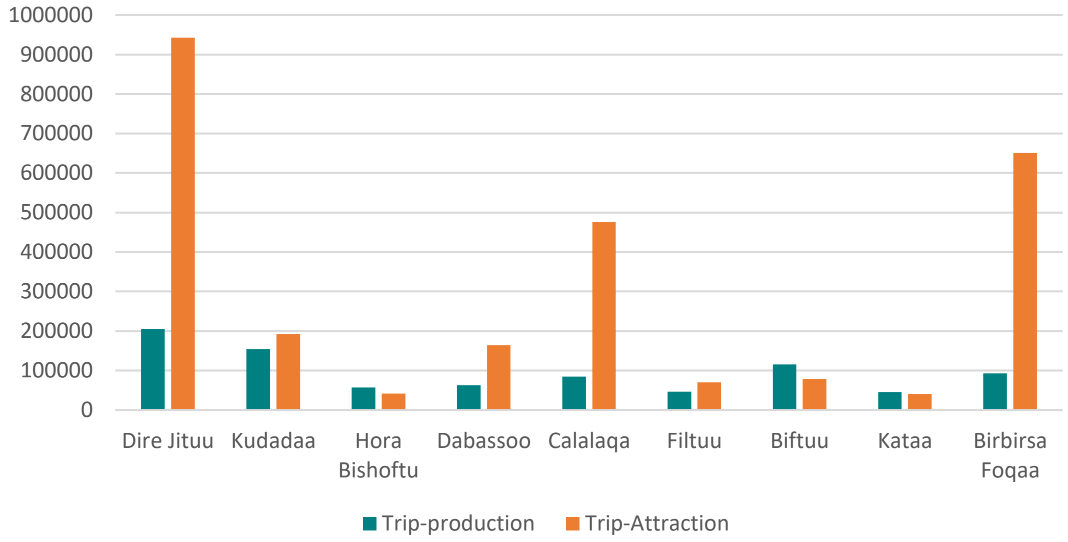

Figure 4.13 Total Trip production & attraction per Gandas

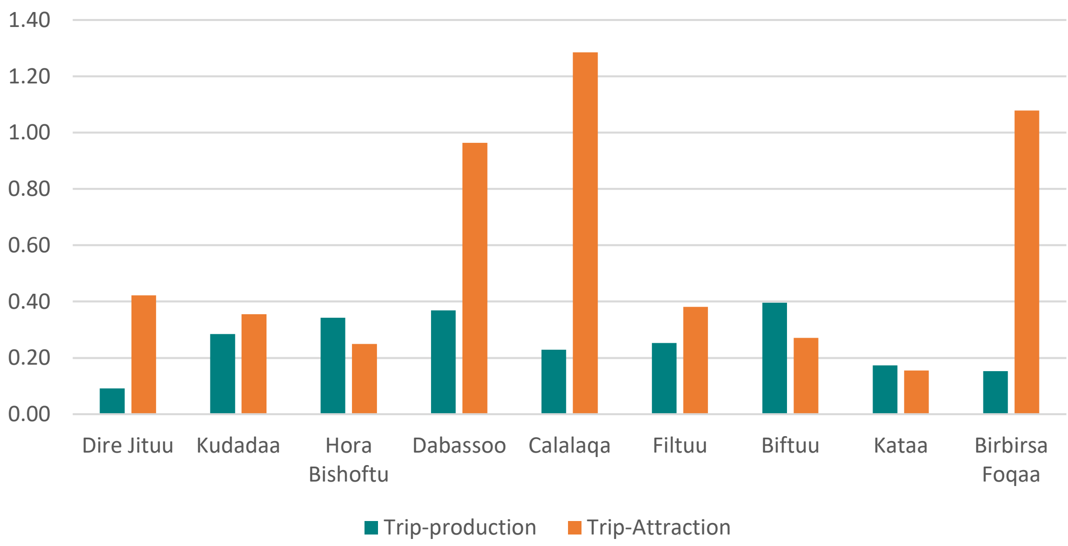

Figure 4.14 Average Trip production & attraction per m^2 of built-up area per Gandas

Comparing total trip generation (figure 4.8) and trip generation per built-up area (figure 4.9), one can see that, even though Gandas like '*Dire Jituu'* have high trip generation, it is Gandas like '*Calalaqa', 'Dabasso'* and '*Birbirsa Foqaa'* that show high level of activity per Ganda area. Of the nine Gandas whose trip generation data is available, six of them have higher trip attraction than trip production per square meter of built-up area. Significant difference observed in Gandas Calalaqa, Birbirsa Foqaa and Dabasso can be explained based on the tourist attraction establishments present in this Gandas and their ability to attract mobility from outside of the city of Bishoftu. Ganda 'Dire Jituu' has the lowest trip-production per built-up area (0.09 trips/m^2). But if we look at the total trip produced from it, it is the highest from all the others due to the size of the Ganda (205572 trips) (See Figure 4.4).

Further trip attraction disaggregation step was performed at this stage to include the effect of land use (Figure 4.15). This is important because the previous disaggregation levels assume that all blocks (TAZs) within the same Ganda have the same level of trip production or attraction. But in reality, TAZs that have different land-use will have different levels of trip production and attraction. '*Services'* and '*commercial*' land use data based on 2019 structure plan revision (see Figure 3.3) was extracted to act as an indicator to identify between TAZs that produce or attract trips. Land use functions that include commercial zones, health facilities, schools and government institutions attract mobility due to their program nature. In contrast, 'residential' land use often serves as trip producer. Block level TAZs are generated for all Gandas within Bishoftu while the trip data available is only for nine urban Gandas. To address lack of data, missing values are approximated using nearby blocks that have available data. This procedure assumes that nearby blocks have similar trip production and attraction level due to geographical and demographic properties they share.

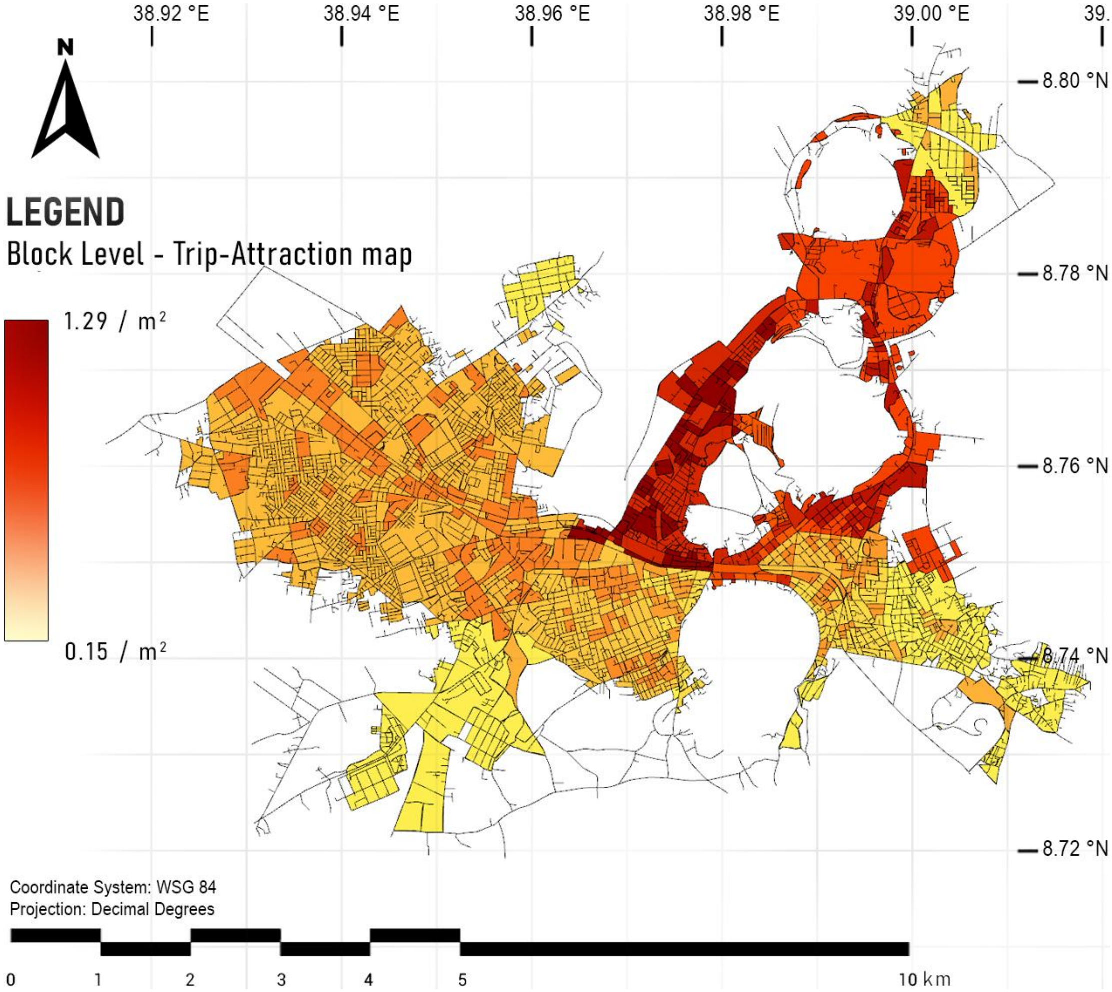

Figure 4.15 Trip-attraction map refined based on block level land use data

4.2.3 Trip Distribution

Trip distribution data shows, how much of the trip produced by each individual TAZs are distributed to destination TAZs. Data from OUPI are used to calculate trip distribution using gravity model as described in chapter 4.6.2. The value of trip distribution is directly proportional to the trip generation values and inversely proportional to the distance between the TAZs (see table 4.3 & Figure 4.14). Data from trip generation passed through row and column correction factor and are presented as a heat map showing level of mobility between Gandas.

Table 4.3 Trip distribution matrix table, based on OUPI (Gezahegn, 2019)

TAZ	1	2	3	4	5	6	7	8	9	Total	Row f
1	0	117281	11075	36375	171911	8803	11301	9218	144709	510672	0.8492
2	452620	0	6977	22917	27077	3151	16181	5808	40114	574844	0.1786
3	82185	13416	0	16644	19666	2289	11752	4218	29135	179306	0.3522
4	36347	5934	2241	0	34790	4049	1299	821	117139	202619	0.1407
5	174647	7128	2692	35370	0	4864	6244	3944	61913	296802	0.5008
6	15748	1461	552	7248	8564	0	5118	1837	115346	155874	0.1880
7	100812	37403	14128	11601	54825	25522	0	11759	81224	337273	0.4814
8	43116	7039	2659	3842	18158	4803	6166	0	61140	146922	0.9170
9	36753	2640	997	29774	140713	16376	21023	3320	0	251596	0.3861
Total	942229	192300	41321	163771	475704	69856	79083	40926	650720	2655909	0.3253
Clm f	4.0433	1.7294	2.6904	2.6437	2.5242	2.4859	3.1278	2.7330	3.5082	3.0745	

Legend

1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
Dirre Jiitu	Kudada	Burqa Hora Bishoftu	Dabbaso	Calalaqa	Filtu	Biftuu	Katta	Birbirsa Foqa

Table 4.3 shows, the travel relationship between nine Gandas where the rows indicate the origin of the trip (Trip production) and the columns indicate the destination of the trip (Trip attraction). The diagonal relationship shows intra-zonal trips made, which in this case is assumed to be minimal or zero. But in reality, there is mobility by PT within the Gandas and the study tries to capture this reality by disaggregating both trip generation and trip distribution data.

Table 4.3 shows, Gandas like '*Dire Jituu*' and '*Kudada*' have a high movement between each other due to their high population and closeness to each other. Gandas '*Dire Jituu*', '*Kudada*' and '*Biftu*' combined, generate about 42% or all trip production and Gandas *'Dire Jituu', 'Calalaqa'* and *'Birbirsa Foqaa'* combined attract 77% of all trips. Based on Table 4.3, high (O-D) origin -destination pairs are, *'Kudada' - 'Dire*

Jituu', 'Dire Jituu' – 'Calalaqa', Birbirsa Foqaa' - 'Dire Jituu' and '*Biftu*' - *Dire Jituu'.* The table also shows asymmetric relationships when it comes to travel demand between different Gandas. For example, more people travel from '*Hora Bishoftu*' to '*Filtu*' (2289 trips) than the other way round (522 trips) despite having similar number of residents.

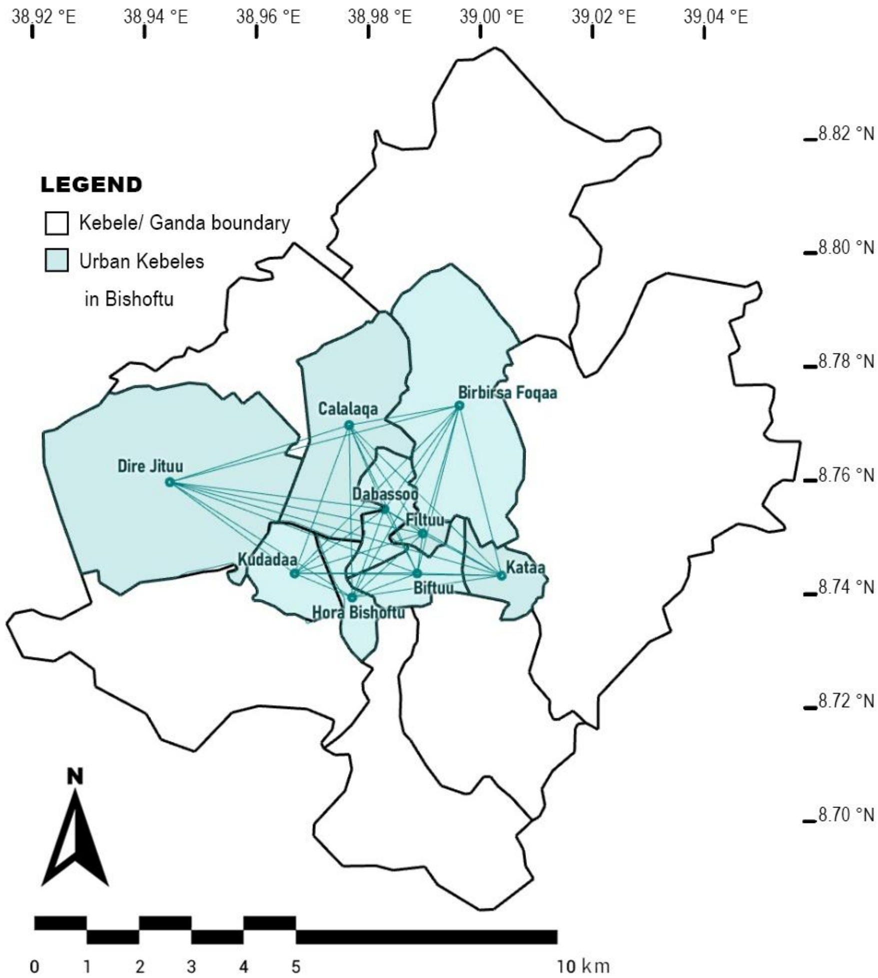

Figure 4.16 Trip distribution between nine Gandas of Bishoftu

Since trip distribution data was aggregated based on Gandas, a similar procedure used for trip generation is used to disaggregate trip distribution data to block level TAZs. The final result of the trip distribution stage is origin-destination trip matrix table with 2156 columns and rows. The data is processed using Rhino software, grasshopper plugin and Decoding spaces toolbox for urban analysis.

4.2.4 Modal Choice

Mobility within a city can be performed using different modes of transport depending on variables such as, car ownership, travel distance, cost of travel, availability of transport mode, environmental factors etc. For the purpose of this study, public transportation mode choice decision is projected based on traffic data from Bishoftu transport authority and surveys conducted by OUPI. Traffic data collected on Addis Ababa - Adama corridor reveal the predominance of three-wheelers and mini-bus public transportation modes (Figure 4.17).

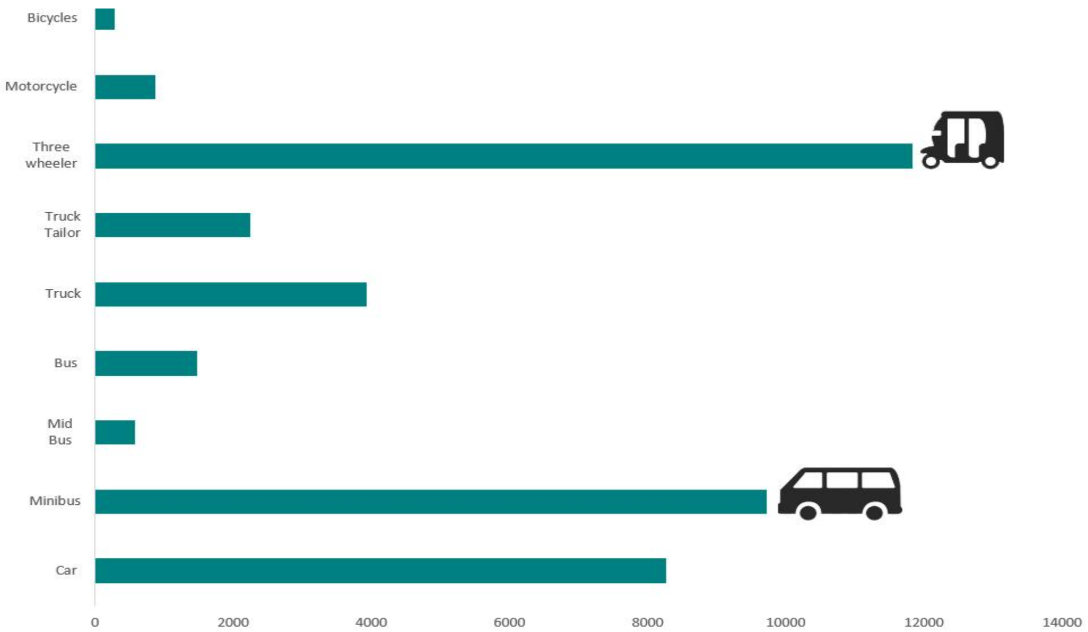

Figure 4.17 Bishoftu city traffic count survey (OUPI, 2019)

Figure 4.17 shows that, 30.2% of traffic is composed of three-wheelers and 24.8% of the traffic is accounted to mini-buses on the Addis ababa – Adama corridor. This data not only considers traffic generated within Bishoftu but also vehicles passing through Bishoftu having their origin and destination outside of the city and not contributing to intra-city public transport. Data by Bishoftu city transport authority on public transportation modes shows, three- wheelers are accounted for 70.5 % of public transport mode and mini-bus taxis cover the rest 29.5%. Three-wheelers are discouraged from using the major Addis Ababa – Adama corridor while mini-buses operate only on the asphalted routes. Such segregation of routes between mini-buses and three-wheelers explains why the traffic count on the main corridor indicates close modal share (30.2 % & 24.8%) (Figure 4.17) despite three wheelers being the dominant PT service providers (70.5 %).

. Data from trip distribution stage of the Four stage modeling approach can be interpreted by assuming that, people who travel short distance will be pedestrian while people taking longer trips will want to use assisted transport means. Since the aggregation level used to generate trip distribution data was on the level of Gandas, it can be assumed that, people moving within the Gandas are pedestrian and people traveling between Gandas require a form of public or private transport. By merging data taken from the main Addis Ababa - Adama corridor and the PT mode share between three-Wheelers and mini-buses, transport mode share between PT (three-wheelers and minibuses) and private ones (car, bicycles, motorcycles) can be calculated.

Figure 4.18 Private and public transport mode share

Among the total trips generated and attracted between the Gandas, 22.3% travel will be conducted using private modes of transport while 77.7% of the travel will be completed using PT modes.

4.2.5 Route Assignment

Route assignment is a stage in the four-stage modeling approach where specific routes connecting TAZs and their accompanying frequencies are set. A set of assumptions are considered before performing this step. The first one is deciding on the level of accessibility that the PT network should provide based on methodology developed in chapter 4. Ethiopian transport authority recommends providing PT nodes within 500 m in urban areas (Institute for Transport & Development Policy, 2020). The study is experimented with the possibility of providing 100%, 95%, 90% and 80% PT routes coverage within 500 m radius, and the resulting PT network characteristics are presented on Figure 4.20. PT routes are generated by identifying road segments that are used the most to connect TAZ O-D pairs. Trips are assigned to routes using an 'all-or-nothing' approach, where, all trips are assumed to take the shortest possible route between origin and destination. Result from shortest routes between O-D pairs is then aggregated using betweenness-centrality measure (Figure 4.19). Betweenness centrality measures, how often a road segment lies on the shortest route calculation of all O-D pairs and thus indicate the likelihood of that road segment becoming part of a PT network. The study assumes that, all travelers using PT have the knowledge of the shortest route (less time) they should take to reach their destination and all road segments are free-flow (no congestion or events that could hinder the time it takes to travel along the dedicated route).

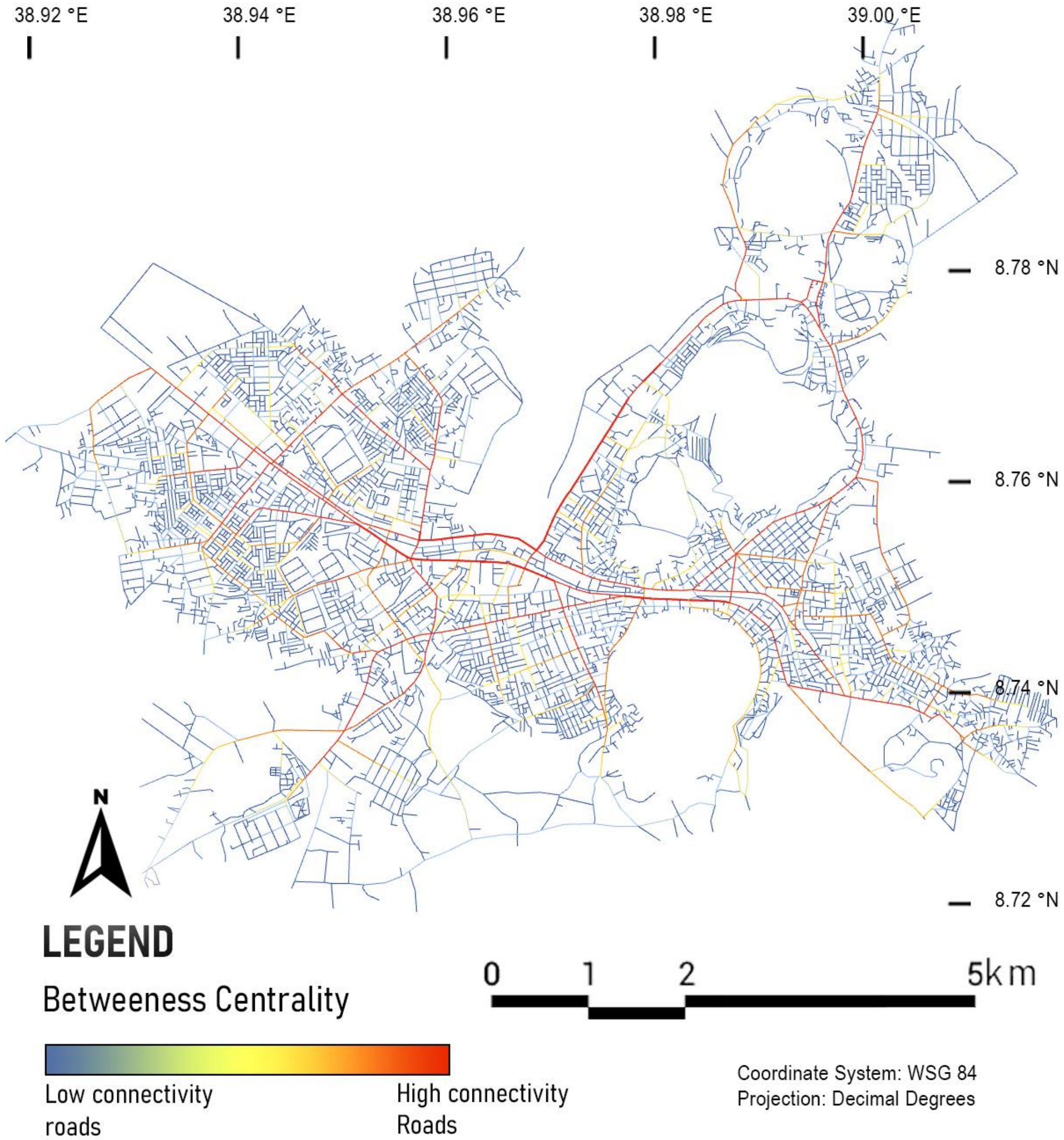

Figure 4.19 Bishoftu road network Betweenness centrality measure

Figure 4.19 shows betweenness centrality value of individual road segments of Bishoftu city road network. Addis Ababa – Adama corridor is the most active segment of the road network providing high connectivity between urban plots. Next in line are routes branching from Addis Ababa Adama corridor towards '*Babogaya*' and '*Arbashi*' direction. Potential PT routes are identified based on the values of their betweenness centrality value and are aggregated to create a possible route assignment (Figure 4.20)

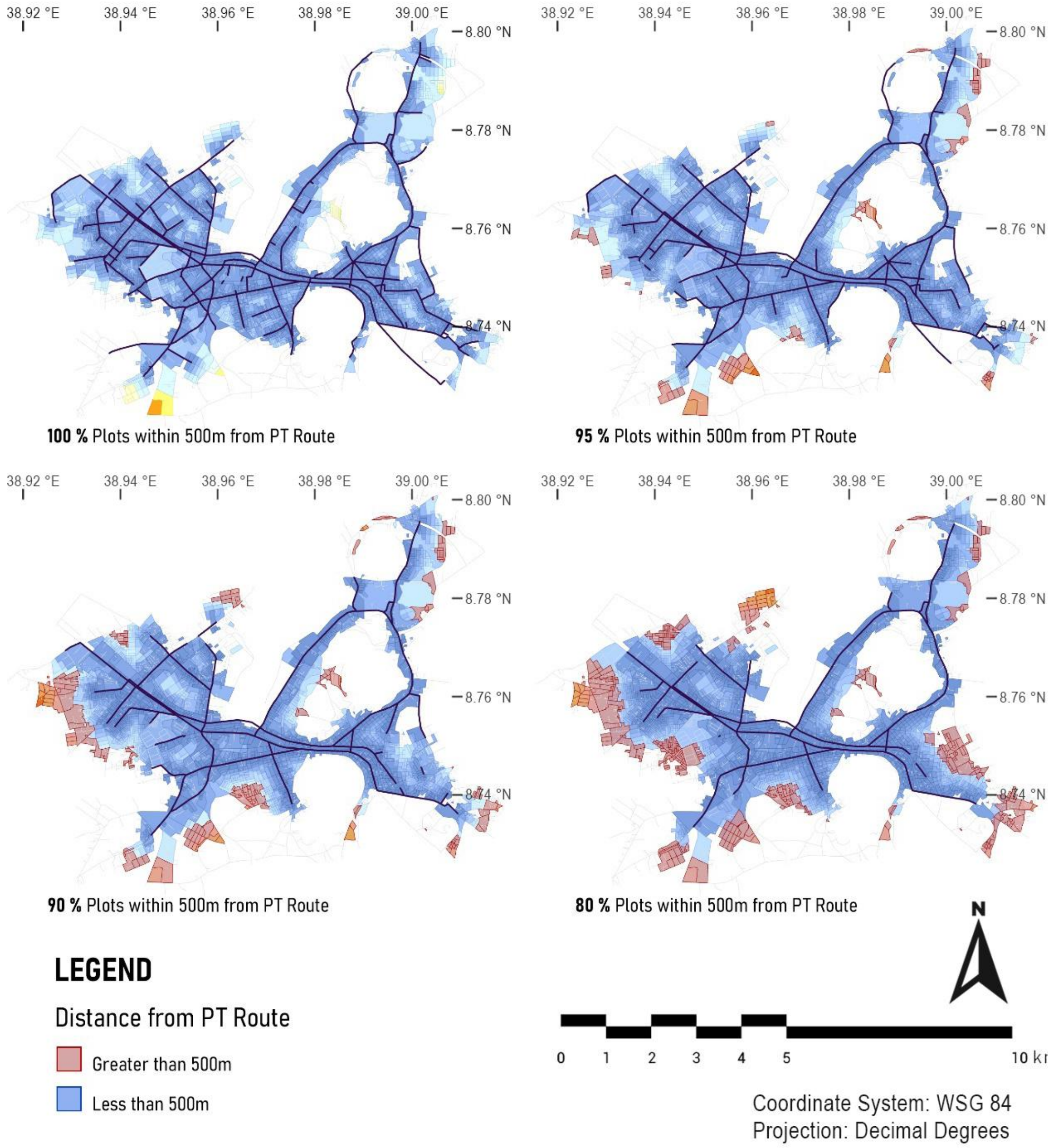

Figure 4.20 Identification of PT network segments using shortest path calculation and betweenness centrality measure

Figure 4.20 explores which segments among the road network should be part of PT network in order to create ideal level of accessibility by PT routes. Trying to serve 100% of the city by PT routes will require large network of PT road segments, indicating expensive investment. On the other hand, it is possible to serve 80% of the city by providing PT routes within 500m radius. But this means creating more disadvantaged areas and less road density even in central parts of the city.

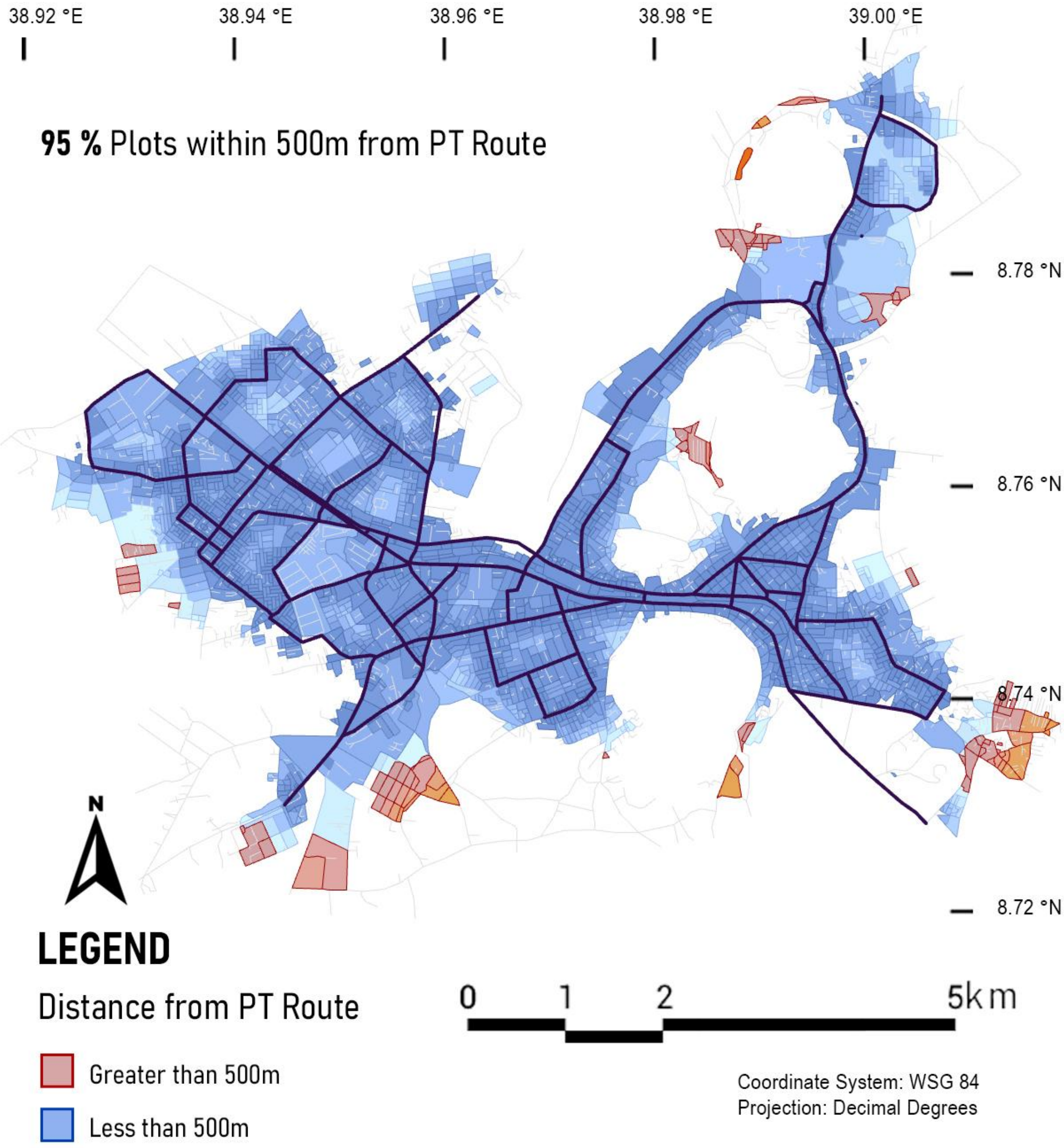

Figure 4.21 Proposed PT Routes based on trip distribution and assumed variables

An ideal version of PT route will have high route & interchange density on central parts of the city. At the same time neighborhoods far from the center should have connection not only to the central nodes but also to adjacent neighborhoods by direct connection. Figure 4.21 shows, PT route assignment based on trip distribution data, accessibility, route directness and route density assumptions. 95% of all plots will have an access to PT routes within 500m radius.

4.3 Accessibility

Bishoftu has two modes of PT; minibuses and three-wheelers, each operating on dedicated routes assigned by Bishoftu transport authority. Accessibility of Bishoftu using PT is studied based on Minibus and Bajaj routes data from Bishoftu transport authority. Table 4.4 shows routes and daily deployment data of mini-buses in Bishoftu.

Table 4.4 Minibus routes and daily deployment, Bishoftu city Transport Authority

No	Route	Daily deployment	%
1	Air Force to INOVA/ NOC/Dukam	84	23.8
2	INOVA/ NOC to Babogaya	65	18.4
3	Babogaya to NOC/Dukam	63	17.8
4	INOVA/ NOC to Air Force	61	17.3
5	Market to NOC/Dukam	34	9.6
6	Air Force to NOC/Dukam	31	8.8
7	Kora Hora to Dankaka	15	4.3
	Total	**353**	**100%**

Minibus transportation not only serves urban areas of Bishoft, but also help to connect neighboring settlements like '*Danakaka*' and city of '*Dukem*'. Considering the focus of this study is intra-city public transport of Bishoftu city, these destinations are not taken into account. But their contribution towards enhancing PT accessibility of the city is taken into account since their outer most destinations of 'Airforce' and 'INOVA/NOC' are addressed by other minibus routes. Based on the assumptions stated above, we can see that, there are only three corridors where minibuses give service in Bishoftu city. These are '*INOVA/NOC'* – *'Airforce'*, '*INOVA/NOC'* – '*Babogaya*' and '*Market* – *INOVA/NOC*' (Figure 5.22).

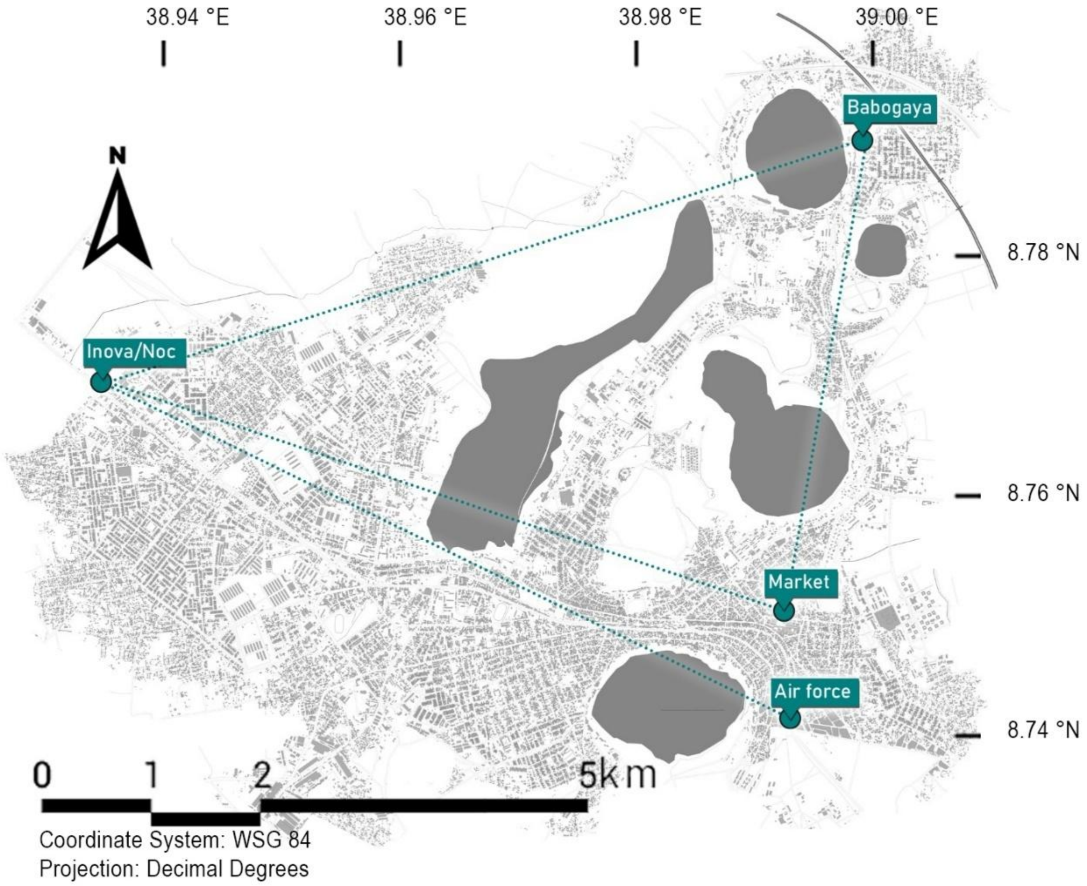

Figure 4.22 Bishoftu Minibus route origins and destinations

During market days mini-bus operation routes from *'Babogaya'* extend up to *'Dukem'*, outside the perimeter of the city, to accommodate increasing travel demand. Bishoftu has a central bus station that serves as a regional transportation hub for people traveling to Addis Ababa, Dukem, Adama and Mojo. But at the same time, mini-buses giving service intra-city service address travel demand by going outside of the perimeter of the city to destinations like Dukem.

The second and most predominant PT mode in Bishoftu are three-wheelers or '*bajaj*'. According to data from Bishoftu transport authority, there are 5 *'bajaj'* associations operating along 34 routes. Three-wheeler and mini-bus routes overlap in few places as three-wheelers are discouraged from using sections of the asphalted main Addis Ababa – Adama corridor. On the other side, minibuses do not operate on cobblestone roads.

Table 4.5 'Bajaj' routes and daily deployment, Bishoftu city Transport Authority

No	Route	Daily deployment	%
1	Market - INOVA/NOC	61	7.22
2	Market - Kidanemiret	72	8.52
3	Market - Migira	47	5.56
4	Market - Babbogaya	44	5.21
5	Market - Payilet	40	4.73
6	Market - Arbashi	151	17.87
7	Market - Shi 80	19	2.25
8	Market - Misgana church	34	4.02
9	Market - Katta School	18	2.13
10	Market - Godino	14	1.66
11	Market - Robgabaya	10	1.18
12	Market - Sunshine	9	1.07
13	Market - St George/stadium	6	0.71
14	Market - Ganda 15	11	1.3
15	Ziqquwala - St George/Stadium	28	3.31
16	Ziqquwala - Abbo	10	1.18
17	Ziqquwala - 01 Health center to Arbashi	6	0.71
18	Ziqquwala - Qajima	9	1.07
19	INOVA - Bolla Bishan #3	9	1.07
20	INOVA - Qurqura #2	7	0.83
21	INOVA - Qurqura #1	5	0.59
22	Air Force - INOVA/NOC	15	1.78
23	Hirna - Tele to Babogaya	10	1.18
24	Hirna - Condominium 05	31	3.67

25	Getishet - BCI Academy	25	2.96
26	Getishet - Hashim Abattoir	6	0.71
27	Babbogayya - INOVA/NOC	36	4.26
28	Rozmari - Payilet	39	4.62
29	Abbay Butcher - BCI Academy	25	2.96
30	Circle - Babbogaya	7	0.83
31	Doro Tera - China Condominium	10	1.18
32	Makalakaya - Abdi bldg	6	0.71
33	Agada Tera - Katta	8	0.95
34	Others - Others	17	2.01
	Total	**845**	**100**

Table 4.5 and Figure 4.23 show the routes and daily deployment count of three-wheelers. The most important origins and destinations generating high traffic are, the ‘Market’ and ‘Arbashi’ destinations. There are 151 daily deployments between the two nodes making up 17.9% of all travels by three-wheelers.

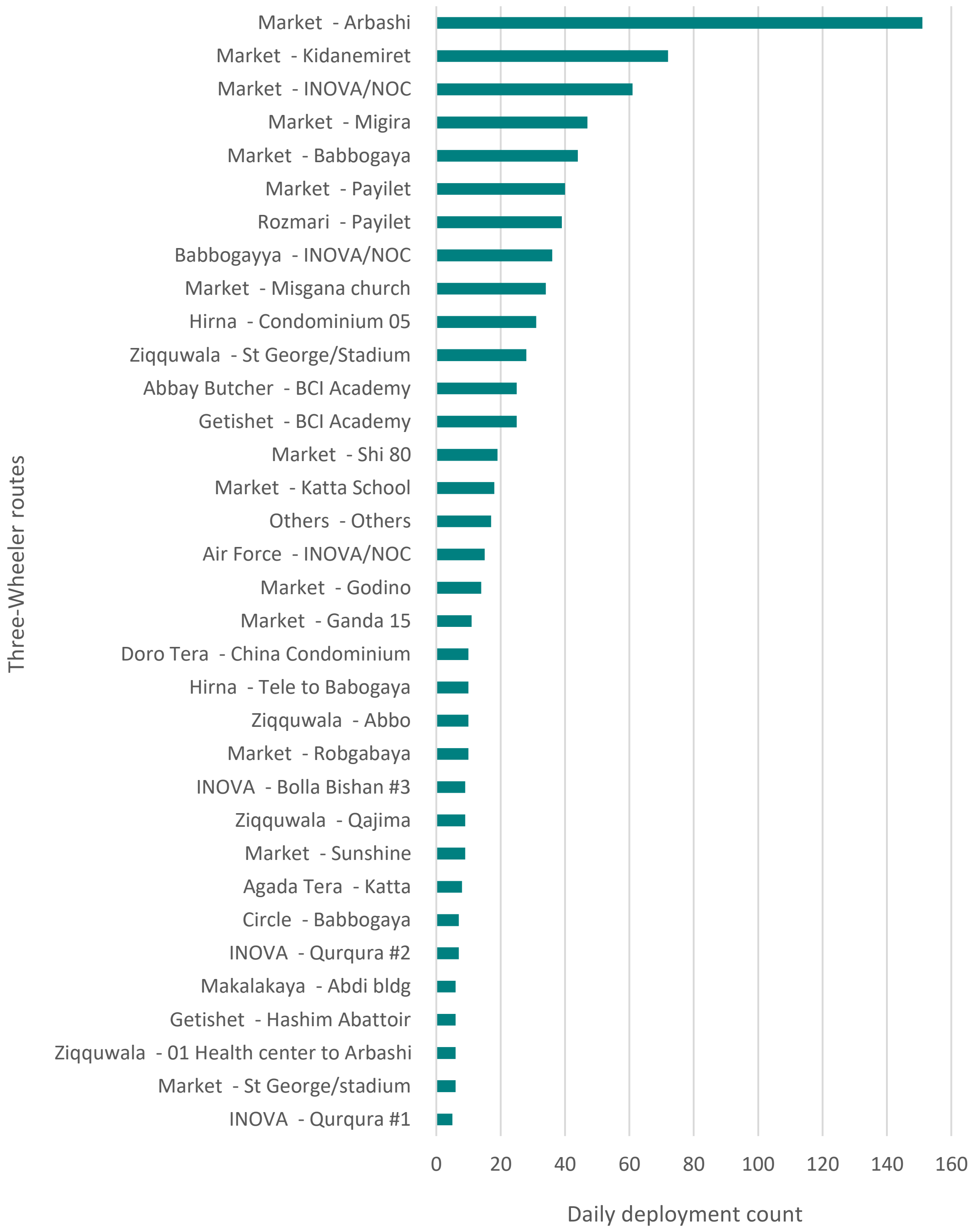

Figure 4.23 'Bajaj' routes and daily deployment

'*Arbashi'* is a place where many industries and manufacturing plants are located. It attracts large number of employment and mobility in Bishoftu. which justifies the assignment of large volume of three-wheelers towards it. At the same time there are companies in *‘Arbashi’* that have their own dedicated buses transporting workers to and from their establishments, easing transport shortage for workers.

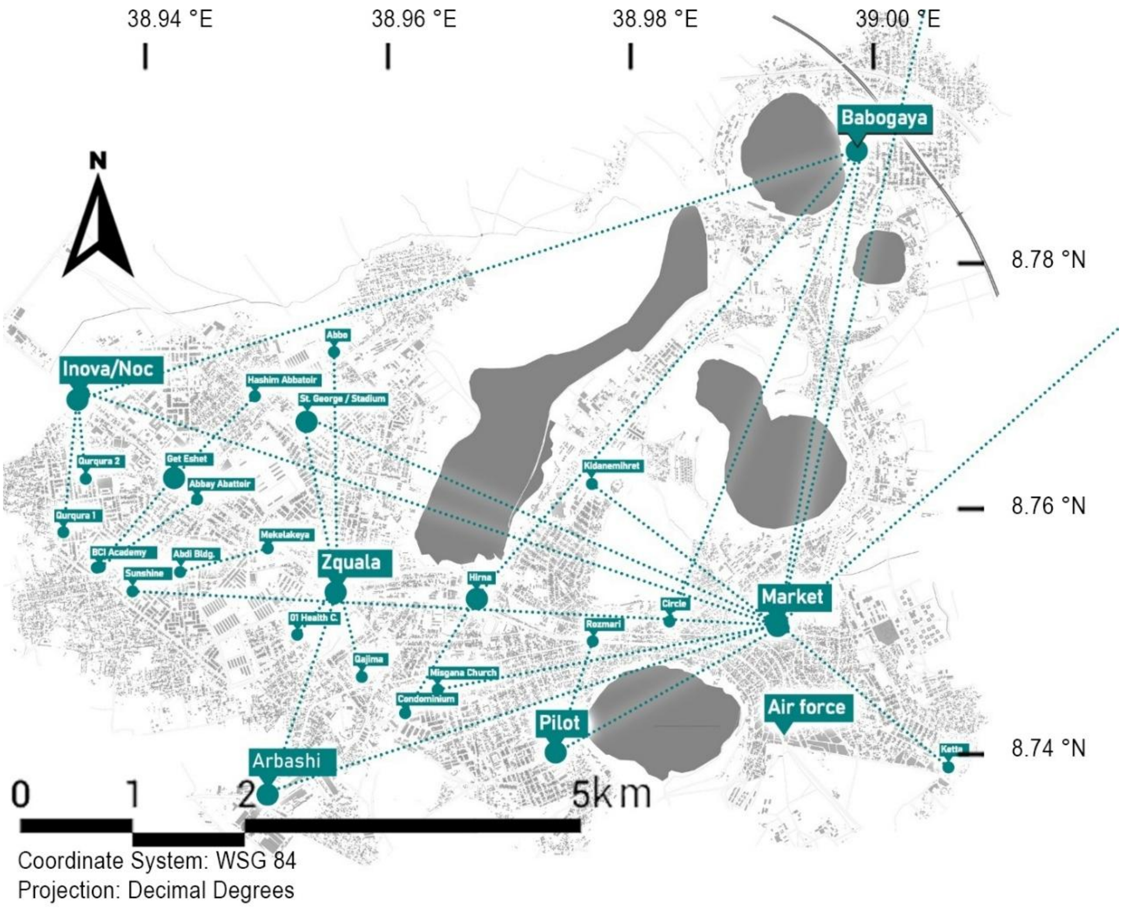

Figure 4.24 Bajaj (Three-Wheeler) origin and destinations

Three-wheelers operate not only in the dense parts of the city, but also travel to further destinations like ‘*Rob Gebeya’* and to remote plots around the outskirts, providing demand responsive transport service. But such service comes at an expensive cost because of the low carrying capacity of three-wheelers. Three wheelers charge two to three times more than minibuses for the same distance (Gezahegn, 2019).

Figure 4.25 Analysis of existing PT routes between origin and destination pairs

All existing three-wheeler and mini-bus PT routes are studied based on their origin-destination pairs and the routes they take. Figure 4.25 shows the process of analyzing existing individual PT routes (34 three-wheeler and 8 mini-bus routes). All routes are then combined to create existing PT Network of Bishoftu city (Figure 4.26).

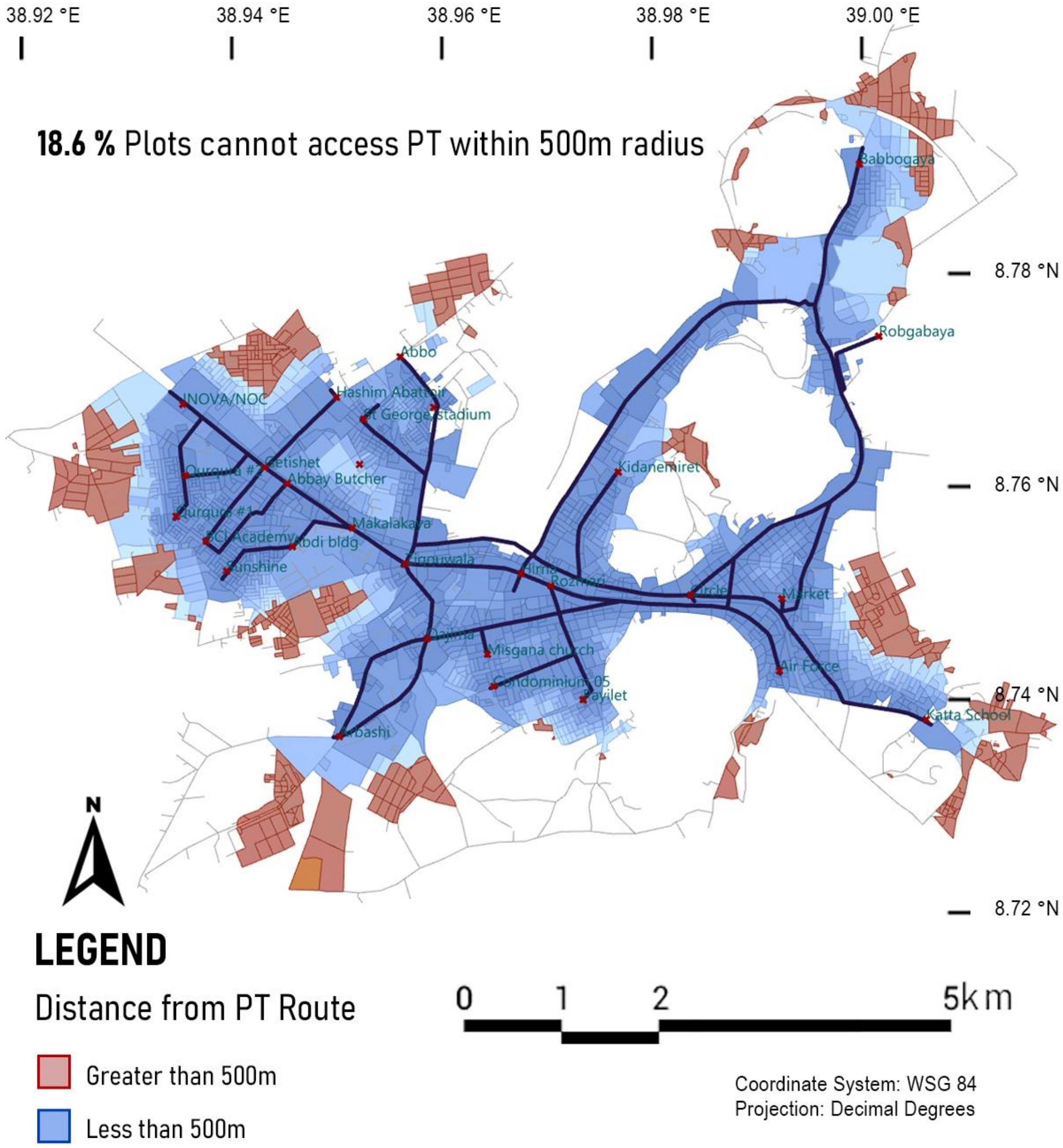

Figure 4.26 Bishoftu PT network (three-wheelers and mini-bus routes combined)

Figure 4.26 shows, current state of public transport network provision in Bishoftu. The map shows **18.6 %** of urban residents do not have access to PT routes within the recommended 500m radius. Most plots that are less accessible by PT route are those located in the outskirts of the city. Some plots that are closer to major interchange such as those found between *'Ziqquwala'*, '*Qajima'* and '*Sunshine*' also suffer from low accessibility due to lack of alternative routes connecting peripheral nodes.

4.4 Mobility index / Route directness

Bishoftu has lakes and terraneous topography that could affect PT route formations. In addition, morphology, block size and road network characteristics affect the time it takes to travel between two points in the city. To understand the relationship between Euclidean distance and exiting PT routes, mobility index / route directness index is calculated for all PT origin – destination pairs (see chapter 4.7).

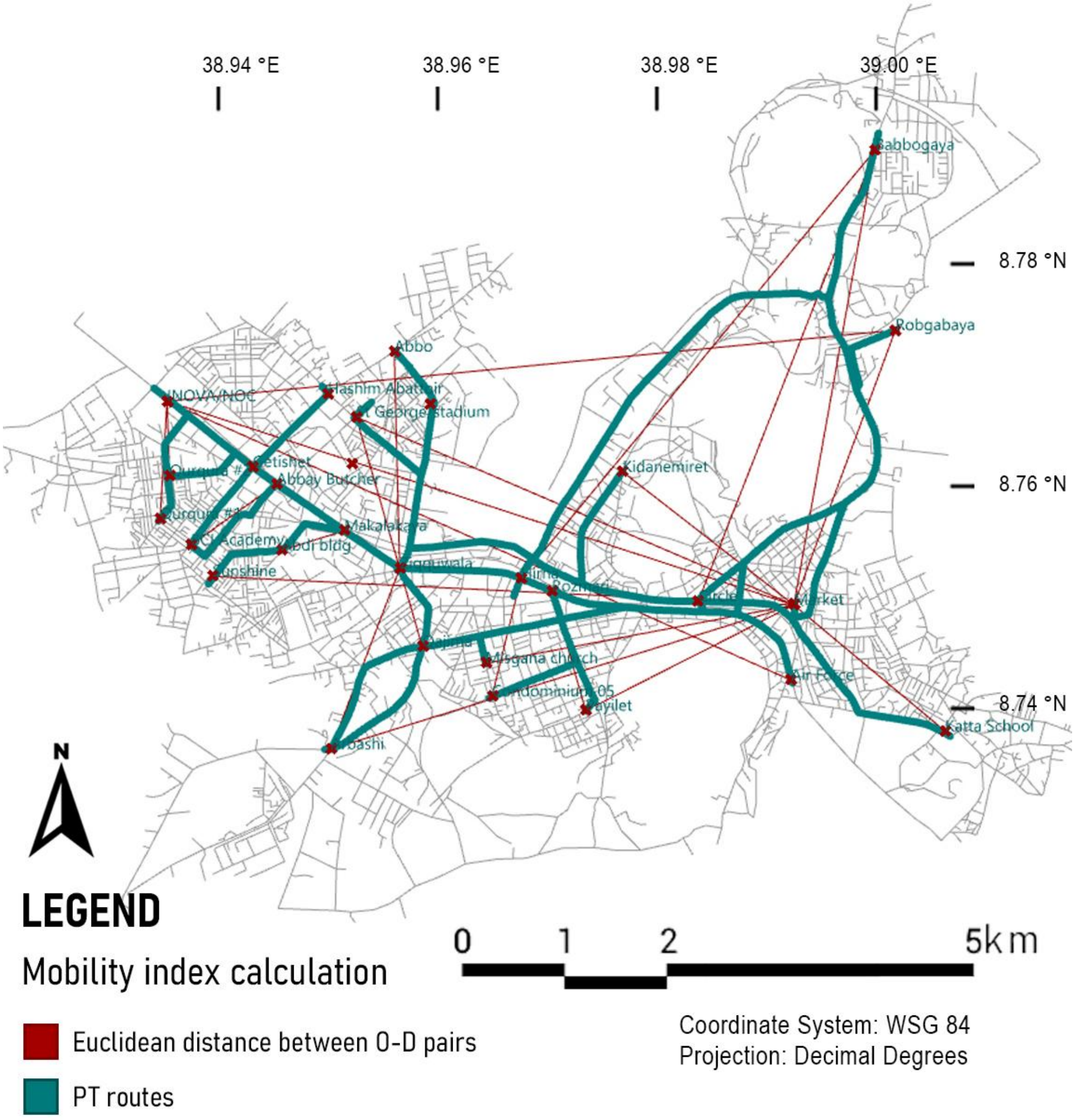

Figure 4.27 Mobility index/Route directness analysis

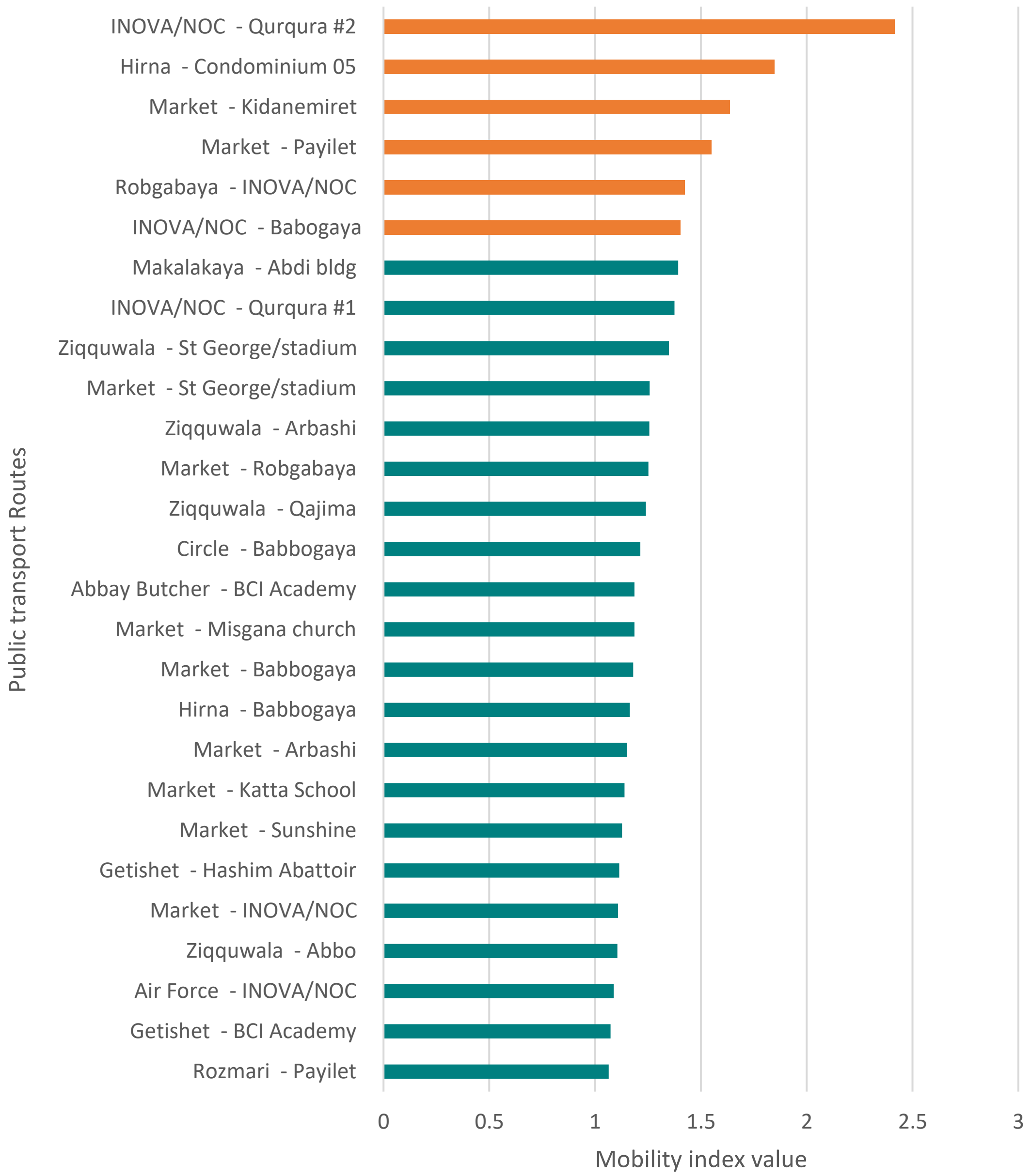

Figure 4.28 Mobility index / route directness of O-D pairs

PT routes that have mobility index value closer to 1 follow an efficient route to connect the origin and destination of the trip while a value above 1.4 indicates possible room for optimization. Figure 4.28 shows that, there are 6 routes that have a mobility index value of more than 1.4. These are, '*INOVA/NOC*' - '*Qurqura #2*', '*Hirna*' - '*Condominium 05*', '*Market*' - *Kidanemiret*', '*Market*' – '*Payilet*', '*INOVA/NOC – Robgabaya*', *and* '*INOVA/NOC*' – '*Babogaya*' routes. '*INOVA/NOC*' - '*Qurqura*

#2'and 'Hirna' - 'Condominium 05' routes take longer time to reach their destination because of the existence of large urban blocks between the nodes. The rest 4 routes are affected by the topography of Bishoftu forcing them to take longer routes. As an example, the route from '*INOVA/NOC' – Babogaya'* takes 9.4 km to travel by a mini-bus despite the Euclidean distance between the two destinations being 6.6 Km. This is because of the presence of lake '*Calalaqa*', forcing the road network to follow dry land. The connection between '*Market*' and '*Pilot*' is also affected by the existence of Lake '*Bishoftu*' in a similar way. Even tough parts of the city are segregated by lakes and mountainous terrain, most short distance PT routes still have a mobility index closer to 1 indicating better connection between O-D pairs. This analysis is based on routes assigned by Bishoftu transport authority and does not include a scenario where a person wants to move between places that do not have a direct PT mode assigned. In such instances, the mobility index value will be higher, and the trip will require using additional interchanges and take longer distance.

4.5 Route Diversity

Resilient urban mobility requires multiple PT modes and routes that can act as alternatives to manage mobility demand of cities. A PT transit map is prepared to study PT route diversity and network characteristics of Bishoftu. These include:

- The ability to access destinations using different PT modes and routes
- PT distribution in relation to land use
- PT route efficiency and
- design of PT interchange nodes

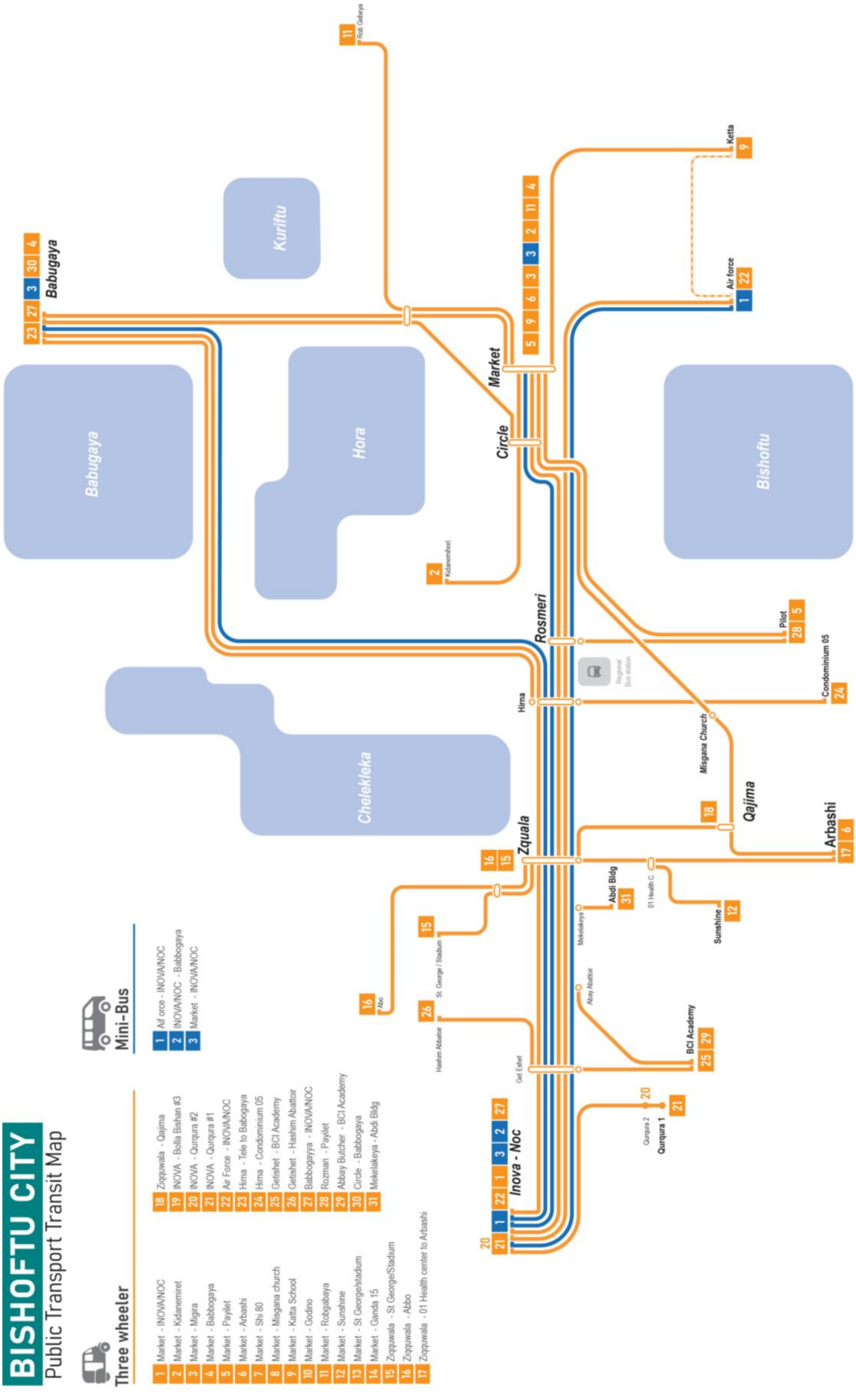

Figure 4.29 Bishoftu PT transit map (by the Author)

Figure 4.29 illustrate, the departure, destination and simplified route followed by three-wheelers and mini-buses in Bishoftu. As expected from previous analysis, the major Addis Ababa – Adama corridor is the busiest route acting as the back bone of the city. Many three-wheeler PT routes branch from the main high way and serve a dedicated destination. Many origin - destination pairs do not have alternative PT routes in case someone wants to avoid dedicated routes due to congestion or any other reason. Destinations found on the edges of the city are not connected with each other requiring lengthy routes and interchange to get from one edge to the other.

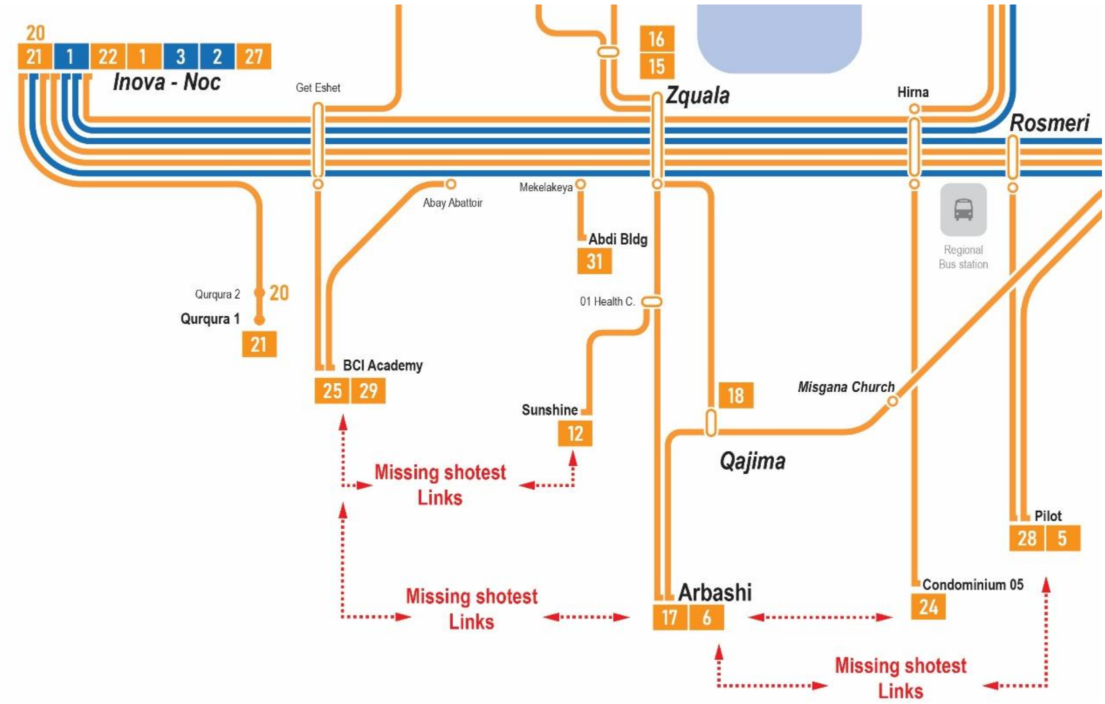

Figure 4.30 Missing alternative PT routes between destination

Figure 4.30 shows missing links between destinations found at the edge of the city. As an example, if someone wants to travel between *'Arbashi'* and '*Pilot*', first they have to take a three-wheeler to '*Qajima*', next catch another three-wheeler towards the direction of '*Rosmeri'*, and then again a last one to 'Pilot'. Such routes not only increase travel time and distance, but also the number of interchanges required. This wastes more time by increasing waiting time for the next vehicle. PT routes in Bishoftu are assigned towards a popular place and usually named after important destinations. Such designations can help make important land use, commercial centers and services accessible by PT. On the other hand, there are many routes connecting origin and destinations located within short distance from one another. Such routes are inefficient and increase the need for changing vehicles more than once for long distance travels. Routes '*Mekelakeya' – 'Abdi Bldg'*, '*Geteshet' – 'Hashim Abattoir'* and '*Geteshet – BCI Academy*' are all below 1 km long.

4.6 Infrastructure condition

To understand and have a generalized overview of PT infrastructure in Bishoftu, road material condition is chosen as an indicator. PT routes were surveyed and their road material was recorded and categorized in three groups. These are, Asphalt roads, Cobblestone roads and Dirt roads. Bishoftu has more than 42 km of PT route. Most of which is covered by Asphalt pavement.

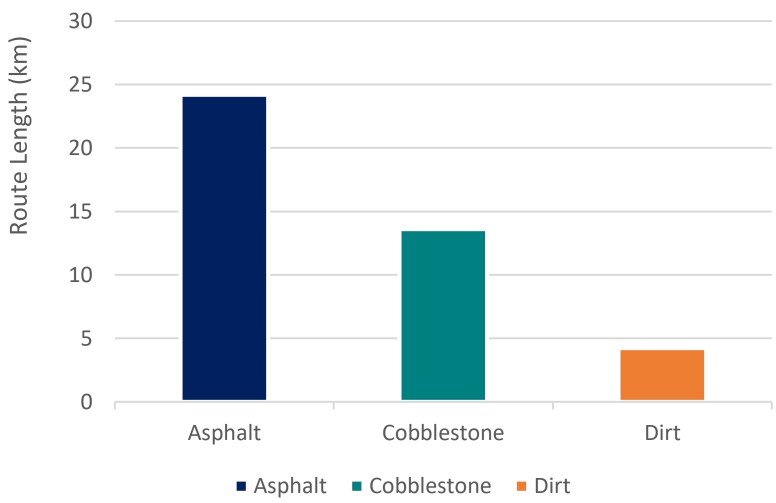

Figure 4.31 Bishoftu road material of PT routes

Figure 4.31 shows the proportion of road material cover of PT routes in Bishoftu. Even though Bishoftu has 20.7% of its road network paved with asphalt (see chapter 3.4), when it comes to PT routes, asphalted roads constitute 57.6 % (24km) of all PT routes. This is because the longest PT routes from '*INOVA NOC'* to '*Airforce*', '*Market'* to '*Babogaya'*, '*Hirna'* to '*Babogaya*' and '*Market*' to *'Arbashi'* are all paved with asphalt. These roads are used by all modes of PT with restriction for three-wheelers on certain section. Bishoftu has an extensive network of more than 130 km long cobblestone paved roads (Gezahegn, 2019). But when it comes to mobility, it is not clear how much of it is used as PT routes since three-wheelers can use any road in the network as long as they could find passengers and do not deviate from their destinations. The study tried to identify routes that are frequented by three wheelers and found 13.6 km long cobblestone paved roads and 4.2 km dirt road.

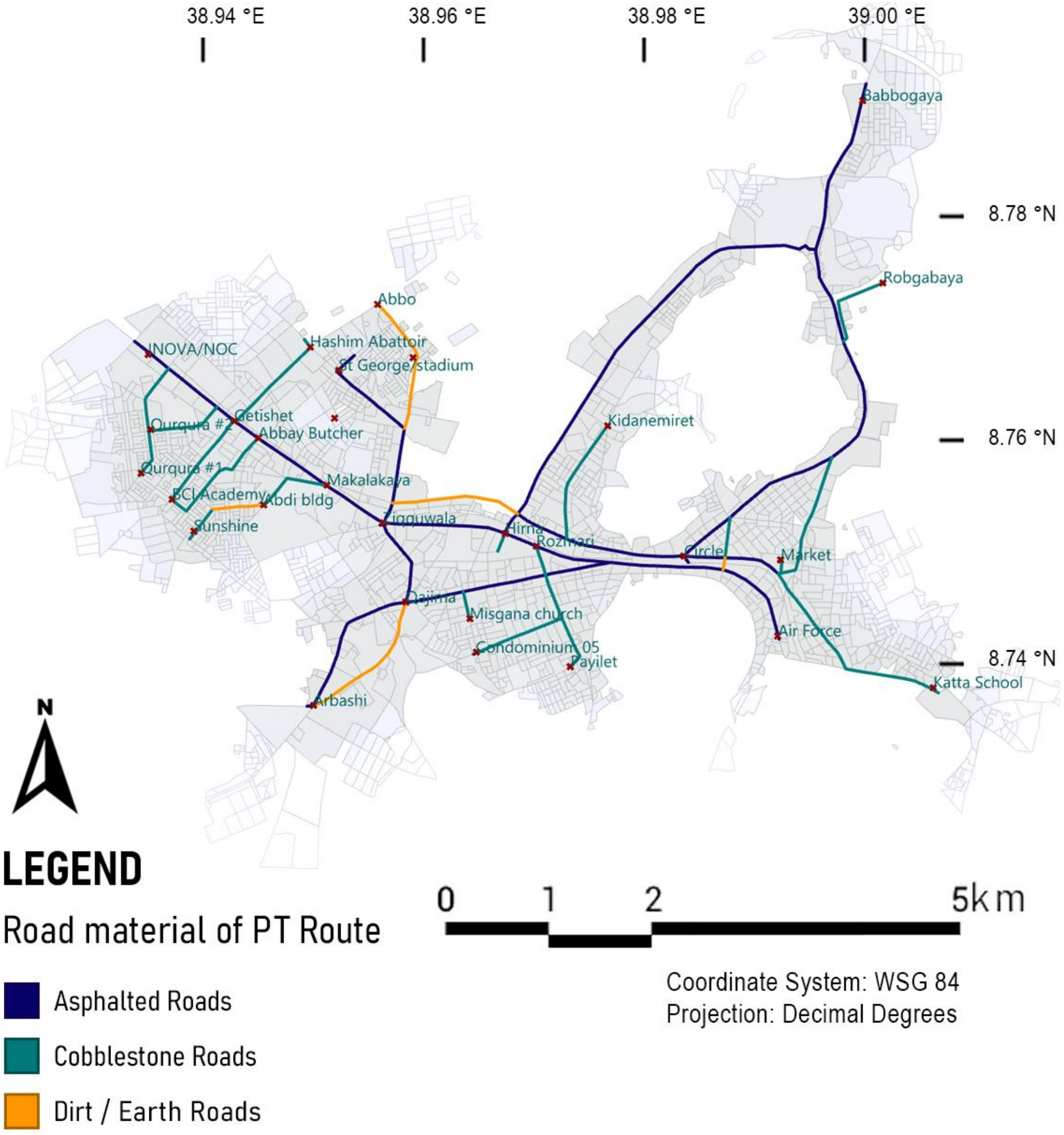

Figure 4.32 Road material of PT routes in Bishoftu

4.7 Summary of Findings

Thes study systematically evaluated the performance of Bishoftu's public transport network against the PT mobility demands of its residents, using a Four-Stage Modeling (FSM) approach and a set of four key network performance indicators: accessibility, route directness (mobility index), route diversity, and infrastructure condition.

Findings of the study based on indicators developed reveals that, there is a mismatch between demand and PT provision in periphery areas of Bishoftu. Inefficient PT route assignments, and lack of adequate infrastructure are also identified by the study.

The study experimented working with smaller block level TAZ definitions, which gave it the possibility to analyze travel demand more accurately. When trip generation data is analyzed by Gandas, it was found, Gandas like '*Dire jituu'* had a higher trip production and attraction. But when the data is disaggregated by built-up area and block level TAZs, Gandas like '*Biftu'* and '*Dabasso*' score high in trip production and Gandas '*Birbirsa Foqaa'* and '*Calalaqa*' have high trip attraction. Comparing trip generation data and PT frequency and route assignment by Bishoftu transport authority, we see there is a mismatch between the required route density (Figure 4.21) and actual PT routes (Figure 4.26).

Despite the existence of many routes within Gandas 'Dire Jituu' and 'Kudada', most of these routes do not serve periphery areas within the comfortable walking distance. The study found 18.6 % of Bishoftu urban blocks do not have access to PT routes within a walking distance of 500m.

Mobility index or route directness is calculated for PT routes assigned by Bishoftu transport authority. Among the studied routes, 6 routes are identified for having a value higher than 1.4. It is important to notice mobility index is calculated only for currently existing PT routes. If a realistic mobility scenario is modeled and movement from one point to the other in the city using interchanges is considered, average mobility index values could be much higher.

Route diversity analysis shows that, many origin-destination pairs do not have alternative routes that users can choose from. PT routes that are very short are identified by the study. In some instances, routes are even less than 1 km in length. The abundance of such inefficient routes could affect the performance and resilience of the whole PT network by distributing vehicles inefficiently and increasing the number of interchanges. In addition to low accessibility, peripheral areas do not have direct PT links with adjacent neighborhoods. Such missing links between adjacent neighborhoods are identified by study.

Bishoftu city has a large network of cobblestone paved roads. These roads give service to pedestrians as well as to three-wheeler PT modes. But no mini-bus rides along cobblestone paved roads and gives service only on asphalted roads. Mini-buses provide the advantage of comfort, larger carrying capacity and charge less for similar distance. But because of lack of asphalted roads and inadequate infrastructure, passengers are forced to commute using less comfortable and more expensive PT modes i.e., three-wheelers.

The findings of the study can be characterized by three major findings. First, the PT network exhibits an accessibility issue, particularly in peripheral and newly developed areas. This gap forces residents to walk long distances, undermining equitable access to urban opportunities.

Second, the PT network suffers from structural inefficiencies and low resilience. The lack of connectivity between peripheral neighborhoods and absence of alternative routes and ring connections increases travel time, forces multiple transfers, and reduces the system's overall robustness.

Third, the analysis highlighted a critical infrastructure-service mismatch. While minibuses offer higher capacity and lower fares, their operation is constrained to limited asphalt corridors. Conversely, three-wheelers, which dominate the modal share

(70.5%), provide essential coverage on cobblestone and dirt roads but do so with lower comfort and higher cost. This shows how physical infrastructure directly dictates service quality, affordability, and mode availability.

4.8 Discussion

The finding that Bishoftu residents living in the peripheral areas, lack access to public transport within a walking distance aligns with a similar study by Bogale (2012), who analyzed lack of accessible transport in peripheral areas of Addis Ababa. Both studies indicate a similar trend in Ethiopian cities where the central parts of cities enjoy provision of accessible PT while coverage is substantially reduced as one moves outwards. The studies further support report by UN-HABITAT's (2012) paper that observed rapidly urbanizing countries have a hard time developing infrastructure at a pace of the expansion of their urban settlements.

The route directness and diversity analysis show there is a connectivity challenge in Bishoftu. While similar results are found in the study of Addis Ketema sub city in Addis Ababa by Sadek and Al Sadimy (2024), the causes differ significantly. In the case of Bishoftu it, is the existence of lakes like Calalaqa and surrounding wetlands that forced long detours while in the case of Addis Ketema it is the informal settlement patterns and irregular street networks.

The finding that adjacent neighborhoods in Bishoftu lack direct PT connection and are forced to have multiple transfers through major hubs reflects points made by Van Nes, Hamerslag, and Immers (1988) about the importance of PT network layouts. Their paper highlights how the cost of rerouting public transport modes within a network requires little investment but can improve overall system performance and connectivity.

Findings of this study echo the importance of rerouting PT routes so that more connection between adjacent neighborhoods can be achieved.

The study found there are multiple short PT routes in Bishoftu contributing to overall inefficiency of the PT system, providing more evidence to similar observations by Gezahegn (2019).

Observed use of Asphalt roads by minibuses and coble stone & dirt roads by three-wheelers, supports Ethiopia's National Transport Policy (2020) of integrating different modes of transport for an efficient operation. But since the dominant PT modal share in Bishoftu are three-wheelers, forcing them out of major streets can affect frequency of PT availability.

This research explored the use of block level Traffic analysis zones (TAZs) in Ethiopian Transport Studies. Previous studies by Gezahegh (2019) and Bogale (2012) used administrative boundaries on a woreda level failing to capture detailed trip generation and distribution patterns. The study tried to demonstrate an alternative methodology by disaggregating available data into urban blocks based on land-use designation of each block providing a more accurate modeling of mobility behaviour in Bishoftu City. The paper provides a spatially referenced evidence to previous observations of areas of low PT accessibility and inefficient PT route networks in Bishoftu City.

CHAPTER FIVE: CONCLUSION AND RECOMMENDATION

5.1 Conclusion

The study set out to investigate the performance of Bishoftu's public transport network in relation to the mobility demands of its residents. The research was structured sequentially: beginning with a contextual and theoretical foundation, followed by a detailed profile of Bishoftu's urban characteristics, then a rigorous methodological framework, and culminating in spatial analysis and interpretation of results. This organization allowed for a systematic progression from problem identification to actionable recommendations.

The first objective sought to assess the gap between existing public transport networks and mobility demand using Traffic Analysis Zones (TAZs) as the analytical unit. By disaggregating data to the block level and creating 2,157 TAZs, the Four-Stage Modeling approach provided a detailed understanding of trip generation, distribution, and expected optimal route assignment. The findings confirm a significant mismatch between the optimal route assignment and existing PT provision. The study shows, peripheral settlements generate substantial trip demand but receive disproportionately low service coverage, while central corridors experience route duplication and inefficiency.

The second objective aimed to evaluate the level of public transport accessibility and connectivity in Bishoftu. Using a 500-meter walking distance from the nearest PT route as the benchmark, spatial analysis revealed that 18.6% of urban blocks lack access to any public transport route within this threshold. Furthermore, connectivity analysis demonstrated centralized and concentrated routes along the Addis Ababa - Adama corridor, with missing connections between peripheral neighborhoods. The mobility index assessment identified six routes with values exceeding 1.4, indicating very long routes requiring optimization. These findings show the PT network is simultaneously over-concentrated in core areas and under-served in peripheries.

The third objective focused on developing key indicators to evaluate public transport networks in a manner suited to Bishoftu's context. Based on literature review and adapting global metrics to local realities, the study identified four performance indicators: accessibility (measured by proximity to PT routes), mobility index/route directness (ratio of network distance to Euclidean distance), route diversity (presence of alternative paths and interconnections), and infrastructure condition (road surface material along PT corridors). These indicators proved effective in diagnosing deficiencies and provide a replicable framework for assessing other Ethiopian secondary cities facing similar paratransit-dominated mobility challenges.

The fourth objective sought to forward research-based public transport network improvement measures. The study's findings directly suggest expected recommendations, including extending routes to underserved peripheries, merging inefficient short distance routes, introducing ring-road connections to enhance connectivity and upgrading infrastructure.

In conclusion, this research demonstrates that Bishoftu's public transport network, while adaptive and responsive in its paratransit nature, is not optimally aligned with the city's spatial structure or the mobility needs of its growing population. The gap between demand and provision creates inequitable accessibility, inefficient route geometries, less resilience, and PT route segmentation. By systematically diagnosing these deficiencies through a context-sensitive analytical framework, the study contributes both a methodological template and an empirical baseline for advancing public transport optimization in Bishoftu and similar Ethiopian urban centers. The path toward more sustainable, compact, and equitable urban development lies in understanding such evidence to guide strategic improvements to PT networks that millions depend upon daily.

5.2 Recommendations

Bishoftu is a city that hosts more than 200,000 residents, multiple tourist attraction sites, manufacturing plants and vibrant commercial corridors. Such a city deserves to have efficient and resilient public transportation system that could solve current challenges and accommodate future growth ambition. The following recommendations are proposed, based on the output of the study, to help Bishoftu optimize its public transport network and services.

Accessible public transport routes

The study identified inaccessible peripheral urban blocks. It is important to extend current public transport routes so that everyone can have access to public transport within 500m walking distance. As the city becomes more vibrant, more people are going to be living in the peripheries and work in other parts of the city. Investing towards expanding accessibility to these areas will benefit the whole economy in turn.

Merging and redesigning of routes

Currently, there are many short distance three-wheeler routes that are poorly connected with each other. The number of routes should be reduced, by merging short routes, and creating longer routes that pass through multiple destinations. Such intervention will also reduce number transfers and intern will reduce travel time.

Introduce mass transit

Bishoftu city structural plan indicates plans to introduce mass transit and BRT options as major modes of public transport. Such interventions will help to move large number of people with less cost.

Introduce loops and a ring-road

Currently, Bishoftu is expanding to the west and north. This process will create more periphery areas that are far from the center and from existing public transport routes. Extending routes to every corner the city might not be realistic, since the volume of travelers will decrease as vehicles travel towards the peripheries, reducing revenue from passengers. Instead, introducing a ring road and loops, that give peripheries rapid access to adjacent periphery neighborhoods and to the city center, will solve accessibility, route diversity and route directness problems all at once.

Better Data Collection

Public transport sector should be supported by technological advancements that use real time data for better calibration of route assignment, frequency estimation and vehicle deployment. At the same time, detailed demography and transport data should be collected, to form accurate understanding of long-term travel behavior of commuters.

Better urban Block and road network

There are large urban blocks in the middle of the city that force vehicles to take longer routes to reach their destinations. Breaking down such plots can increase the legibility of the street network. At the same time, there are settlements that developed informally, creating irregular street network which are not convenient as public transport routes. Regularization of such plots could create better mobility as the city continues expanding. Making sure future expansions are planned with proper public transport routes, will address network problems ahead of time.

Densification of the inner city

Despite the rapid urbanization and population growth observed in Bishoftu, there are still unused open spaces that are not utilized properly. Inner city densification will reduce traffic flow, since people will have a chance to live closer to where they work and closer to active commercial zones.

Investing on infrastructure

Cobblestone paved roads serve most urban areas well as they require less cost and provide durable all-weather roads. But when it comes to introducing mass transit options such as buses into the system, it is important to have asphalt paved streets. Such streets will accommodate vehicles with better speed, high carrying capacity and comfort. By turning cobblestone and dirt public transport routes into asphalt paved ones, travel time and comfort can be improved dramatically.

REFERENCE

Abebe, T.T. and Garuno, M.D. (2022) 'Analyses on three-wheeled vehicles in relation to congestion: A case study in Bishoftu City, Ethiopia', *International Research Journal of Science, Technology, Education, and Management*

Abreha, D.A. (2007) *Analysing Public Transport Performance Using Efficiency Measures and Spatial Analysis: The case of Addis Ababa, Ethiopia*.

Addis Standard (2023) 'Oromia region announces restructuring of major cities'.

Barabino, B. (2009) 'Transit Bus Route Network Design: A model and its application in a real network', *WIT Transactions on the Built Environment*

Barthelemy, M. (2010) 'Spatial networks', *Physics Reports*

Bell, M.G.H. and Iida, Y. (1997) *Transportation Network Analysis*. John Wiley & Sons.

Bhat, C. *et al.* (2000) 'Development of Urban Accesssibility Index: Literature Review'.

Bogale, Y.A. (2012) 'Evaluating Transport Network Structure: Case Study in Addis Ababa, Ethiopia'.

Debas, M. (2019) 'Housing Development and the Public Transportation Mismatch ':

Ethiopian Ministry of Transport (2020) 'Federal Democratic Republic of Ethiopia: National Transport Policy'

Fenta, T.M. (2014) 'Demands for Urban Public Transportation in Addis Ababa', *Journal of Intelligent Transportation and Urban Planning*

Gadisa, M. (2019) *Bishoftu City Structure Plan Revision: Assessment of Social Development Issues*.

Gezahegn, A. (2019) 'THE REVISION OF STRUCTURE PLAN OF BISHOFTU CITY:Report on Urban Transport Planning and Traffic Management Study'.

Girão, R. e S., Pereira, W.A. de A. and Fernandes, P.J.F. (2017) 'Accessibility Index Elaboration By Network Geospatial Analysis', *Mercator*

Gkiotsalitis, K. (2022) *Public Transport Optimization, Public Transport Optimization*. Springer Nature.

Gudina, T. (2019) *History of Bishoftu City*.

Hensher, D.A. and Button, K.J. (eds) (2000) *Handbook of Transport Modeling*.

Institute for Transport & Development Policy (2020) 'Ethiopia non-motorised transport strategy 2020-2029'

Jafino, B.A., Kwakkel, J. and Verbraeck, A. (2020) 'Transport network criticality metrics: a comparative analysis and a guideline for selection', *Transport Reviews*

Kalpana, H.N., Jayasinghe, A. and Abenayake, C. (2020) 'Accessibility Assessment of Cities Based on Network Analysis and Centrality', *Journal of the Eastern Asia Society for Transportation Studies*

Knight, P.L. and Marshall, W.E. (2015) 'The metrics of street network connectivity: their inconsistencies', *Journal of Urbanism*,

Koroso, N.H., Lengoiboni, M. and Zevenbergen, J.A. (2021) 'Urbanization and urban land use efficiency: Evidence from regional and Addis Ababa satellite cities, Ethiopia', *Habitat International*

Kreindler, G. *et al.* (2023) 'OPTIMAL PUBLIC TRANSPORTATION NETWORKS :EVIDENCE FROM THE WORLD'S LARGEST BUS RAPID TRANSIT SYSTEM IN JAKARTA Gabriel', *NATIONAL BUREAU OF ECONOMIC RESEARCH* [Preprint].

Lave, R. and Mathias, R. (2000) 'State of the Art of Paratransit', *Transportation in the New Millennium*

Lin, J. (2017) *Spatial analysis and modeling of urban transportation networks*.

Mcnally, M.G. (2000) 'The Four Step Model'

Minister of Transport and Logistics (2022) 'Ethiopian Transport Master Plan, 2022-2052'

van Nes, A. and Yamu, C. (2021) *Introduction to Space Syntax in Urban Studies*, *Introduction to Space Syntax in Urban Studies*

van Nes, R., Hamerslag, R. and Immers, B.H. (1988) 'Design of public transport networks', *Transportation Research Record*, (1202)

Ortuzar, J. de D. and Willumsen, L.G. (2011) *MODELLING TRANSPORT*.

Pankhurst, R. (1985) *History of Ethiopia Towns From the Mid-19th Century to 1935*. Franz Steiner

Wiesbaden Stutgart.

Rodriguez, C. *et al.* (2016) 'Bogota's Bus Reform Process: Accessibility & Affordability effects, Lessons Learnt & Alternatives to Tackle Informal Services'

Sadek, H. sadek abdul-T. and Al-Sadimy, M.Z.H. (2024) 'Evaluating the connectivity level of the Addis Ababa city road network -Addis Kitema- using GIS', *Labyrinth: Fayoum Journal of Science and Interdisciplinary Studies*

Silman, L.A., Barzily, Z. and Passy, U. (1974) 'Planning the Route system for Urban Buses'

Tanku, M. and Woldetensae, B. (2023) 'Pathways to Industrialisation and Urban Spatial Outcomes: The Case of Addis Ababa - Bishoftu Economic Growth Corridor, Ethiopia', *International Journal of Urban Sustainable Development*

Tsehay, B. (2024) 'Dynamics of land use and land cover changes in Bishoftu City, Oromia Regional State, Ethiopia', *Asian Journal of Environmental Research*

UN-HABITAT (2011) 'People and Mobility: Promoting non-motorised transport options and compact cities as complements to public transport'.

United-Nation-HLPF (2023) 'SDG 11, Sustainable Cities and Communities', *SDG 11, Sustainable Cities and Communities*

World Bank (2014) 'Addis Ababa Urban and Metropolitan Transport and Land Use Linkages Strategy Review', *World Bank*.

Zewde, B. (1991) *A History of Modern Ethiopia, 1855-1974*. Addis Ababa University Press.

ANNEXES

Annex 01 – Publishable Manuscript

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OPTIMIZING URBAN MOBILITY:

Accessibility of Bishoftu city by paratransit public transportation modes

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Abstract

Like many Ethiopian cities, Bishoftu is experiencing fast physical expansion and sustained population growth. Studies show that, Ethiopian cities like Bishoftu do not have an efficient, resilient and organized public transport systems and rely heavily on two paratransit public transport providers; mini-buses and three-wheelers. This paper investigates accessibility of Bishoftu by paratransit public transportation modes. The study used public transport routes used by paratransit service providers and origin destination data from Bishoftu transport authority. The study found peripheral areas of Bishoftu do not have adequate public transport route coverage. 18.9 % of the residents in Bishoftu do not have access to public transport routes within a walking distance of 500m. The study recommends optimizing public transportation modes and routes in Bishoftu, to incorporate mass transit options and routes connecting peripheral areas.

Keywords: *Accessibility, Public transport, paratransit transport modes, Bishoftu,*

1. Introduction

Research shows that mobility and accessibility are major determinants of lifestyle and prosperity (Bell and Iida, 1997). Efficiency of public transportation is an important precondition for development of cities, flourishing of economic activities and social inclusion (UN-HABITAT, 2011). United nations sustainable development goals (SDGs) 11.2 highlights the importance of providing safe, affordable, accessible and sustainable public transportation systems as part of SDG 11 of creating sustainable cities and human settlements. Rapidly urbanizing countries like Ethiopia, face multiple challenges in public transportation because of rapid population growth, limited infrastructure investment, and urban sprawl (UN-HABITAT, 2011). Cities like Bishoftu, lack investment in institutionalized public transport services. This has created a gap for private paratransit public transport providers to emerge, addressing mobility demand of the city.

2. Literature Review

2.1 Paratransit public transport

Paratransit PT modes are characterized by their nature of private ownership, demand responsivity and complementarity to conventional mass transit. Their use being highly relevant to users in areas of low-density land use and demand, which are areas not served cost-effectively by conventional transit (Lave and Mathias, 2000). But in Ethiopia, paratransit PT mode is predominant in many high-density settlements. There are few large companies and many private paratransit public transport providers in Ethiopia (Minister of Transport and Logistics, 2022). In Bishoftu, All PT modes are paratransit with the largest modal share of **70.5%** being **Three-wheelers** *(Bajajs)* (Bishoftu Transport authority, 2019)(Gezahegn, 2019). While they are free to work on their own schedule (frequency), transport authority of Bishoftu assigns routes to paratransit providers individually. The transport authority tries to manage frequency of different public transport modes indirectly by assigning more vehicles on routes that are assumed to be busier.

2.2 Public transport networks

Transport networks dictate urban development and growth and access to such infrastructure "*predict and plays a role in navigation future development potentials and the urban movement in investment and resource allocation*"(Kalpana, Jayasinghe and Abenayake, 2020). Public transportation reduces greenhouse emissions and traffic congestion; and promote equity due to its affordable nature (United-Nation-HLPF, 2023). Rapidly urbanizing countries like Ethiopia are also faced with the task of creating a good urban form that responds to economic social and economic constraints. Characteristics and challenges of public transportation are everchanging depending on the current developmental and geospatial context of cities (Gkiotsalitis, 2022). When it comes to developing countries, these challenges can be characterized by the lack of investment in infrastructure, urban sprawl, informal modes of transportation that are hard to manage and lack of coordination of planning between different modes of Public transport (Bogale, 2012). The city of Bishoftu faces similar challenges (Gezahegn, 2019). Optimization of Public transportation network and its components in cities like Bishoftu will ensure the development of a good urban form that is livable, economically vibrant and environmentally sustainable.

2.3 Study area

Bishoftu is a city located 47 km South-East of Ethiopian capital city Addis Ababa. Located in Oromia region, East Shewa zone with an average altitude of 1920m. The city is organized into Four sub cities each having four '*Gendas*' (Administrative zones) (OUPI, 2019).

The formation of the city is directly related to the construction Ethio-Djibouti rail way between 1894 – 1917. Being located along the rail way and a major trade and import-export route shaped the development of the city (Zewde, 1991; Gudina, 2019).

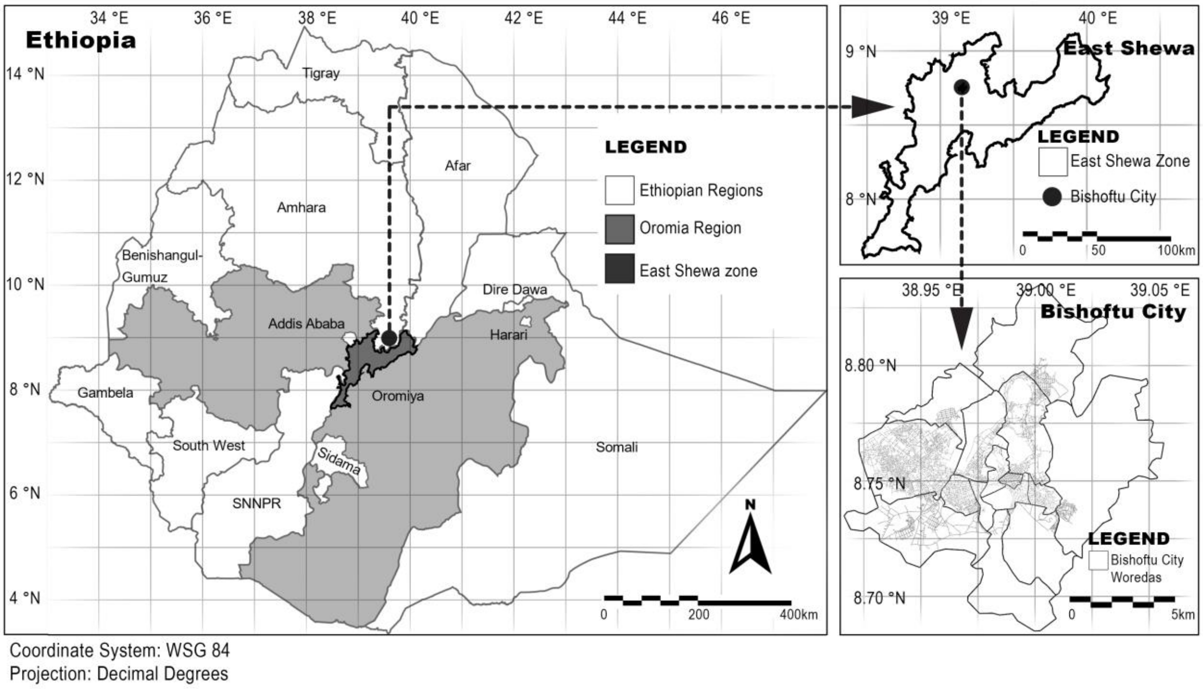

Figure 2.1 Location map of Bishoftu

Bishoftu is also a popular recreation resort town that hosts a number of volcanic lakes attracting local and international tourists. The city hosts a number of industries, manufacturing plants and facilities. As of 2018, there were about one hundred thirty-nine active industries in Bishoftu providing employment opportunities for more than twenty thousand people (Gadisa, 2019).

As of 2019 according to Bishoftu city infrastructure asset inventory, there was a total of 540.36 km of road that is 7m or wider (Gezahegn, 2019). Among these roads, only 20.7% of it is asphalt road and accessible by all modes of public transport (Gezahegn, 2019).

The two main public transport modes in Bishoftu are Bajaj (three-wheeler) and mini-buses. The three- wheelers operate on 34 routes and has a PT modal share of 70.5% while minibus taxis have 29.5%. Mini-bus taxis operate on asphalted roads and operate on eight routes (Bishoftu transport Authority, 2019).

Figure 2.2 Bishoftu road network structure samples

Bishoftu has a diverse road network structure. Some areas have road network that developed naturally following informal settlement patterns while other areas are well structured and planned. Areas that developed informally exhibit a road network characteristic that are not well connected and dominated by dead-end nodes.

3. Methods and Materials

The study focuses on analyzing accessibility of Bishoftu by paratransit public transport mode. According to Bhat et al., “accessibility is a measure of the ease to pursue an activity of a desired type, at a desired location, by a desired mode, and at a desired time” (Bhat *et al.*, 2000). The study measures how much an individual has to travel on foot to access the closest public transportation route within the study area. Studies reviewed suggest using bus stops as points of reference for calculating distance from nearest public transport hub. But the paratransit nature of transport mode in Bishoftu indicates anyone can access public transport once they have access to the routes where public transport services run. Studies also show public transport nodes should be available at maximum distance of 500m – 700m in urban areas. Ethiopian transport authority developed a guideline as part of promoting non-motorized transport in cities stating that, public transit lines should be accessible within a walking distance of 500m (Institute for Transport & Development Policy, 2020). The study uses the suggested distance of 500m to draw conclusion regarding accessibility of an area by public transport network in Bishoftu city.

4. Results and Discussion

4.1 Public transport coverage

Bishoftu has two modes of PT; minibuses and three-wheelers, each operating on dedicated routes assigned by Bishoftu transport authority. Accessibility of Bishoftu using PT is studied based on Minibus and Bajaj routes data from Bishoftu transport authority.

Minibus transportation not only serves urban areas of Bishoftu, but also help to connect neighboring settlements like '*Danakaka*' and city of '*Dukem*'. Considering the focus of this study is intra-city public transport of Bishoftu city, these destinations are not taken into account. There are three corridors where minibuses give service in Bishoftu city. These are '*INOVA/NOC*' – '*Airforce*', '*INOVA/NOC*' – '*Babogaya*' and '*Market – INOVA/NOC*'.

The second and most predominant PT mode in Bishoftu are three-wheelers or '*bajaj*'. According to data from Bishoftu transport authority, there are 5 '*bajaj*' associations operating along 34 routes. Three-wheeler and mini-bus routes overlap in few places as three-wheelers are discouraged from using sections of the asphalted main Addis Ababa – Adama corridor. On the other side, minibuses do not operate on cobblestone roads.

Figure 4.1 show the routes and daily deployment count of three-wheelers. The most important origins and destinations generating high traffic are, the 'Market' and 'Arbashi' destinations. There are 151 daily deployments between the two nodes making up 17.9% of all travels by three-wheelers. '*Arbashi*' is a place where many industries and manufacturing plants are located. It attracts large number of employment and mobility in Bishoftu. which justifies the assignment of large volume of three-wheelers towards it.

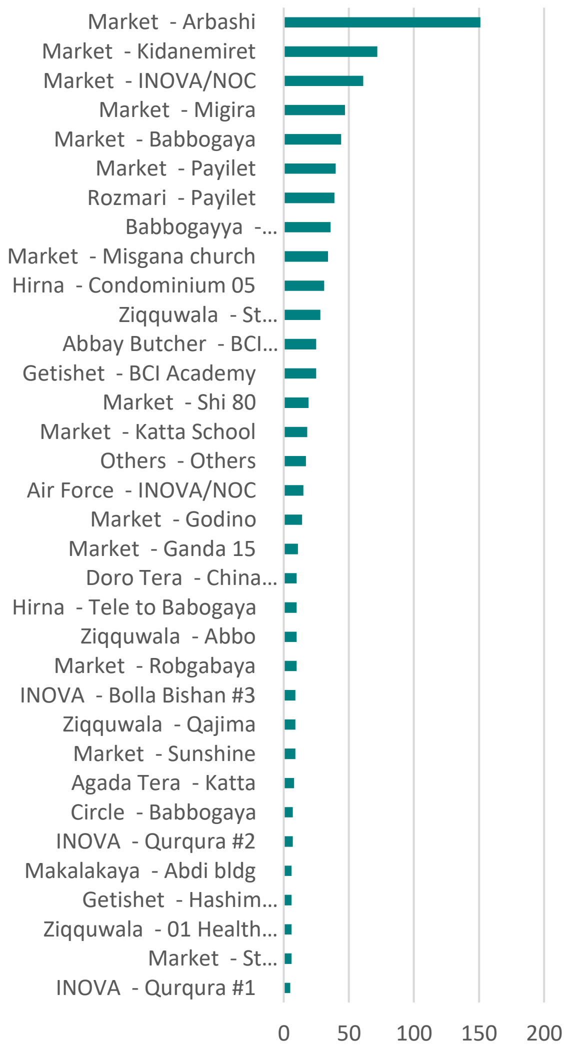

Figure 4.1 '*Bajaj*' routes and daily deployment

Figure 4.2 Analysis of existing PT routes between origin and destination pairs

All existing three-wheeler and mini-bus PT routes are studied based on their origin-destination pairs and the routes they take. Figure 5.2 shows the process of analyzing existing individual PT routes (34 three-wheeler and 8 mini-bus routes). All routes are then combined to create existing PT Network of Bishoftu city (Figure 5.26).

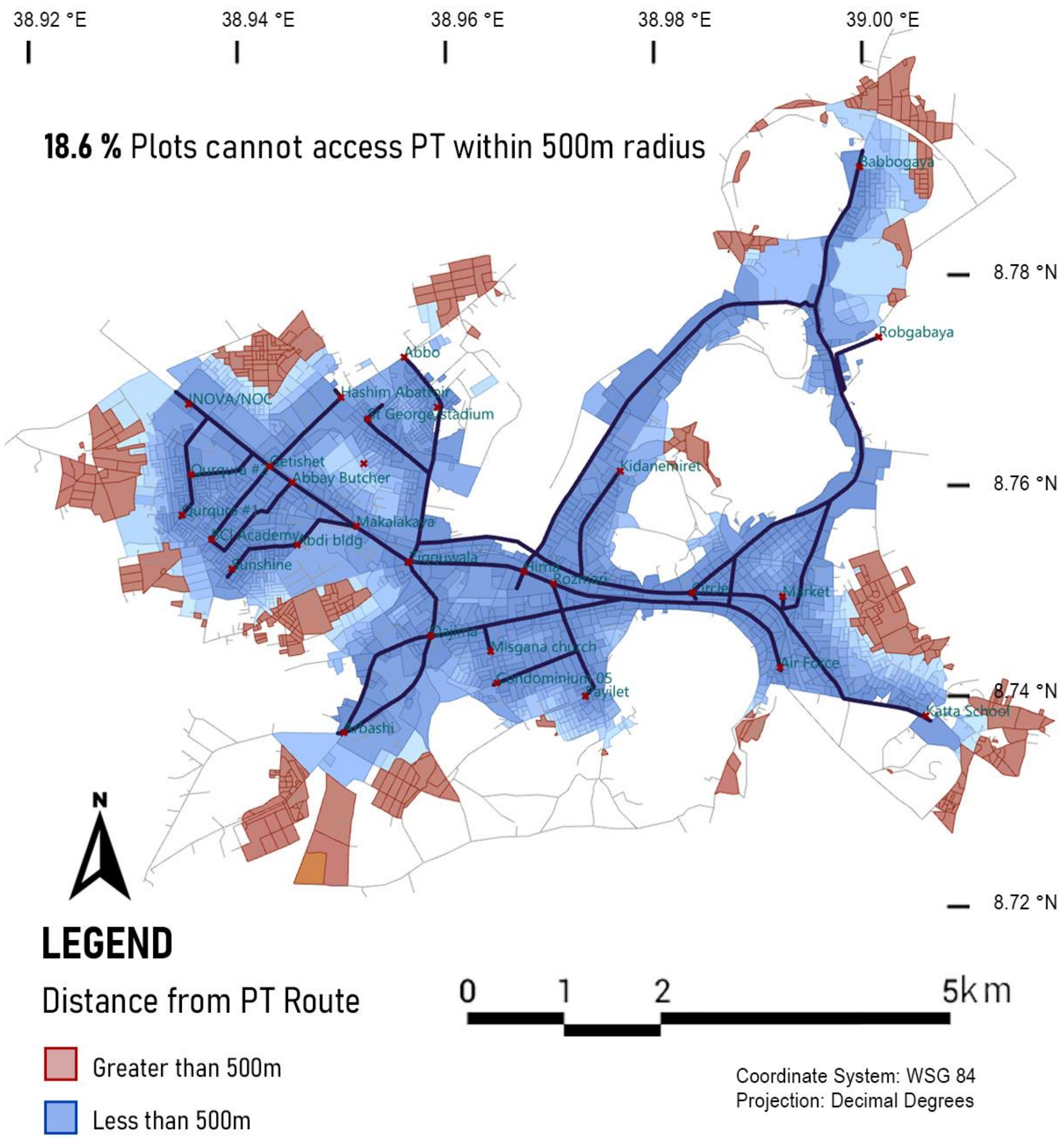

Figure 4.3 Bishoftu PT network (three-wheelers and mini-bus routes combined)

Figure 4.3 shows, current state of public transport network provision in Bishoftu. The map shows **18.6 %** of urban residents do not have access to public transport routes within the recommended 500m radius. Most plots that are less accessible by PT route are those located in the outskirts of the city.

4.2 Public transport network road condition

Figure 4.4 shows the proportion of road material cover of PT routes in Bishoftu. Even though Bishoftu has 20.7% of its road network paved with asphalt, when it comes to PT routes, asphalted roads constitute 57.6 % (24km) of all PT routes. This is because the longest PT routes from '*INOVA NOC*' to '*Airforce*', '*Market*' to '*Babogaya*', '*Hirna*' to '*Babogaya*' and '*Market*' to *'Arbashi'* are all paved with asphalt. These roads are used by all modes of PT with restriction for three-wheelers on certain section. Bishoftu has an extensive network of more than 130 km long cobblestone paved roads (Gezahegn, 2019). But when it comes to mobility, it is not clear how much of it is used as

PT routes since three-wheelers can use any road in the network as long as they could find passengers and do not deviate from their destinations. The study tried to identify routes that are frequented by three wheelers and found 13.6 km long cobblestone paved roads and 4.2 km dirt road.

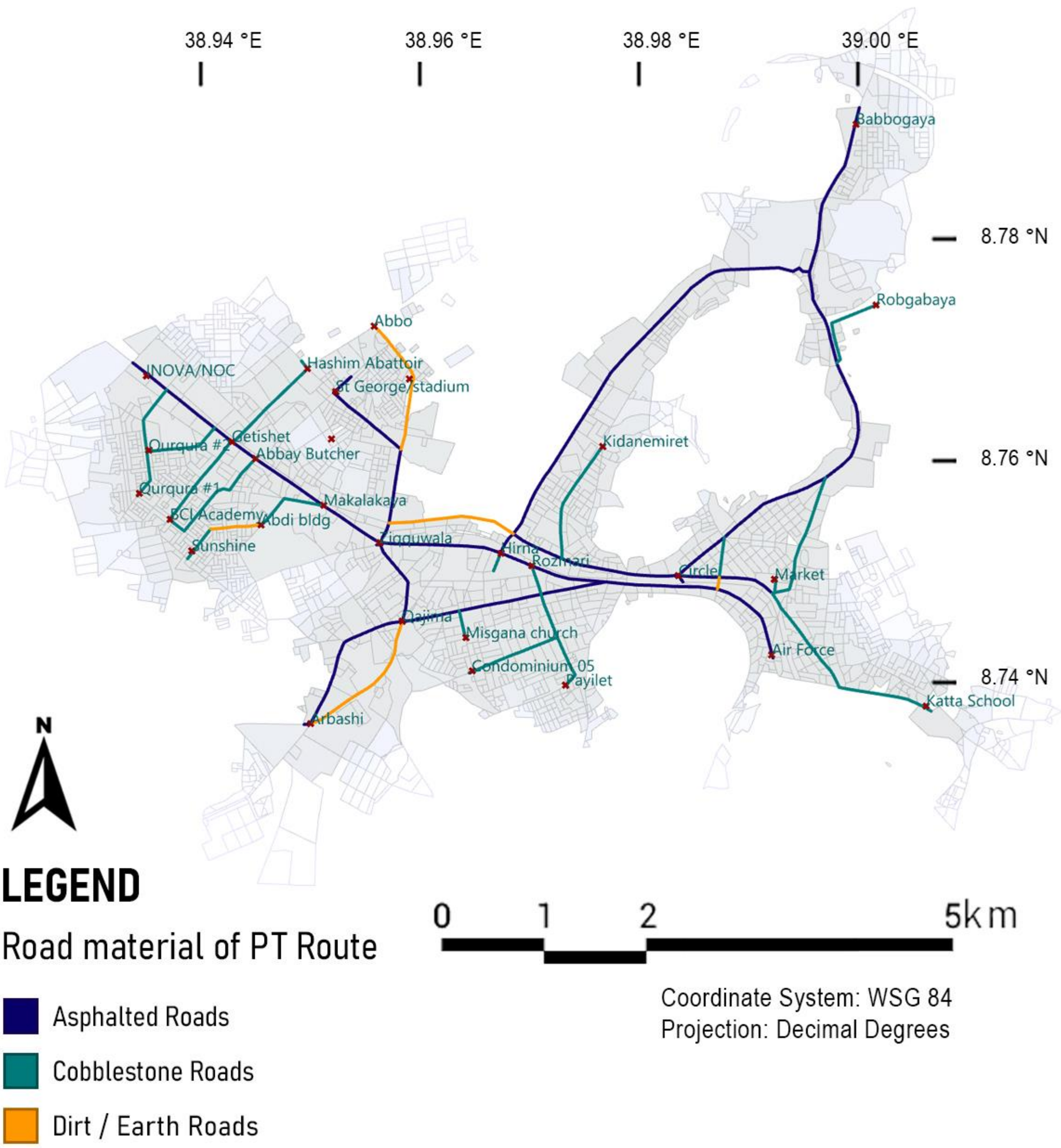

Figure 4.4 Road material of PT routes in Bishoftu

5. Conclusion

Public transportation networks are powerful organization tools that can manage urban settlement efficiently if designed well. Public transport in Bishoftu is dominated by paratransit service providers i.e., three-wheelers and mini-buses. The study found that, there are parts of the city that are not accessible by public transport within a comfortable walking distance and inadequate level of infrastructure that requires investment.

The study identified inaccessible peripheral urban blocks. It is important to extend current public transport routes so that everyone can have access to public transport within 500m walking distance. As the city becomes more vibrant, more people are going to be living in the peripheries and work in other parts of the city. Investing towards expanding accessibility to these areas will benefit the whole economy in turn.

Bishoftu is a city that hosts hundreds of thousands of residents. Such cities require a well-organized mass transit systems and should not rely on low carrying capacity paratransit service providers. Introducing mass transit and BRT options as major modes of public transport and opening the possibility for paratransit providers to operate around the peripheries can address current mobility challenges of Bishoftu

REFERENCE

Bell, M.G.H. and Iida, Y. (1997) Transportation Network Analysis. John Wiley & Sons.

Bhat, C. et al. (2000) 'Development of Urban Accesssibility Index: Literature Review'.

Bogale, Y.A. (2012) 'Evaluating Transport Network Structure: Case Study in Addis Ababa, Ethiopia'.

Gadisa, M. (2019) Bishoftu City Structure Plan Revision: Assessment of Social Development Issues.

Gezahegn, A. (2019) 'THE REVISION OF STRUCTURE PLAN OF BISHOFTU CITY:Report on Urban Transport Planning and Traffic Management Study'

Gkiotsalitis, K. (2022) Public Transport Optimization, Public Transport Optimization. Springer Nature

Gudina, T. (2019) History of Bishoftu City

Institute for Transport & Development Policy (2020) 'Ethiopia non-motorised transport strategy 2020-2029'

Kalpana, H.N., Jayasinghe, A. and Abenayake, C. (2020) 'Accessibility Assessment of Cities Based on Network Analysis and Centrality', Journal of the Eastern Asia Society for Transportation Studies

Lave, R. and Mathias, R. (2000) 'State of the Art of Paratransit', Transportation in the New Millennium,

Minister of Transport and Logistics (2022) 'Ethiopian Transport Master Plan, 2022-2052'

UN-HABITAT (2011) 'People and Mobility: Promoting non-motorised transport options and compact cities as complements to public transport'.

United-Nation-HLPF (2023) 'SDG 11, Sustainable Cities and Communities', SDG 11, Sustainable Cities and Communities

Zewde, B. (1991) A History of Modern Ethiopia, 1855-1974. Addis Ababa University Press.