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GIS-BASED EVALUATION OF URBAN ROAD TRANSPORT NETWORK STRUCTURE: A CASE STUDY OF ARADA SUB-CITY

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GIS-BASED EVALUATION OF URBAN ROAD TRANSPORT NETWORK STRUCTURE: A CASE STUDY OF ARADA SUB-CITY

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A Thesis Submitted to School of Graduate Studies in Partial Fulfillment of the Requirement for Degree of Master of Art in Geography and Environmental Studies with Specialization in GIS and Remote Sensing

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Declaration

The thesis is my original work, has not been presented for a degree in any other university and that all sources of material used for the thesis have been properly acknowledged.

Addis Ababa University

College of Social Science

This is to certify that the thesis prepared by Paulos Birhanu, entitled: GIS Based Evaluation of Urban Road Transport Network Structure in Arada Sub-city, Addis Ababa and submitted in fulfillment of the requirements for the Degree of Master of Arts in Geography and Environmental Studies with Specialization in GIS and Remote sensing.

Signed By the Examining Committee:

Advisor ___________________________Signature __________ Date ___________

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Chair of Department of Graduate Program Coordinator

Abstract

It is well understood that, infrastructure is a profound determinant of nationhood, a measure of a country success on the world stage. Among the broad infrastructure parts, this study focuses on the network of road transport structure. The true goal of urban road network is to have access and link to a destination places. However, providing efficient road transport for the ever increasing demand is a challenge in developing country cities, like Addis Ababa. Thus the need to evaluate current road network efficiency is a solution to identify opportunities and deficiencies. Thus, this study assesses the existing road network performance, aiming for effective road transport service to all group of society in the Arada sub-city. In order to investigate road network structure, the research employed GIS techniques. *The data collection used was a secondary source from Addis Ababa City Road Authority and several Arada sub-city offices. Arada sub-city being as a Central Business District area of Addis Ababa, used as a hub of transportation of the city and experiences low level of road network performance.*

The overall findings of this study revealed that despite the fact that an efficient road transport service is the best way to maximize urban mobility, in reality this mode of transport is in a critical condition with in Addis Ababa and in Arada sub-city. There are service deficiencies in some part of the study area, particularly areas that are found far from the centroid of the sub-city suffers from lack of efficient road transport infrastructure and roads in the central area have a capacity limitation. The research has also identifies the low level of road network condition. Further, recommendations are made to improve the existing road network structure considering proximity and accessibility objective that enable the goal of transport system.

Keyword list: Road Network Evaluation, Road Transport Performance, GIS, Central Business District, Indicators

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Dedication

This study is dedicated to my father, Birhanu Haile.

I hide my tears when I say your name, but pain in my heart is still the same.
Although I smile and seem carefree, there is no one who misses you more than me.
I'd give anything to say hello again.

Paulos

ACRONYMS AND ABREVITIONS

AACRA- Addis Ababa City Roads Authority

AACRNR- Addis Ababa city Road Network Report

AAUTS- Addis Ababa Urban Transport Study

AutoCAD- Computer Aided Design

CBD - Central Business District

CSA - Central Statistics Agency

ERA - Ethiopian Roads Authority

ESRI – Environmental Systems Research Institute

FDRE - Federal Democracy Republic of Ethiopia

GIS – Geographic Information System

GIS-T – Geographic Information System for Transportation

NBI - Network Based Indicators

ODM - Origin Destination Matrix

ORAAMP - Office for the Revision of Addis Ababa Master Plan

UN - United Nations

UNECA - United Nations Economic Commission of Africa

UTPS - Urban Transport Planning System

UTS - Urban Transport Study

VPD- Vehicle per Day

WGS - World Geodetic System

WHO - World Health Organizations

Table of Contents

Table of Contents

CHAPTER FIVE

CHAPTER SIX

CHAPTER SEVEN

Chapter One

1.1. Background

"Urban global quality" can be considered in terms of the efficiency, functionality, value, economy, safety, durability and the appearance of utilities. Infrastructure usually holds central place in nations economic planning. And it also promotes economic growth, expands trade, reduces poverty and improves the environment. Urban utility network is considered vital for the proper and smooth functioning of a society. Any malfunctioning or breakdown of these services can cause considerable damages on the society's life (Zerihun, 2008).

It is believed that, infrastructure is a profound determinant of nationhood, a measure of a country's success on the world stage. Physical infrastructure may be viewed as the indicator of a country's economic power. A nation's physical infrastructure is generally taken to mean its public capital: its community buildings such as hospitals and schools, transport nodes, rail and road networks, utility services such as water, power and waste services. Social infrastructures are also the social capital and the standard of living of its citizens. A country's infrastructure capital may accumulate over generations or centuries, or it may occur over more decades. Infrastructure in all its commercial indicators is viewed by governments as the means to attract significant private sector investment (Reungsri, 2010).

As studies show, at the beginning of the twenty-first century, one of the most stubborn and challenging problems facing African cities are inadequacy of urban infrastructure and the subsequent fall in urban environment (Vincent, 1999).

Today's developing countries are urbanizing at a much more rapid pace than that of their ancestors (Henderson, 2002). The combination of this urban population explosion with limited public assets accounts for a worldwide deficiency in urban infrastructure. According to UN-Habitat report (2003), large portions of the population in metropolitan areas throughout the developing world do not benefit from basic urban infrastructure such as piped water, electricity, sewerage lines, and asphalted roads (UN-Habitat, 2003).

Among the broad infrastructure types, this study focuses on the network of road transport structure. The reliability and efficiency of this infrastructure provision is very important to modernize urban localities through the responsive act of utility authorities, municipalities, planners, policy makers as well as stakeholders.

Transportation system is a critical component of urban infrastructure and the lifeline of the city. It plays a key role in the economic growth of that region and also displays region's economic condition (Praveen et al, 2013). Transportation system consists of streets, highways, railroads, port and waterways and the like. It links town and villages and enable the people of one place to communicate with people of another place; it is true that good road network helps people to travel easily to places where they can work and develop their life (Ndiwari, 2014; Irfan, 2005).

The urban road network plays a key role in the urban spatial structure and it is the main city socio-economic activities and transportation carrier (Hu and Wu, 2014). Several studies admit that, the quality of life of the citizens is heavily dependent on the efficiency and effectiveness of its transportation system. The true goal of urban road network is to have access and link to places, facilities, utilities and services etc. (Olowosegun and Okoko, 2012).

When we look at the transport planning and decision making strategies of cities of developing countries, most of the times, planning decisions are made based on pure speculation and it is hard to explain how decisions are made that affect the road network plan. Because of this reason cities grow in uncontrolled manner and change into more and more inefficient transport networks.

Many researchers agree that major changes in transport network structure affects patterns of urban development and location of social and economic activities, households and employment centers. On the other hand, Waddell (2011), in his study suggests that, major changes in land use influence the trip making behavior of people, destination and mode choice (Waddell, 2011). And also, the network structure of an area also affects accessibility and destination choice of travelers (Huang & Levinson, 2011).

As a result of increasing urban population and the changing way of life, the road transport in most developing countries suffers from many problems like high accident levels, inadequate infrastructures both in capacity and availability, poor quality infrastructure and mismatch between demand and supply. These problems are caused by high urbanization, city growth and lack of proper transport planning and management strategies in the cities of Third world countries. Such cities, especially those found in Africa, are mostly capital cities like Addis Ababa.

The road network of Addis Ababa has mainly radial developmental pattern which is highly influenced by topography, the nature of housing and building characteristics. It forms a dense network in the north-south direction. Mekete, (1997), states that, there is an absence of direct connections, particularly in the east-west direction. The designs of the road network are not satisfactory and there are many intersections. The arterial network includes all asphalted roads. The local streets are often in poor conditions. The streets between houses are narrow, unpaved and usually damaged by the heavy rain. Most of them serve as pedestrian ways. As a result, vehicular access is limited. Several studies that are conducted on the nature of public transport confirmed that there is inadequacy of public transport facilities in the city. As stated earlier these inefficiency resulted from the design of the road network.

The Addis Ababa City Road Network Report analyzed the nature and problems of the existing road network. Because of poor planning, there is a critical lack of hierarchical system in the road network and inadequate traffic management is significant factors which limit the capability of the existing road network to provide adequate transport service. Moreover, there are bottlenecks of narrow bridges, poorly designed intersections, and alignments.

As road network is a most important component of urban infrastructure and is a key to the quality of life of the societies in that area. Knowing the process of city infrastructure provision and reliable information base is essential for successful infrastructure management and strategic decision making. Lack of information contributes to problems such as ineffective infrastructure provision and management. Hence, there is a strong interest to apply any tool that contributes to prevent such problems. Geographic Information System (GIS) is certainly one of these tools, which serves both as a database and as a toolbox for urban planning. In a database-oriented GIS, spatial and textual data can be stored and linked using the geo-relational model.

It is true that, every day planners use geographic information system (GIS) technology to research, develop, implement, and monitor the progress of their plans. GIS provides planners, surveyors, and engineers with the tools they need to design and map their neighborhoods and cities, and they use GIS to facilitate the decision-making process (Pettit, 2006).

Planners also extract data from their databases and input them to other modeling and spatial analysis programs. When combined with data from other tabular databases or specially conducted surveys, geographical information can be used to make effective planning decisions.

As a toolbox, GIS allows planners to perform spatial analysis using geo-processing functions such as map overlay, connectivity measurement, and buffering (Berry, 1987, Tomlin, 1990).

This study employs GIS technology to access information and to evaluate the current performance of the road network and the level of mobility provided by the network in the Arada sub-city of Addis Ababa City Administration.

1.2. Statement of the problem

The present day urban society needs an efficient system of transport network, water supply, and telecommunication services and utilities. However, the provision of such infrastructures is highly constrained by planning, institutional, technological and policy factors.

Among the main challenges facing urban centers particularly those in the developing countries is how to provide adequate level of public infrastructure and services for growing urban population. The recommendations of the Millennium Development Goals of Africa Steering Group in 2011 clearly indicated that the sub-Saharan Africa is not only characterized by lack of infrastructural services but also not carefully installed programs that pose constraints on economic growth and expansion of poverty (MDG, 2011).

The Federal Democratic Republic of Ethiopia Growth and Transformation Plan reports, inadequate human capacity in the sector has hampered in achieving the desired development of the infrastructure sector (FDRE GTP, 2010).

Addis Ababa city is experiencing rapid growth. Thus, the demand for infrastructure and services is surpassing the current capacity. Existing infrastructural services are also unpromising rapidly and in need of urgent solution. For instance, road construction often resulted in unearthing of underground electricity and telecommunication cables, as well as water networks. A number of reasons were used to explain the poor infrastructure management system.

The main reasons for these problems are linked with poor infrastructure planning and an overall lack of understanding of how to effectively manage the infrastructural services (Nyarirangwe, 2008). Another major problem has to do with high capacity utilization levels, characteristics among most part of the city. This is mainly due to the increasing urban population and resultant demand for infrastructure and service.

Road transport is the one and frequently used mode of transport in most countries of the world. It is relatively cheap (affordable) and convenient mode as compared to other modes of transportation. Road transport is particularly suitable for short and medium distance travels. In the case of Addis Ababa the majority of travel (mobility) is based on this mode for motorized systems. Fentahun, (2012) identified that, in Addis Ababa because of the rapid economic growth and transformation there is a high mobility of goods and peoples which leads to high transportation demand.

Based on studies that are conducted on the same issue shows that, the road network of Addis Ababa suffers from many inadequacies including quality of roads, low accessibility level, narrowness, limited network extent and pedestrian walkway, shortage of road network with respect to the size of the city, lack of street parking facility and over utilization of off street parking facility, over utilization of road spaced by parked vehicles, poorly designed road junctions, substandard terminals for passengers and freight transport and inconvenient bus and taxi ways, lack of segregated bikeways (Fantahun, 2012).

The transport sector being one of the basic requirements for an area, road network remains the main component of transport system in the city. Addis Ababa has a radial form of road network which is shaped by five major roads radiating out of the Central Business District (CBD) into outskirts. However, the road network of Addis Ababa city in general and Arada sub-city in particular is characterized by, high volume of traffic congestion, low accessibility levels, high accident levels, negative environmental impacts and unsafe public transport.

There are few researches conducted with regards to the whole transportation system. Abate (2007) analyzed public transport performance using efficiency measures, Yared (2010) investigated the impact of vehicular traffic congestion of Addis Ababa, Fantahun (2012) discussed integrating public transport network and built up environment. Yetnayet (2012) tried to evaluate the whole status of transport network structure of Addis Ababa. These studies conduct their study by basically taking into account the demand side of the transport system.

However, the above studies have a gap of focusing on the current road network structure which might be the major cause for the transport problem and they are not effectively using GIS instruments for analysis part. These studies also have taking into account the demand side of the transport system only. On this ground GIS- based evaluation of road transport network structure and the level of mobility provided by the network is important for evidence based policy making as well as planning, monitoring and evaluation programs in the study area. Therefore, there is an urgent need to carry research on the existing problem compatible to GIS environment for better planning and management.

1.3. Objective of the Study

The general objective of the study is to evaluate the road network structure, by employing GIS technology, taking Arada sub-city as a case study.

Specific Objectives

i, To develop indicators to weigh the existing road transport network structure;

ii, To assess the capacity of the road networks in Arada sub-city;

iii, To examine the capacity of the road network by taking into account the demand and supply side of the road transport system;

iv, To identify the road network deficiency and pinpoint the area;

v, To make recommendations for policy makers to improve performance of road networks;

1.4. Research questions

The research objectives identified above are translated into the following specific research questions:

- Which road transport network indicators are suited for network structure analysis and better traffic performance?
- How to identify inadequacies in the existing road network through the assessment of road network indicators?
- Are the existing roads having a capacity limitation?
- In the existing road network structure, which areas are observed to be missing road network links?
- What are the policy implications of such transport decisions regarding road network?

1.5. Significance of the study

The vision of the city's transport plan is "affordable transport, enhanced access and mobility". Addis Ababa, the administrative and financial capital of Ethiopia, is experiencing continuous growth and change. It is truly accepted that, change is experienced in all dimensions of the city but different parts of the city grow at different rates. Due to population growth, the city is expanding rapidly but the road network fails to serve the demand for transport.

This study is significant in identifying the indicators that are used to investigate and assess the existing road network structure of Arada sub-city, which is the start line of roads in the city and which involves the Central Business District of the city.

At the same time the study will serve as a reference material for the city road authority, and it will add input for policy making process in the area of the subject matter. Moreover, GIS students who want to study about transportation by integrating Arc GIS with AutoCAD have a clue to combine those of two elegant tools.

1.6. Scope of the Study

The study area which is Arada sub-city is located roughly in the northern part of the capital city of Ethiopia, Addis Ababa. The total area of Arada sub-city is 950 hectares with the total area of road network accounts about 186.81 hectare including all asphalt, coble, gravel, paved and unpaved road. The study area contains different types of land uses i.e. road network, business districts, administrative area, several educational institutions, residential area and the like.

GIS is a spatial technique which is particularly used in this research. The parameters used by this research to evaluate road network structure are selected indicators of road network performance.

1.7. Conceptual Framework

Transport system is a combination of supply and demand. It is not an end process by itself, transportation is the means by which people are able to involve in activities that require people themselves and material goods to be in different places at different times. The rapid growth of cities has been accompanied by an increased demand for urban transport. The demand for travel depends on the socio-economic activity of the people, land use characteristics of the area and accessibility of different places. Transport supply includes infrastructure, services and transport networks. For this reason this research combines travel demand and transport supply to evaluate the network structure that requires criteria that can be used for this purpose.

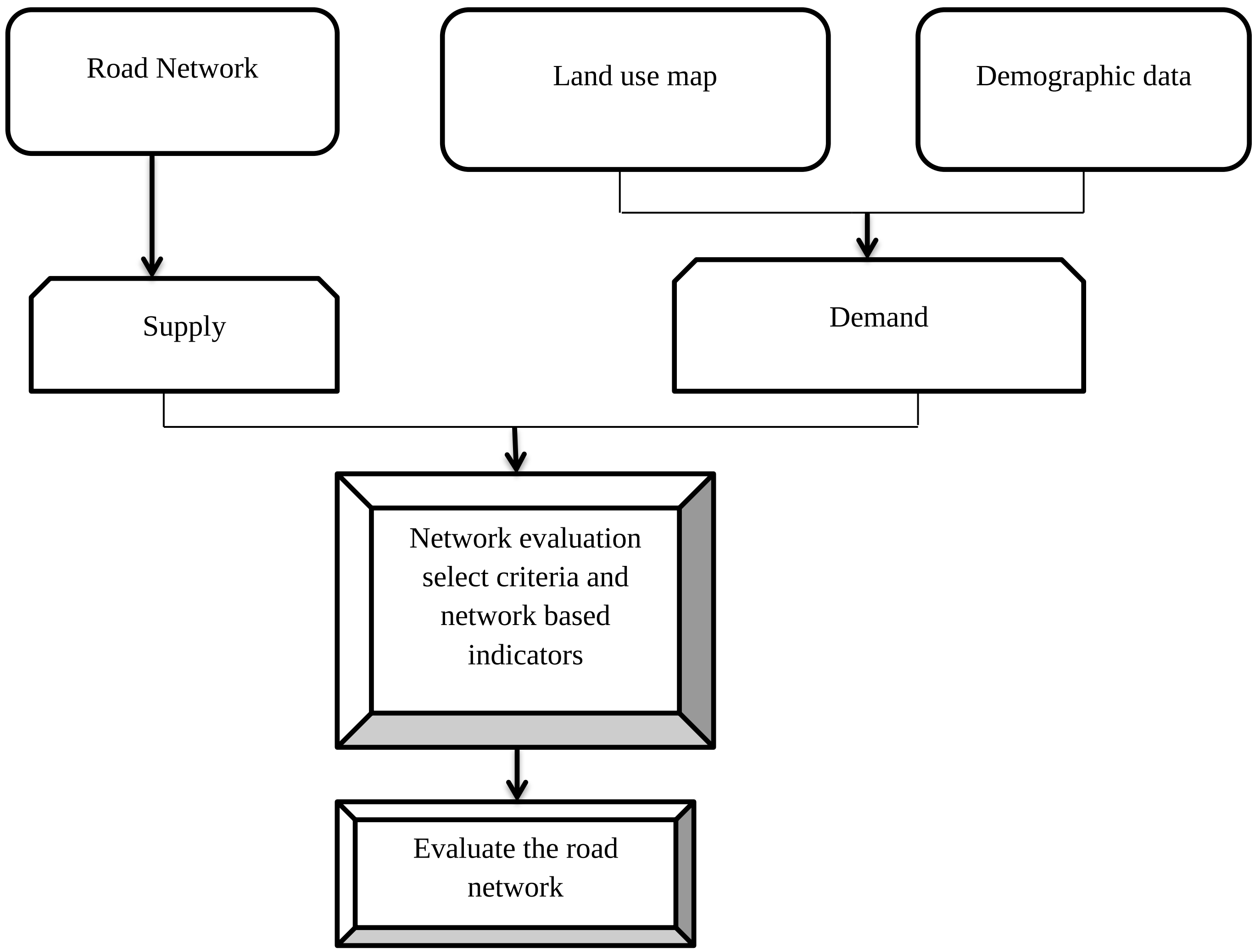


Figure 1.1 Conceptual Framework

1.8. Limitation of the Study

The main limitation of this study is the availability of required data, which is mostly at a *woreda* level while disaggregating these *woredas* data into smaller units assumptions had to be made. This may cause some uncertainty in the actual data. The other limitation is the number of vehicles used. Since Arada sub-city is the major part of Addis Ababa city, the road networks can server for larger amount of loads of vehicles which may not be registered under Arada sub-city administration.

1.9. Thesis Structure

The overall thesis is organized under six chapters: Introduction, Literature review, Description of the study area, Materials and Methods, Results and Discussion and finally Conclusion and Recommendations.

Chapter 1 - Gives brief introduction of the research, identifies research problems, defines research objectives and questions related to the objectives, and also significance of the study and the scope of the study.

Chapter 2 – Briefly review literature on road transport network structure and criteria that are used to evaluate transport network structure.

Chapter 3 – Describes the study area based on its topography, demography, land use and road transport characteristics.

Chapter 4 – Presents the research approach and data collection methods, data and software types used to reach the objectives of this research.

Chapter 5 – Give explanation about a result and discussion of the evaluation of the current road network. As well as, it discusses about the overall performance result of the road network.

Chapter 6 – Identification of inadequate and missing road networks in an area are discussed and interpreted.

Chapter 7 – Provides conclusions and recommendations made based on the result of the research.

Chapter Two
Review of Related Literature

2.1. Introduction

Key services, called infrastructure, such as transportation, communications network, and water supply are necessary for efficient economic development. Without an infrastructure that supports growth, countries will find it harder to meet the unmet basic needs. So, knowing the efficiency of these facilities and improving the service they deliver is properly leads us to better social life.

The literature review is organized in such a way that; first it briefly reviews urbanization and road transport infrastructure and the GIS technology in the road transportation environment, in the second part indicators that are used to evaluate the road network will be identified, and the third part tries to review the overall characteristics and problems of road transport in Addis Ababa city.

2.2 Urbanization and Transport Infrastructure

Based on the report of United Nations Department of Economic and Social Affairs Population Division report (2011), for the first time in history, more people live now in urban than in rural areas. In 2010, urban areas are home to 3.5 billion people, or 50.5% of the world's population will live in urban areas and by 2025 the proportion will be nearing 58%. And also by 2025, only 61% of the population of the developing countries is expected to live in urban areas.

Urbanization patterns differ markedly between the developed and developing regions. The developing regions are undergoing rapid urbanization but it has slowed down in the developed regions. Moreover, most of the expected urban growth will take place in developing countries, where the urban population is expected to double, from 2.6 billion in 2010 to 5.2 billion in 2050 (UN, 2011).

No country has ever reached middle income status without a significant population shift into cities. It is well understood that urban areas have the highest number of population in one country. This urban society needs an efficient system of basic infrastructures. The urbanization process increases substantially the demand for urban services such as transport, on whose efficiency and availability, the successful and continued existence of urban society depends.

Transportation and urbanization are inseparable. Transportation is one of the basic requirements for the proper functioning of societies as its demand is highly related to the movement of people from one place to another. Transport infrastructure plays a vital role in the development of the modern era as an integral part of the socioeconomic and political structure of the country. Thus, urban transport should involve optimal integration of the means and ways of mobility to create maximum ease and comfort maintaining the socio-economic and physical integration of the city.

Urban transport is an important factor for the location and internal structure of cities. Transportation influences the size of cities and the movement of people and commodities within and outside urban areas. According to the paper of Mekete (1999), the morphology of a city is also affected by the street patterns within a city.

Newman and Kenworthy (1999:189) remark, ‘sustainable city’ of the future is one that promotes accessibility through the provision of balanced transport modes and mixed land use in a transit and walking oriented urban villages. Based on their transportation pattern, Newman and Kenworthy (1999:190) classified cities in to four types: walking city, transit city, automobile city and sustainable city (Table 1.1). The ‘sustainable city’ is the hybrid of the first three cities with transit as a backbone, car as supplementary and higher proportion of waking and cycling.

Table 1.1 City Type and Transportation Pattern

	Traditional Walking City	**Industrial City**	**Modern Automobile City**	**Future Sustainable City**
Transportation	Walking and cycling later	Trams and trains (also walking and cycling)	Cars/almost exclusive	Walking and cycling (local) Transit (regional) in and across city, cars (supplementary)
Urban form	Walking City Compact and mixed, organic	Transit city dense mixed center medium density suburban, corridors with green wages	Auto City high rise CBD low density suburban sprawl and separated city function	Sustainable city High density and mixed urban cores linked by transits, surrounded by medium to low density areas No more sprawl

Environment Resource use and waste nature	Low Close to rural areas/dependent	Medium Some connection through green wage	High Little nature	Low medium Close to nature

Source: Newman and Kenworth (1999:190)

Transport technology plays an important role in defining urban form (Rodrigue, 2009; Newman and Kenworthy, 1999). Cities that strive to reduce auto-oriented development patterns must create transit spine along major urban corridors and direct the urban planning work to focus around the key urban nodes along the transit spine (Newman and Kenworthy, 1999).

As a general rule, the optimum urban transport system and the road network should involve the efficient integration of the means and ways of mobility to create ease and comfort. As the work of Mathewos (1999), in planning process of road network system and the overall nature of mobility and accessibility, planners should take environmental dimensions as well into consideration.

Since transportation is the conveyance of people, goods and information from one place to another or it is the relocation of people, goods and information over space." According many studies, the movement of people has various purposes, these purpose are summarized by Mekete (1997), as: journey to work (movement of persons to their places of work); commercial travel for the sake of business; journeys to school by children and students; journey for shopping and personal business; journeys for social and entertainment purposes; journeys to home; and journeys for which there is no specific purpose other than to be with or assist some other person.

Therefore, transportation has a direct impact on the day-to-day activities of people, especially in large cities where the distance to be traveled is too far to cover on foot or by bicycle within a reasonable time.

Economically, transport is an essential element of city development that in turn is a major source of national economic growth. Simply stated, poor transport inhibits growth. Furthermore, socially, transport is the means of accessibility to jobs, health education and social services essential to the welfare of the city residents. Deteriorating transport conditions affect all city residents; they impact particularly the poor through a decline in public transport service levels, increased length of the journey to work and other essential services and the negative impacts on environment, safety and security that the poor are least able to mitigate (World Bank, 2001).

Hence, today developing countries are facing great challenges in their journey towards economic development, may it be socio-economic changes, education, health, the environment. However, urban transport remains largely unaddressed (Michael and Petra, 2003). World Bank, (2008), in the report tells us, as a result of inadequate transport system, in most cities of Africa, authorities have had difficulty in meeting the service demands for the new urban residents, particularly the poor, who are most dependent on public transport. With rise in demand for transportation come congestion and other problems which might be the major cause for the inadequacy of transport infrastructure. Delays, uncertainty, and stress levels are also beginning to take their toll on both individuals and society (Abate, 2007).

Even though urban transport plays a big role in maximizing the rate of mobility of an urban population, it also has its own problems which are being observed in most cities nowadays. The urban transportation problem is actually a complex bundle of interrelated problems.

For instance, according to the report of World Bank (2002), Congestion is become common characteristics in urban road transportation system of cities in developing countries which result in high operating cost, loss of users productive time, and more fuel consumption among others. Due to numerous factors, congestion is becoming more serious problem in Addis Ababa city from time to time, such as population growth- in addition to natural growth, pull factor that immigrate people from different part of the country to the city in searching for livelihood. To sustain the city, it is clear that these added portions of the society also need transport service to attain their day to day activities. However; the city is unable to cope with the existing high transport services demand. In addition, inefficient land use planning, poor infrastructure, and absence of well traffic management are the major reasons for the problem of traffic congestion (Mulu, 2015).

When we look the supply side of transport system, there are also many important decision-making problems in transport planning. One of them is due to the nature of transport networks, projects that are planned for long-term and decisions on investment also need long-term perspective (Santosa and Joewono, 2005). Especially developing countries with limited funds need to spend the money effectively and satisfy the areas which are in need.

The rapid growth of cities has been accompanied by an increased need for urban transport. Unlike small cities or towns where it is possible to reach every point on foot or by bicycle within reasonable time, large cities require motorized transport systems to permit the movement of the people and goods between various locations. In large cities transport provides linkages between places of residence, employment and specialized urban-based activities such as industrial and commercial activities (Dimitrious, 1990).

However, no transport network can serve all travel demand perfectly, the amount by which it fails to do so be useful to study existing network and identify areas with inadequate infrastructures (Davidson, 1998). The absence of one or more network links, especially those that have high travel demand, could lead to overall poor performance of the network in terms of overall system travel time and optimization of supply (Bell, 2000; Chen et al., 2002; Smith et al., 2003 cited by Scotte et al., 2006. Network effectiveness indicators, which compare the real road network to geographically perfect network (direct link) can be used to identify these areas (Davidson, 1998).

The current performance of road network can be evaluated based on the structure of the road network (Xie and Levinson, 2007), the access and mobility it provides (Gutierrez, et al., 1998: Liu & Zhu, 2004), demand and supply equilibrium (Bell and Lida, 1997) by measuring the capacity of the network (Chen et al., 1999) and by assessing the spatial mismatch between demand and supply (Grishchenko, 2011).

2.3. Modeling Road Transport Network

Even though transport is dynamic in nature, modeling large real networks usually is done on the basis of static models as is done in this study. From these and other purpose, GIS is able to handle huge data and analyze the variety of network related problems by itself and can also be integrated with other methods for road network analysis by providing a spatial data base and mapping platforms (Kubyo, et al., 2005). For instance, Rodrigue (2009) explains, it can be integrated with graph theory to measure network efficiency.

2.4 GIS for Road Transport

There are several definitions given by different authors at different time for Geographic Information System. For instance, the Ministry of Urban Development Government of India (2015) defines Geographic Information System (GIS) as an information system that is used to input, store, retrieve, manipulate, analyze and output geographically referenced data or geospatial data, in order to support decision making for planning and management of land use, natural resources, environment, transportation, urban facilities, and other administrative records.

Chrisman (1996), in the earlier period also gives a definition on GIS as it is the organized activity by which people:

measure, aspects of geographic phenomena and processes;

represent, these measurements, usually in the form of a computer database to emphasize spatial themes, entities and relationships;

operate, upon these representations to produce more measurements and to discover new relationships by integrating different sources; and

transform, these representations to conform to other frameworks of entities and relationships.

Accordingly, the owner of GIS software ESRI (2011) also described GIS as an integrated hardware, software, and data for capturing, managing, analyzing, and displaying all forms of geographically referenced information. GIS technology allows you to view, query, and understand data in many ways. You'll see relationships, patterns, and trends in the form of GIS-based maps, reports, and charts.

Now a day GIS is applied in the transportation as the backbone for Intelligent Transportation System (ITS). ITS, utilizes advanced technologies frequently GIS, to improve both the efficiency and safety of transportation system. GIS-based ITS applications are fed with data from GPS units, video cameras, and road monitoring units.

Yohannes (2005) in his paper describes about the application of Geographic Information System (GIS) in transportation (also called GIS-T). According to his view, GIS in transport has evolved from simple graphic and map-based representation of roads and geographic features to serve specific functions in highway agencies to a more complex and powerful tool for integrating data and decision making within and among agencies. It helps to study, improve, and solve problems related to transportation system (Miller & Shaw, 2001).

Geographic database as such consist of spatial and non-spatial data with complex data structures used to analysis. According to Svante (2001), transport data are spatial in a number of aspects. All spatial data is geographically referenced to a map projection in an earth coordinate system and can be "re-projected" from one coordinate system into another, thus data from various sources can be brought together into a common database and integrated using GIS software.

Boundaries of spatial features should "register" or align properly when re-projected into the same coordinate system. GIS database has "topology," which defines the spatial relationships between features. The fundamental components of spatial data in a GIS are points, lines (arcs), and polygons.

An important geographic object of transport data is the network, which in a GIS interpretation will be arc (links) and nodes. Data for transport applications often represent flows of people and goods between points or zones (Svante, 2001).

Routes and networks are the interconnected features that are used for transportation and include highways, railways, city streets, rivers, transportation routes (transit, school buses), and utility systems. Networks are an important part of our everyday lives and analysis of these networks improves the movement of people, goods, services and the flow of resources.

Roads are main arteries of modern society's infrastructure, contributing heavily to the distribution of goods and persons. GIS provides many helpful applications for ensuring a smooth flow, by aiding design, routing, traffic control and real-time navigation (Husdal, 2000). It also provides a valuable tool in the process of planning and designing roads. It can help visualize and communicate the effects of roads on their environment. By collecting significant data for the whole network, repairs and work budgeting would be more reliable and can be calculated in advance. First creating the optimal route between locations and then using GIS to decide how and where to indicate, improve directions and movements in the road network and help avoiding congestion (Marshall, 1995).

As every planner believed that, route planning is one of the most popular applications within transportation, for obvious reasons. In GIS, route planning uses path finding algorithms, that are applied in the solution of routes in transportation networks (Rimsha, 1996). This planning is often referred to as network analysis. Roads are part of the infrastructure that make up the spinal cord of modern society, but roads can just as easily turn into bottlenecks (Husdal, 2000).

2.4.1 **Network Analysis**

When viewing the spatial patterns of lines, they occupy space and occur in particular configurations and patterns on the land. Streets and highways from lines with particular definable patterns that we recognize as being related to the networks produced by humans to move people and things between the spatially arranged points called towns (Michael, 2002). An important aspect of the spatial arrangement of lines is their ability to form networks. A network is a system of linearly interconnected features (Arc view network analyst, 2006). Networks occur in many different forms and are both naturally (river and streams) and anthropogenic (transportation networks such as, roads & rail lines, and communication networks such as, telephone lines) (Jean, 2006).

Agreeing with ESRI (2005) report on the advantage of ArcGIS® Network Analyst, ArcGIS Network Analyst tool is a powerful extension that provides network-based spatial analysis including routing, travel directions, closest facility, and service area analysis. Using a sophisticated network data model, users can easily build networks from their geographic information system (GIS) data. ArcGIS Network Analyst solves a variety of problems pertaining to spatial networks. Capabilities include finding the most efficient travel route, generating travel directions, locating the closest facility, and defining service areas based on travel time.

Moreover, Network analysis in GIS is often used to find solutions for problems occurred in transportation by using either vector or raster models to represent the real world. The vector-based model appears to be more suited to analysis of precisely defined paths such as roads and rivers. The raster-based model seems best suited for analysis of problems where paths are not pre-defined.

All of the main applications, network analysis in GIS is often related to finding solutions to transportation problems. Using GIS in the field of transportation opens up a wide range of possible applications, as diverse as the field of transportation itself.

2.4.2 **Network modeling**

In general, a network model can be defined as a line graph, which is composed of links representing linear channels of flow and nodes representing their connections (Lupien et al., 1987). In other words, a network takes the form of edges or arcs connecting pairs of nodes or vertices. Nodes can be junctions and edges can be segments of a road or a pipeline. For a network to function as a real-world model, an edge will have to be associated with a direction and with a measure of impedance, determining the resistance or travel cost along the network.

In urban transport, the network structure and flow mutually affect each other (Xie & Levinson, 2007). Therefore, while optimizing the network, a combination of spatial data with respect to demand and network indicator is required. Network indicators analyze the network structure whereas the travel demand (trip) consists of the desire to make a trip.

2.5. **Transport Network Evaluation Indicators**

Several studies mentioned that transport is the back bone of urban life. It is one factor which determines the form and socio-economic development of a city. The service which is provided by the transport system have been playing a major role in shaping countries, influencing the location of social and economic activity, the form and size of cities, and the style and pace of life by facilitating trade, permitting access to people and resources, and enabling greater economies of scale, worldwide and through history (Zuidgeest, 2005).

However, urban transportation systems are wilting under the pressure of ever growing demands on an inadequate street network. As a result of increased urbanization and population growth, urban expansions, dispersal of amenity and activity have increased the demand for and dependence on motorized transportation. Consequently, urban transportation problems like congestion, accidents, environmental degradation and urban sprawl have increased. Sustainable transport development plans are thus replacing the routine approach of building more roads to alleviate congestion with an integrated transport system (Davidson et al., 2006).

Similar to any social services, efficiency and performance measures in road transport network are necessary to monitor progress toward a result or goal. Efficiency measures compare realized and optimal levels of outputs and inputs. It is also important in terms of identifying and measuring sources of successful performance and therefore can be used in policy planning and allocation of resources. Efficiency measures can be used as means of evaluating method.

The performance measure criteria's should thus be tools to evaluate system condition, level of service, and safety provided to customers based on economic, environmental and community policy goals. They should also evaluate the day-to-day performances for strategic management, analysis of options and trade-offs. According to Kane (2005), the ultimate purpose of measuring performance is to improve transportation services for customers. Within that simple statement, two important emphases are contained: one regarding customers and the second regarding improving services.

Early work on measuring the structure of transportation networks dates back to the 1960s, when geographers and transportation researchers focused almost exclusively on topologic measures employing graph-theoretic network analysis, constrained by limited data, computational power, and modeling techniques. Since, 1960s, several networks based indicators had been developed to analyze road network based on structural efficiency, connectivity, cyclic property, etc. of the network. For example, (Garrison and Marble, 1962, 1964 and 1965) developed the first of such indicators, including:

- ✓ **Alpha index** (a measure of connectivity which evaluates the number of cycles in a graph in comparison with the maximum number of cycles),
- ✓ **Beta index** (which measures the level of connectivity in a graph and is expressed by the relationship between the number of links over the number of nodes), and
- ✓ **Gamma index** (measure of connectivity that considers the relationship between the number of observed links and the number of possible links).

In recent years, network research has shifted its focus from simple topologic and geometric properties to large-scale statistical properties of complex (and less spatially constrained or non-spatial) networks (Albert et al., 1999; Barabasi, 2002, 2003; Newman, 2003).

In transport studies, different kinds of indicators are used to measure the performance of road network. There are different categories that can be used to describe transport indicators. Some are grouped broadly as Economic, Social, Environmental and System indicators. Others are also grouped as Demand and Supply based indicators.

Demand based indicators are indicators that measure people's use of the transport network while supply based indicators are indicators that measure the performance of transport networks. Conventional transport indicators measures mostly traffic conditions. These include roadway level of service (LOS), average travel speeds, average congestion delay, system-wide travel time, unused capacity in the network and volume to capacity ratio.

In selecting a set of performance measures, it is important to recognize the distinction between input, output and outcome measures. Input measures reflect the resources that are dedicated to a program, output measures reflect the products of a program, and outcome measures look at the impact of the products on the goals of the agency (Dalton et al, 2005).

Other issues that should be considered when selecting performance measures to evaluate a road network sited by Transportation Research Board in 2000 include the following:

- **Forecastability:** is it possible to compare future alternative projects or strategies using this measure?
- **Clarity:** is it likely to be understood by transportation professionals, policy makers and the public?
- **Usefulness:** Does the measure reflect the issue or goal of concern? Is it an indicator of condition, which could be used as a trigger for action? Does it capture cause-and-effect between the agency's actions and condition?
- **Ability to diagnose problems:** Is there a connection between the measure and the actions that affect it? Is the measure too aggregated to be helpful to agencies trying to improve performance?
- **Temporal Effects:** Is the measure comparable across time?
- **Relevance:** Is the measure relevant to planning and budgeting processes? Will changes in activities and budget levels affect a change in the measure that is apparent and meaningful? Can the measure be reported with a frequency that will be helpful to decision makers?

Recently, Xie and Levinson, 2007 developed new indicators which consider flow on the road network for measuring the structure of road network. Even though these indicators consider flow, they do not consider spatial distribution of demand and the other difficulty is, indicators can differ significantly depending on many factors such as city type, regional transportation vision, or travel behavior even between modes (Derrible and Kennedy, 2011).

Evaluation of transport system should be based on defined development of the city. Evaluation criterion is set depending on the goal of development of each city. Criteria and indicators may differ significantly depending on factors such as city type, regional transportation vision, or travel behavior even between modes (Derrible and Kennedy, 2011).

In developing a performance measurement process and implementing it as a management system, the selection of the "right" performance measures is a critical step. But Litman (2007) in his work approves that, there are no standardized indicator sets for comprehensive transport planning. Institutions develop their own set of indicators based on the need and institutions abilities.

2.5.1. **Road Density/Availability**

Road density/availability is a ratio between total road lengths with area width or population size. The road density explains how dense the road network is in that area and road density per unit of population measures the availability of network distance per person. According to Jenelius, (2009) higher road density (road per area) implies a higher availability of alternative routes. If the value of road density shows increasing through years which means construction of new roads in the city giving more access to the people.

The availability of adequate transport infrastructure is one of the major factors affecting the performance of the road network. Transport infrastructures include road and vehicles. The road surface, total road area, road width and symbols have direct effect on the speed of the service, quality of ride, reliability and accident rate (Vasconcellos, 2001). This indicator is rather important in the general context of Addis Ababa city and Arada sub-city in particular, because as is the case with many developing cities, given the lack of the society from enjoying adequate levels of transport accessibility.

2.5.2. Proximity to the Road Network

One of the parameters that show the availability of transport infrastructure is its proximity to the end users. According to Vasconcellos (2001), in most developing countries, road infrastructure is very limited in extent and width. This implies travelers spent much time to gate transport infrastructure. Broadly speaking, proximity measures the distribution level of transport infrastructure in the area.

Due to lack of adequate infrastructure and transport modes, mobility of people in the developing world is low (Zuidgeest, 2005). This is a direct consequence of the inherent transport and socio-economic problems like: poverty, traffic congestion and safety.

2.5.3. **Accessibility**

In measuring the performance, quality and level of provision of urban services, the concept of accessibility has been employed in different forms as an indicator of the guiding principles equity, efficiency (Hodgart, 1978) and effectiveness (Sherif, 2005). Planners and politicians make use of accessibility indices to bolster their everyday propositions (Baradaran et al. 2001). However, there are no universally acknowledged definitions of accessibility and various indicators have been used to quantify it.

Abreha (2007) highlights that, accessibility is a much broader concept than mobility that can describe travel pattern entirely and defined it as “mobility for opportunities”. Accessibility measures include a density of opportunities enabled by transportation services. For example, a number of households within a 30 minute derive of key regional centers or number of employment opportunities within a 10 minute walk of transit stops or the ability of a facility to serve a particular user group. Availability of mode and modal choice also is treated as an accessibility measure (NCHRP, 1997).

Accessibility is the individual’s possibility to take advantage of resources with fixed location in space that requires presence. It is obvious that access to resources is restricted by the possibility of distance. It is evaluated based on the time, money, discomfort and risk (the generalized cost) required to reach opportunities.

Accessibility is one of the important characteristics of urban transport and it shows the relationship between transport and land use (Liu and Zhu, 2004). Accessibility is used as a key element in efficiency analysis of transport network and infrastructure planning (Gutierrez, et al., 1998), and to generate the travel demand on public transport (O’Sullivan, et al., 2000).

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

2.6. **Profile of Road Transport in Addis Ababa**

According to several Ethiopian history books indicates, road building in the modern sense in Ethiopia began during the period of Tewodros, which was strategic rather than economic. It was intended to conquer the local kings and bring all the country under his throne (Pankhrust, 1961). Later, the period of Menelik II had laid down the base for the development of modern means of transport in Ethiopia, especially in Addis Ababa. The first major constructed road, which linked Addis Ababa and Addis Alem, was constructed during the reign of Menelik II in 1902. The length of this road was about 27 miles. The road was intended to facilitate the transportation of wood for both construction and fuel from Addis Alem to Addis Ababa by gharries (Tesfaye, 1986).

Tesfaye (1986) in his paper states, the earliest forms of urban transport in Addis Ababa were the "*Gharries*" which came into existence by the order of Menelik II in 1900, and stayed as chief means of transportation unit until they were ordered to leave the city for the nearby towns in 1964 (Tayech, 1991).

Taxis probably started their services in Addis Ababa in the early 1920s (Gezachew, 1996), and these motorized taxis were called "*Kurukur*" (name derived from the sound of the vehicle itself) (Tesfaye, 1986).

The city of Addis Ababa as a capital city of Ethiopia and a host for many national and international organizations (like the OAU, ECA and many Non-Governmental Organizations (NGO's) and the like) is experiencing an ever-increasing growth of population.

The rising number of urban population coupled with increased usage of low capacity vehicles account for the congested roads and streets of Addis Ababa creating mobility problems to the extent that paralyses the whole traffic on the road. The heavy reliance of urban transport on minibuses and the rise of private automobiles increase the rate of road accidents in the city. Safety is of less priority and concern especially for the informal transport sector (minibuses) that aggressively compete among each other and the city buses in the quest of profit making (Fantahun, 2012). Traffic accident is growing in the city at the rate of 12.5% each year (Meron, 2007) and pedestrians are the most common victims.

The city of Addis Ababa has been expanding spontaneously and in unplanned fashion. Addis Ababa has experienced and undergone a massive spatial change in the last 50 years. The footprint of Addis Ababa tripled itself from 80km^2 in 1960s to 250km^2 in 1985 (Demerew, 2009) and doubled to 540km^2 in 2010 (Woldu, 2010). The spatial doubling of the city in the last 25 years (1985-2010) is due to massive commercial and real estate developments which are taking place at different corners of the city. The city is still stretching further to the East and West to absorb the ever increasing housing demand and to the South for industrial activities (Fantahun, 2012).

Addis Ababa is the economic center of Ethiopia where most financial and commercial institutions and about 85 percent of manufacturing industries are located. As the Federal Democratic Republic of Ethiopia, National Transport Master Plan Study (2007) proves, about 80 percent of the national vehicle fleet is registered in Addis Ababa. The expansion of the city, increasing population size coupled with the economic growth has required respective transport service supply for the increasing mobility needs of the People.

In line of this, Tilahun (2014) in his journal identifies that, 2.2 million people in Addis Ababa are using public transport of which 3.6 million trips happen in the city on daily basis. Currently the modalities of public transport mobility in Addis Ababa are limited to the road transport that mainly comprises 10, 000 white and blue Minibus taxis that can seat at most 12 people, about 460 Higer midi-buses that seat 22 to 27 people, 487 *Anbessa* city buses (which carry 30 people seated and 70 standing), and 25 Alliance buses (have 40 seats and 60 hangers). In addition, the 366 supplementary vehicles, and about 6500 Saloon taxis that seat 4 people. Animal carts also used at the peripheral areas. These providers are hardly able to cope with public's demand for transportation. As a result, residents of Addis Ababa had to face great inconveniences, as well as additional costs to the daily trips to their destinations.

According to the Urban Transport Study, the road network is limited, capacity is low and the prevailing level of service is low. The study found that, the right way of most roads in Addis Ababa ranges between 15 and 60 meters, but about 70 % of the network is with a right of way of up to 30 meters. Only 24 percent of the road length has divided carriageway. Despite high pedestrian traffic, facilities for pedestrians are not adequate and 63 percent of the road length has no sidewalks. Facilities such as drainage, street light, and traffic signs and pavement markings are inadequate on the existing road network.

For the year 2014, *Addis Negarit Gazeta* reports that, Addis Ababa's budget amounts to about 22,193,121,063 Ethiopian birr of which 4,149,334,541 was recurrent expenditure budget and 16,629,848,079 was capital expenditure budget. The share of the transport authority was about 1,069,414,069 Ethiopian birr. Many of the traffic congestions and road safety problems in Addis Ababa may be attributed to inefficient use of road networks, weak enforcement capability and poor design of roads.

2.6.1 **Mobility Characteristics in Addis Ababa**

By 2015, the Sub Sahara African region has been expected to have five cities larger than 5 million inhabitants: Abidjan, Addis Ababa, Lagos, Luanda and Kinshasa. Addis Ababa, the capital city of Ethiopia, has numerous similarities with other Sub-Saharan cities. The mobility problems in Addis Ababa are emergent, since the recent state of road traffic management is considerably poor (Kessides, 2007).

Addis Ababa has a relatively high population density and a high urban population growth, both facts combined with a low GDP per capita put high stress on the quality of mobility services. This stress is reflected by the very low supply of infrastructure. The current road density measured in kilometer of road per 1000 habitant in Addis Ababa is significantly lower than the average of developing countries. Moreover, it is only one third of the African cities average. The public transport plays a dominant role in urban mobility in Ethiopia. The current average number of cars per 1000 habitants in whole Ethiopia is only one (The World Bank, 2011). In Addis Ababa, the car ownership has not gone up corresponding to the population growth. However, the number of trips per public transport is directly related to the urbanization. Meron (2007) in her paper indicates that, the average walking trip length in Addis Ababa is 1.5km and the average car trips are 3.3km. As a result, Addis Ababa is *a walking city*, partly because it is the only affordable means of transport and partly because the severe shortage of transport leaves people with no practical option but to walk.

Currently, in Addis Ababa thousands of people wait for hours at public transportation stops while public transportation vehicles are unable to get to them because they are stuck in queues on the roads. In addition, walkways are often non-existent or in very poor condition. In places where there are walkways, pedestrians are often forced to walk on the streets due to market and trading activities occurring on the walk ways. Traffic delays are ubiquitous and rides by any vehicle are uncomfortable and unsafe. Furthermore, there is little or no classification of roads in general and inadequate distributor and access roads in particular.

2.6.2 **Modes of Trips in Addis Ababa**

Urban transport modes are broadly classified in to two categories, motorized and non – motorized modes of transport. Walking, cycling and animal drawn/packed fall under the category of non-motorized mode of transport. Motorized urban transport modes include those ranging from individualized motorcycle and vehicles to mass transport systems like buses, trams, trains, metros and ferryboats. The choice of particular mode of transport depends on degree of accessibility of the urban area and availability and quality of the respective modes (Fantahun, 2012).

According to a joint research done by International Association of Public Transport (UITP) and African Association of Public Transport (UATP) Non-motorized transport, predominantly walking and the collective informal sector(minibuses ,taxis) are the dominant means of transport that account for 35 to 40 % of urban trips across the whole continent of Africa(UITP and UATP, 2010).

The dispersion of various urban activities at different locations generates urban trips. The purpose of travel from point of origin to point of destination encompasses broad range of life activities. These include work trips, school, shopping, recreational and social activities and trips to social services (medical visits and worship center). Work and education are the dominant purposes of urban trips in Addis Ababa (Meron, 2007; Abreha, 2007).

Walking is the predominant mode of transport that accounts for about 60% of urban trips in the city of Addis Ababa (Meron, 2007; Abreha, 2007). However, according to the transport studies by UITP and UATP (2010), walking takes a modal share of only 44% and is followed by minibus (34%). Unlike other cities of Ethiopia, the share of cycling is insignificant in Addis Ababa and is used only in the city center where people bike for recreation in reserved and open urban spaces like Meskel Square and Stadium (Fantahun, 2012). Public transport network of the city is at its lowest level with the city bus taking the lowest market share in the provisions of the urban transport service. Despite the high tax on imported vehicles, the car market has picked up its momentum in recent years and its modal share is raised to 9% (Fantahun, 2012).

Table 2. Addis Ababa City Public Transport Profile

City profile and public Transport		
Inhabitants	City	4,000,000(UN-2007/8)
	Metropolitan area	4,567,857
Area	City Metropolitan area	540 km^2
Density		5750 inh/km^2
Basic Urban structure	Street-liners and in-fills	
Typical Built Environment	Single-store family house	
Public Transport (PT)	City buses	535 (350 operating) on 93 routes
	Minibuses	12,000
	Mid-buses	495
Total PT*trips per year		800,750,000
PT* trips/person/year		215
Car/1,000 inhabitants		40

Source: UITP and UATP (2010), UN-HABITAT (2007)

Urban transport case studies in Addis Ababa show the incompatibility of the traffic composition and the proportion of people transported by respective vehicle types. Cars transport only 15% of people, while accounting for 60% of vehicle traffic. Minibuses take up 23% of all vehicle trips to carry 39% of people, whereas buses carried 45% of people with only 4.5% of the traffic flow (IBIS Transport Consultants Ltd, 2005). This shows that there is an inefficient use of road space by low capacity vehicles. 100 people are carried either by 50 cars, 10 minibuses or just by a single bus.

2.7 Problems of Road Transport in Addis Ababa

The rate of traffic accidents and pollution in Addis Ababa goes up together with the increase of motor vehicles and population size. The rise in automobile ownership together with the poor condition of the roads has resulted in the high level of traffic safety and congestion problems (Mulu, 2015). Accordingly, Addis Ababa traffic Police reports shows; more than 12, 000,000 Ethiopian birr is being lost every year because of traffic accidents. Thus the rise in automobile ownership together with the poor conditions of the road has resulted in high level of traffic safety and congestion problems. In general, several studies approve that, the major road transport problems in Addis Ababa include among others:

- Shortage and low quality of transport services and facilities
- Poor quality of roads, pedestrian walkways
- Low affordability level by most urban citizens
- High rate of congestion at peak hours and hence high rate of traffic accidents

However, no transportation network can serve all travel demand perfectly, the amount by which it fails to do so be useful to study existing road network and identify areas with inadequate transport infrastructure. Hence, this study tries to assess the performance of the existing road network structure of Arada sub-city.

Therefore, evaluating the current road network with respect to the current demand will help decision makers to understand how much the network satisfies the demand and identify which areas need more attention for future development plan.

Chapter Three
Description of Study Area

3.1. Introduction

Addis Ababa is geographically located at $9^0$02' North and $38^0$42 East. As a capital city of the Federal Democratic Republic of Ethiopia, it is located almost at the center of the country. The northern borderline runs along the Entoto maintains while its southern borderline runs across a plain land extending towards the Akaki River on to the Debre Zeit road. The eastern limits extend along the road to Debre Berhan and Dessie, while the western boundary runs along Mount Wechecha (EMA, 1988).

Addis Ababa lies at a maximum altitude of 2900 meters above sea level. Because of having the highest altitudinal position, Addis Ababa ranks the fourth highest capital city in the world and takes the first rank from African cities. There is a great variation of height within the city, so that much of it is built on the slope (Tesfaye, 1986).

The city has an expanded area of 540 sq. km and divided into 10 sub-cities and 100 *woreda* for administrative purpose. The city has experienced spatial spread mostly towards the southern, eastern and south western parts. The spatial spread is mainly guided by topography and road network development. The topography of Addis Ababa is not favorable from the transport network development point of view (Tesfaye, 1986). The city's landscape is very sloppy and mostly exposed to flooding.

The current population estimate of the city ranges from 3.5 to 5 million inhabitants, depending on who the source is. As per the UN-HABITANT 2007 report, the city had an estimated population of 4 million in 2007. According to Central Statistics Agency of Ethiopia (CSA), the medium population size of the city was 2.7 million in 2007. However, the CSA’s (2005) estimate for the same year was 3.1million (Abreha, 2007 and Johanson, 2008).The medium population estimate and projection of the agency for years 2010 and 2015 are 3.75 and 4.6 million respectively (Meron, 2007). More than 50% of the city’s residents live under poverty line and 80% of the built up urban area is categorized as slum according to UN criteria (UN-HABITAT, 2008).

Addis Ababa is the 4th largest diplomatic center in the world as it is a headquarter of UN Economic Commission for Africa (UNECA), African Union (AU) and a home of more than 90 embassies and various international organizations (UN -HABITAT, 2007). The city is often referred as the "political capital of Africa" due to its historical, diplomatic and political significance for the continent. Addis Ababa is the hub of social, political, cultural and economic activities of the country and is one of the fastest growing cities in the world. It is a "primate city" in the full sense of the term" (UN -HABITAT, 2007 as cited by Johnson, 2008).

Addis Ababa City Administration is divided into ten sub-cities: namely, Addis Ketema, Akaki-Kaliti, Arada, Bole, Gulelle, Kirkos, Kolfie-Keraniyo, Lideta, Nefas Silk-Lafto and Yeka Sub-city. The study area is in the Arada sub-city (figure 3.1).

3.2 The Geographic Location of Arada Sub-City

Arada sub-city is geographically located at $9^0$2'6''N $38^0$45'28''E / 9.036000^0N 38.7523. Arada is one of the 10 sub-cities of Addis Ababa, the capital city of Ethiopia. It covers an area of 950 hectares. The sub-city is roughly situated in the northern part of Addis Ababa, nearby the center, bounded from the South by Kirkos and Lideta, from West by Addis Ketema, from East by Yeka and from North by Gulele sub-cities (figure 3.1). It is divided into 10 *woreda's*, 31 *sub-woredas*, 100 *sefers*, and 316 blocks.

Arada is known as the center of the old and the new generation artistic, social and urban life style. The district is one of the oldest commercial and historical centers of Addis Ababa and also one of the most important parts of the city. Because the Palace, the Parliament, Addis Ababa City Administration Office, Ministry of Education, Ministry of Finance and Economic Development, National Museum, Yekatit 12 and Ras Desta Hospital, Taitu Hotel, Hager Fiker Theater, Addis Ababa University 4kilo, 5kilo and 6kilo campuses all are found within the sub city. The oldest known places in Arada sub city are Piassa, St. George's Cathedral, the great Menelik II Square, *Doro Manekia*, *Eribekentu*, *Talian sefer*, *Dejach Wube sefer*, *Sumale tera*, *Ginfile*, Datson, *Kebena*, 4kilo, 5kilo, 6kilo, Ras Mekonin (Arada news, 2014).

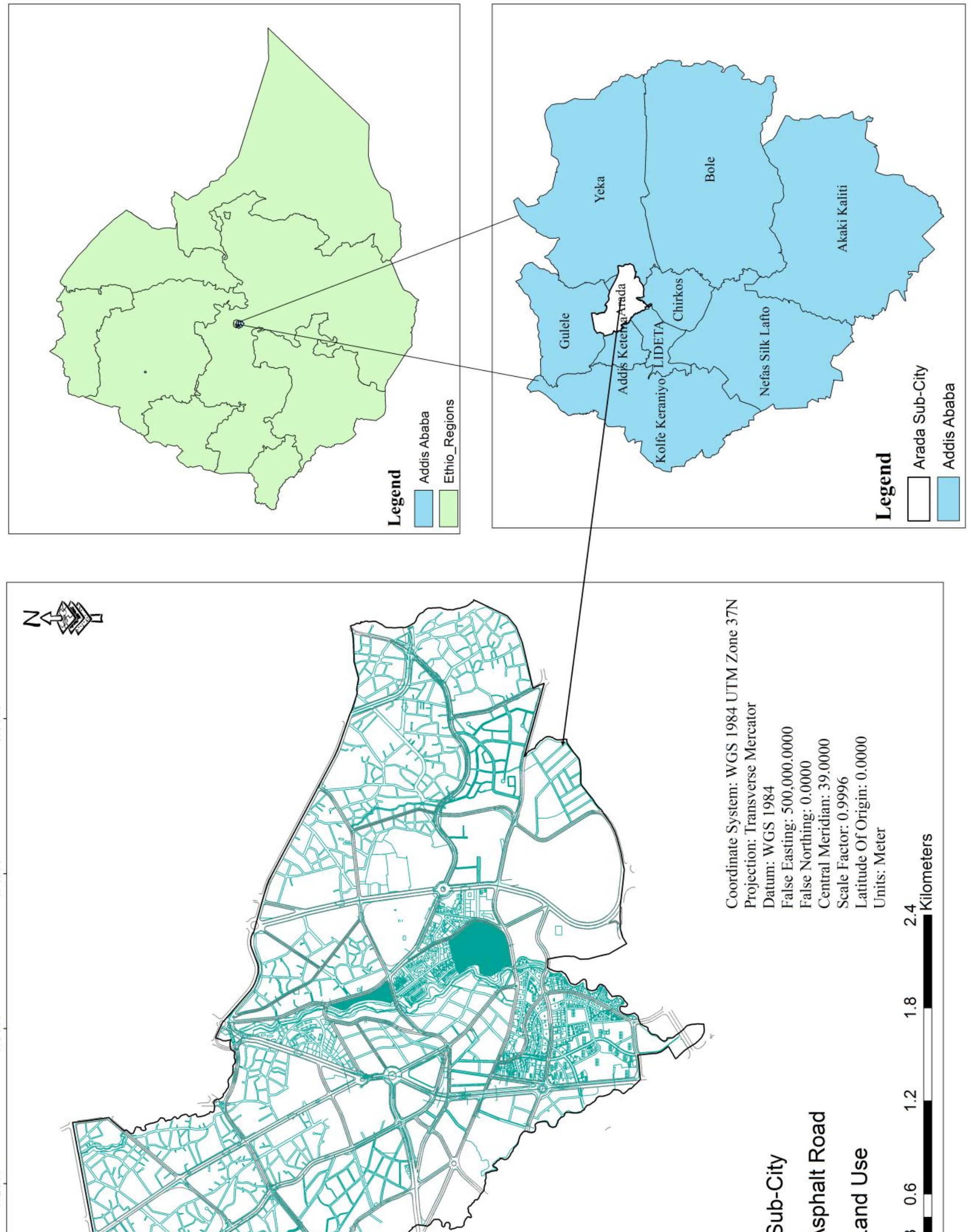


Figure 3.1 Map of the Study Area (Arada sub-city)

Source: Adopted from Arada sub-city Land Administration

The sub-city's altitude ranges from 2343 to 2545 meters above sea level. The difference between the lowest and the highest point is 202 meter. The highly elevated land exists in the north while relatively lower elevation exists in the south. The highest peak of the sub-city exists at *Semen Mazgaja* that indicated high altitude value of 2545 meters. Generally speaking most of the Arada sub-city land is gently sloppy with a gradient ranging between 26.32% and 37.96% respectively.

3.3 Population

According to the 2007 census result, the total population of Arada sub-city was 211,501 out of the entire city population of 2.7 million. From the total population, 99,165 were males while 112,336 were females. The largest number of population lives in *woreda* 07 with population of 28,157 which is 13.31% comparing with the other *woredas* of the sub-city. And relatively few people live in *woreda* 10 with population of 13,521 which is 6.39% of the sub-city population.

Table3.1 Population distribution of Arada sub city (2007)

Area	Male	Female	Both sex	Area/Ha	Pop Density/Ha
ARADA-SUB CITY	**99,165**	**112,336**	**211,501**	**949.86**	**222.67**
Woreda 01	10,289	11,147	21,436	150.04	142.87
Woreda 02	10,709	11,301	22,010	58.02	379.35
Woreda 03	6,373	7,296	13,669	65.59	208.40
Woreda 04	11,524	13,779	25,305	110.84	228.30
Woreda 05	11,571	13,779	24,725	95.15	259.85
Woreda 06	9,238	10,623	19,861	90.59	219.24
Woreda 07	12,852	15,305	28,157	131.98	213.34
Woreda 08	11,601	13,026	24,627	107.97	228.10
Woreda 09	8,335	9,059	17,394	99.66	174.53
Woreda 10	6,337	7,184	13,521	39.54	341.96

Source: CSA 2007

Depending on the population density, land area coverage can be generally classified in terms of higher density and lower density area.

According to Addis Ababa City Administration Integrated Land Information Center report, the land area covered by Arada sub-city is 949.86 hectares and this constitutes 1.82% of the total land area of the city which puts the sub-city in 8th place in terms of areal coverage. Among the 10 *woredas* in Arada sub-city, *woreda* 01 with 150 hectares takes the largest areal share and *woreda* 10 with 39 hectares takes the least areal share.

3.4. Land Use

The land use distribution of the study area is indicated in table 3.2

Table 3. 2 Land use type and Areal Coverage of Arada sub-city

Land Use Type	Area Covered
Residential	342.77
Open space	33.88
Administration	74.98
Plantation	0.68
River and riverine	14.34
Road Network	0.21
Manufacturing and Storage	16.97
Municipal Services	15.42
Commercial	48.00
Special use	0.38
Education	62.45
Cultural and Social welfare	6.50
Mixed Residential	43.40
Infrastructure and Utility	0.18
Health	8.19
Under Construction	12.67
Recreation	2.03
Transport terminal	0.49
Religious Institution	20.09
Mixed forest	1.71

Source: Addis Ababa City Administration, 2014

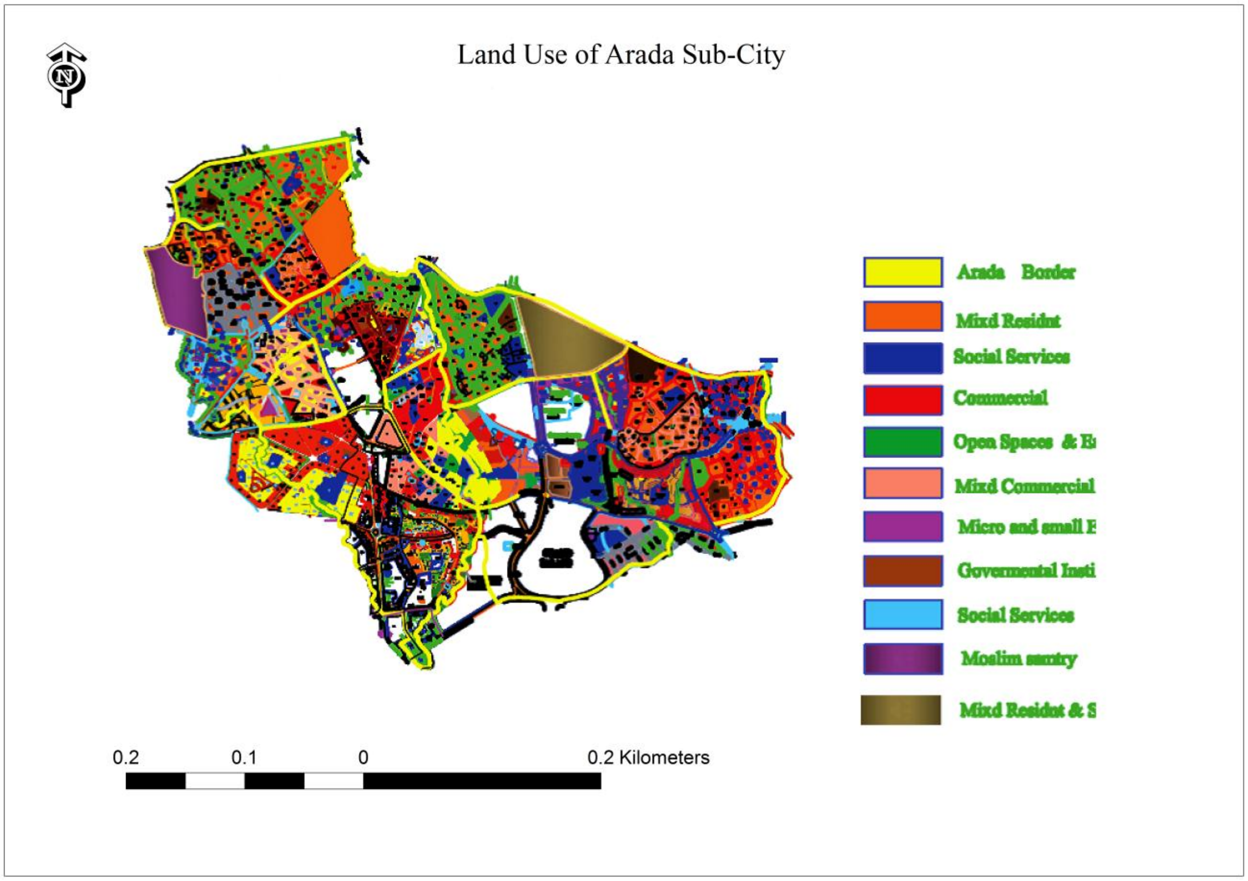


Figure 3.2 Land use Map of Arada sub-city

Source: Arada Sub-City Land Management Office, 2016

The land use distribution as identified in table 3.2 and figure 3.2 shows that most of the land use characteristics of Arada sub-city is mixed with residential, commercial, educational and administration areas.

3.5 Transport and Existing Road Network

The main components of Addis Ababa transport system in general and Arada sub-city in particular are the road network, city buses, minibuses, taxis, small number of private vehicles and large pedestrian. The road network provides the means for travel through the city. Recently, the light railways supplement the intra-city transportation service.

The road network of Addis Ababa City has a radial form which is shaped by five regional roads radiating out of Central Business District. There is no well-defined hierarchical system. However, SMEC International (during the development of a pavement management system) divided the road network into the following four categories. The distribution of road network length provided by AACRA is given in table 3.3 and 3.4.

Arterial Roads: As per the Master plan these roads have varying width ranging from 30m to 60m. These roads provide continuous traffic flow, including intra-urban and inter-urban public transport lines. The ring road is included in this category.

Sub-Arterial Roads: have a road width ranging from 20m to 25m. These roads include a lower level of intra-urban mobility than the main arterial streets and connect adjoining areas.

Collector Roads: The proposed width of these road categories is 15m and includes minor public streets used to collect and distribute the traffic to and from local streets and provides access to arterials streets.

Local Roads: The proposed width of these types of roads is 10m. Streets that provide access to residential, business areas are included in this category.

Table 3.3 shows the trend of the different hierarchical roads as described and given by Addis Ababa City Road Authority.

Table 3.3 Addis Ababa City Road Hierarchy

Road Hierarchy	Total Length(km)	Length in 7m Width	No of Bridges	Pavement Status
Arterial Roads	364	1130	171	Very Good
Sub-Arterial Roads	152	425	80	Very Good
Collector Roads	225	342	34	Good
Local Roads	267	267	430	Good
Total	**1008**	**2164**	**715**	

Source: AACRA, 2015

The following table shows the road type classification in Addis Ababa.

Table 3.4 Addis Ababa City Road Type Classification

Road Type	**Master Plan Road Length(km)**	**Local Road Length(km)**
Asphalt	466.66	474.31
Cobble	13.15	514.08
Gravel	71.42	1,018.16
Care Stone	1.32	258.35
Earth work	39.36	291.35
Total	**591.91**	**2556.25**
Under Construction	101.36	-
Planned Asphalt	253.47	-

Source: AACRA, 2015

As indicated on the table above, the total length of roads in the city has increased to 591.91 km i0f which 466.66 km was asphalt road and the rest 13.15, 71.42, 1.32, 39.36 km was cobble, gravel, care stone and earth work road respectively.

In Arada sub-city more than 25km of the existing road is covered by asphalt/concrete (table 3.5). However, most of the Asphalt roads need maintenance. Currently, the size and the type of road may change a lot, because of the construction of small scale train rail way from *Dejach Wubie* to *Merkato.*

Table 3.5 Arada Sub-City Road Classification by Road Type

Road Type	**Equivalent Road Length(km)**	**%**	**Road Area(km)**	**%**
Asphalt	26.29	34.16	184.04	34.16
Gravel	2.69	3.49	18.85	3.49
Care Stone	27.95	36.21	195.62	36.21
Coble Stone	2.86	3.71	19.99	3.71
Earth work	17.17	22.31	120.17	22.31
Total	**76.96**	**100**	**538.67**	**100**

Source: AACRA, 2015

The predominant public transportation in the city in general and in Arada sub-city in particular includes: Anbessa City Bus, which serves the majority of the public transport users in the city, blue and white Mini-Bus, Higer Midi-Bus and Star Alliance Bus. There is also a small proportion of private car user. According to studies done before, more than one third of the total population Addis Ababa City is a pedestrian. This is not only because of the society cannot afford to use the existing facilities, but also because of uncontrolled and rapid horizontal expansion and poor road network of the city (narrowness, limited network extent, almost no pedestrian walk way, etc.). Those are the major contributor for the low level of transport service in the city and in the study area as well.

Table 3.6 Registered Vehicles in Arada sub-city

Code	Number	%
01 AA	2872	7.39
02 AA	14620	37.63
03 AA	6175	15.89
03 ET	8484	21.84
03 ET Long-Vehicle	3087	7.95
04 AA	983	2.53
04 ET	2012	5.17
05	313	0.81
Police motor	305	0.78
Total	**38851**	**100**

Source: Arada sub-city transport office, 2014

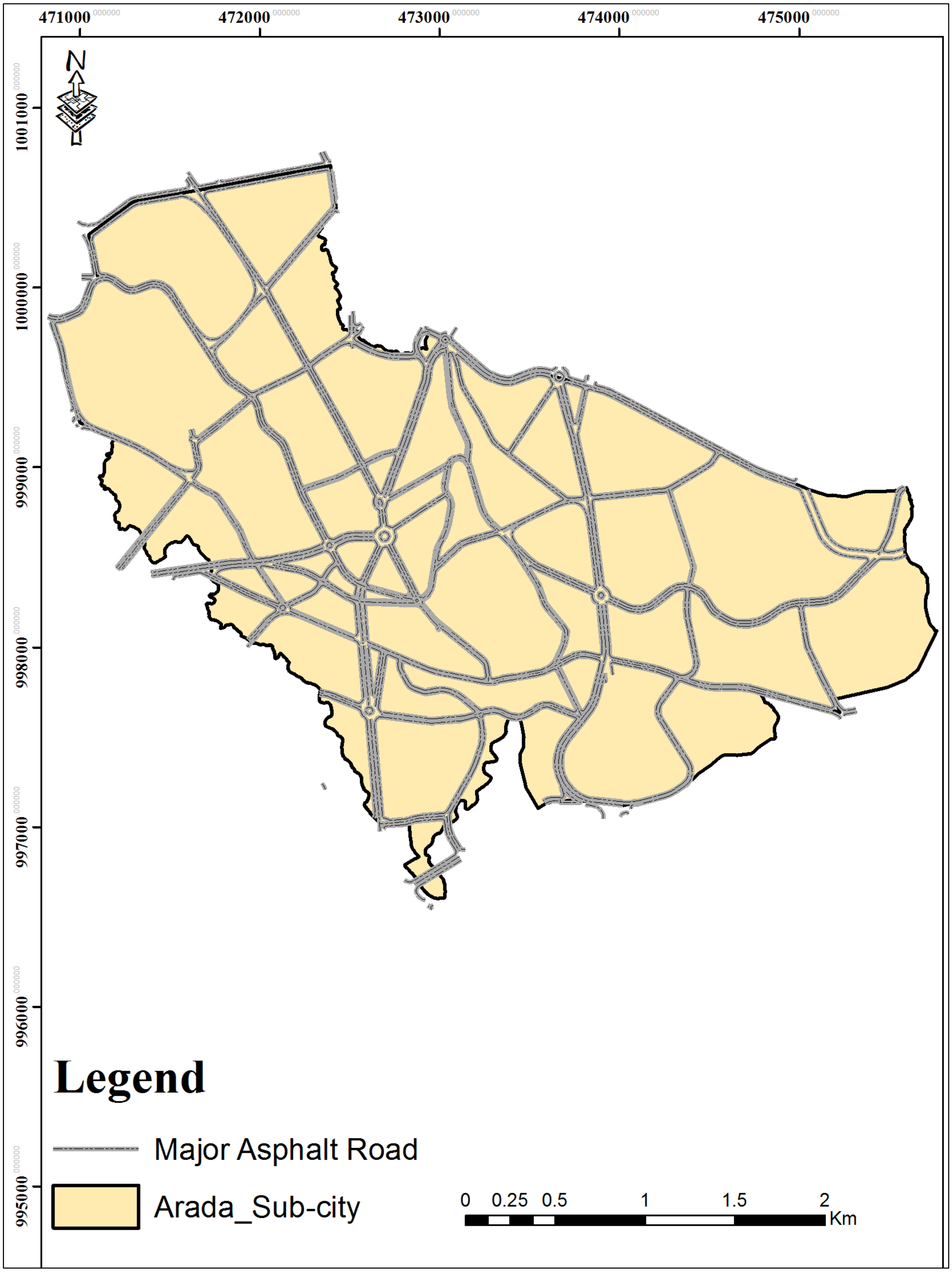


Figure 3.3 Map of Major Asphalt Road Network in Arada Sub-City

Source: Adopted from AACRA

Chapter Four
Methodology

Based on the research objectives and questions stated in the introduction chapter, the method of the research is discussed in this chapter. The methods of data collection and data preparation are also discussed. Generally, the research is focused on the data and methods required to analyze and evaluate the nature (the fair distribution, accessibility and effectiveness) of the existing road transport network structure of the study area using GIS techniques.

4.1. Data Sources

Both primary and secondary sources were explored to collect the required data. The type and the availability of data are evaluated before commencement of the field work.

Primary Data: - The primary data was collected by visiting relevant offices like Addis Ababa City Road Authority (AACRA) and different offices under Arada Sub-city Administration. Interviews with Arada sub-city administration, Addis Ababa City Road Authority, and experts were conducted for capturing thier experience on the current practice of road network design.

Secondary Data: - The secondary data was collected from the city and sub-city administration, Arada sub-city Police Department, Arada sub-city Transport Office, AACRA, as well as from published and unpublished materials. Moreover, different books, journals and reports were also referred.

Table 4.1 shows types and source of data those were contributed toward the construction of this study.

Table 4.1 Type and Source of data

Data	Source	Format	Remark
Demographic data	Arada Sub-City Administration	Excel	Aggregated at *Woreda* level
Land use data	Arada sub-city land management office	PDF	The data contains land use classification of Addis Ababa city and Arada sub-city
Current road network	AACRA	Auto CAD	This data is obtained from AACRA in AutoCAD format and converted to Shape file, This data contains the existing road network of the study area with hierarch, length width and conditions
Traffic data	Arada sub-city police Department	Hard copy	This data is obtained from Police Department of Arada sub-city in paper format and converted to Excel file
Transport data	Addis Ababa City Road Transport office and Arada Sub-city Road Transport Office	Hard copy	The data contains information about vehicle, It is obtained in paper format and converted into Excel file

4.2. Data Collection Techniques

Semi-structured interview was employed as the major means of data gathering tools. Interview questions were prepared for the collection of primary data with the assumption that the authorities and officials might not have to give the required information because of many reasons. The questions were organized for both AACRA and Arada sub-city Administration. So it was made as short as possible to obtain the required information.

Interviews were conducted with AACRA officials to get more information about road transport network and the performance of the road network structure of the entire city and Arada sub-city in particular. Interviews were also conducted with Arada sub-city Administration and Arada sub-city transport office. Finally, field survey to assess the condition and accessibility of the existing network structure within the boundary of the sub-city was undertaken by the researcher using checklist and physical maps. During the observation, the researcher visited the main roads of the sub-city to see how the dwellers of the area make travel, and to assess their satisfaction with the transport service.

4.3. Data Preparation

After gathering all the necessary data, the next step was preparing the data for analysis. The major tasks were converting data format, joining the alpha-numeric data collected on demography with map data, converting the questionnaire survey into statistical environment, defining projection and coordinate transformation.

Most maps were collected in AutoCAD format and for analysis in ArcGIS these data were converted into ESRI shape file. The method used is export the data in ArcGIS 10.1. This is done by unifying data, changing data formats, building geo-database, updating the demographic data, joining with map and adding missing attributes.

The available data in AutoCAD format was also converted into ESRI shape files. Before exporting these files to ArcGIS, the data was cleaned and topological rules were defined in AutoCAD based on ArcGIS Topological rules. All shape files were transformed to Ethiopian coordinate system (WGS1987 zone 37 N).

4.4 Building the Network Dataset

Using the collected data, the real network is built in ArcGIS using the following procedure. The road network data that is found in AutoCAD format is defined the network topology and cleaning the data. The next step is to convert the data format from AutoCAD to Shape file. At the heart of any GIS system there is always a well-developed and organized database.

Following data format conversion, Geodatabase was defined in ArcGIS. Topological rules are defined to check the network data once again. Topology is created for the tracked roads of the sub-city in order to have a smooth road network analysis. After validating and correcting the topological errors for the road network layer, the data is exported to a new feature class. The *Woreda* Centers are added to the map as a layer. The road network is edited to connect to the nearest road. Finally, using this road network, network dataset is built using distance as a measure.

The idea of spatial mismatch was first developed in U.S.A in the late 1960s' to assess the availability of jobs in black neighborhood. Since then it has been used by different authors to detect the availability of jobs for the low income group within their reach depending on the cost of travel (Joseph, 2011 and S. McLafferty, 2001). This concept is used to analyze the spatial difference that exists between demand and supply. OD-Cost Matrix defines the least cost paths along the road network from point of origin to point of destination.

The OD cost matrix is computed using ArcGIS Network Analyst Cost-OD-Matrix. Road junctions are used as origin and destination points. The lines have important attributes including origin, destination and total distance on the existing network. The lines represent the Euclidean distance between areas within the sub-city. To add the shape and length of the desire lines, these lines were exported to shape file. The attribute table was then exported to excel file for further analysis and described in table 4.2.

Table 4.2 Attribute Table of desire lines

Table

spatial mismatch_Lines

ObjectID	Shape	Name	OriginID	DestinationID	DestinationRank	Total_Length
1	Polyline Z	Location 1 - Location 1	1	1	1	0
2	Polyline Z	Location 1 - Location 13	1	13	2	94.380917
3	Polyline Z	Location 1 - Location 23	1	23	3	157.991822
4	Polyline Z	Location 1 - Location 36	1	36	4	242.344134
5	Polyline Z	Location 1 - Location 42	1	42	5	334.864616
6	Polyline Z	Location 1 - Location 57	1	57	6	493.857821
7	Polyline Z	Location 1 - Location 68	1	68	7	559.271444
8	Polyline Z	Location 1 - Location 75	1	75	8	640.672167
9	Polyline Z	Location 1 - Location 81	1	81	9	698.200018
10	Polyline Z	Location 1 - Location 88	1	88	10	848.104695
11	Polyline Z	Location 1 - Location 162	1	162	11	1398.811145
12	Polyline Z	Location 1 - Location 168	1	168	12	1444.55561
13	Polyline Z	Location 1 - Location 190	1	190	13	1571.432617
14	Polyline Z	Location 1 - Location 211	1	211	14	1660.359865
15	Polyline Z	Location 1 - Location 216	1	216	15	1723.107455
16	Polyline Z	Location 1 - Location 229	1	229	16	1795.129374
17	Polyline Z	Location 1 - Location 252	1	252	17	1878.291126
18	Polyline Z	Location 1 - Location 265	1	265	18	1941.571845
19	Polyline Z	Location 1 - Location 282	1	282	19	2188.131932
20	Polyline Z	Location 1 - Location 288	1	288	20	2222.176837
21	Polyline Z	Location 1 - Location 342	1	342	21	2500.15864
22	Polyline Z	Location 2 - Location 2	2	2	1	0
23	Polyline Z	Location 2 - Location 11	2	11	2	81.504176
24	Polyline Z	Location 2 - Location 22	2	22	3	145.115081
25	Polyline Z	Location 2 - Location 32	2	32	4	216.806417
26	Polyline Z	Location 2 - Location 38	2	38	5	309.326898

0 (0 out of 22105 Selected)

spatial mismatch_Lines

Map of Real Road Network and Referenced Network

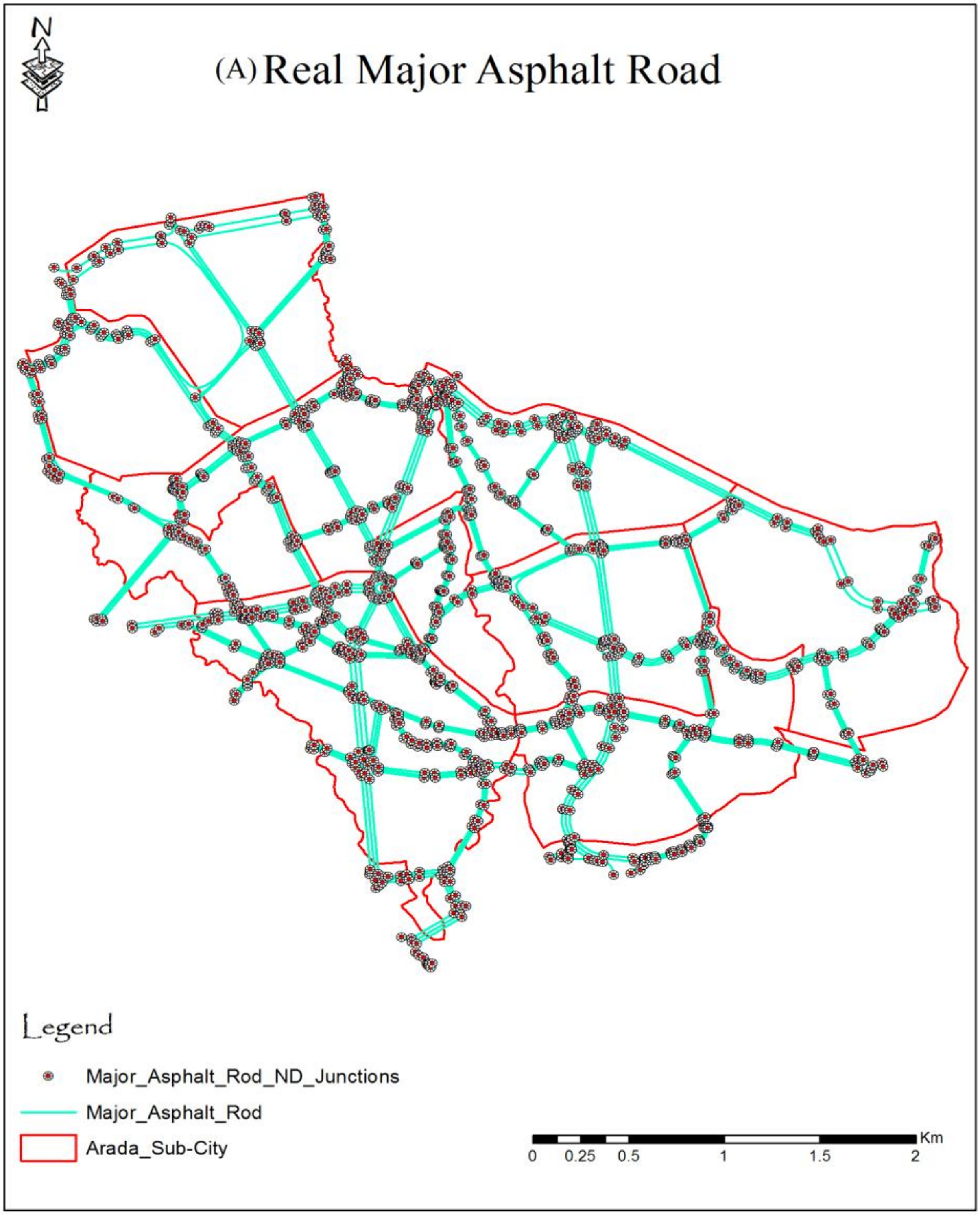


Figure 4.1(A) Real Road Network

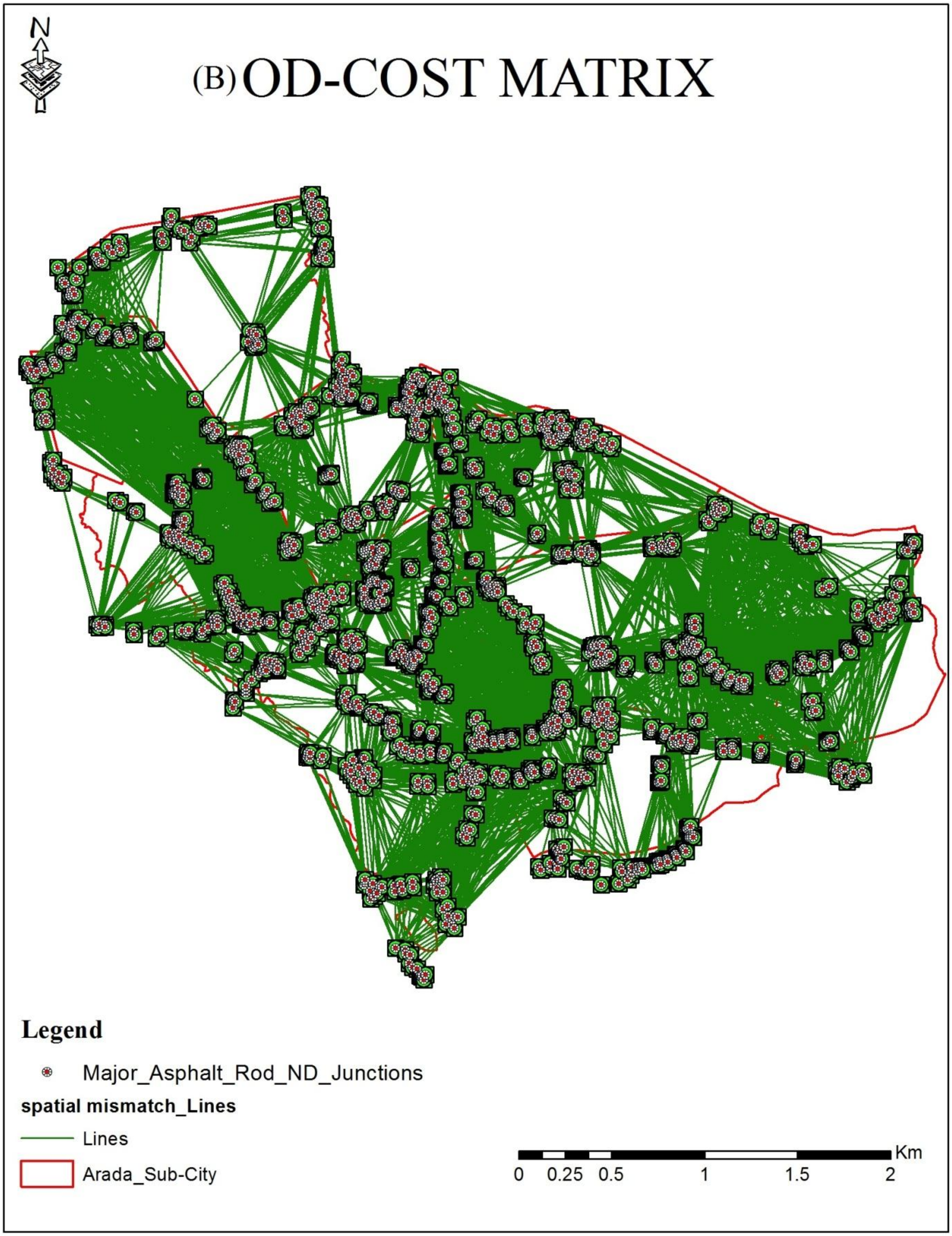


Figure 4.1(B) OD-COST Matrix

4.5 Road Network Evaluation Indicators

As mentioned in the literature review, in this study the current road network structure of Arada sub-city was investigated by using network performance indicators. The selected road network evaluation indicators are presented below.

4.5.1 Road Density/Availability

Road density is a ratio between total road lengths with area width or total population. Road density has a unit km/km^2. The road density explains how dense the road network is in the study area and we have to compare the result with some standards. If the value of road density shows a decreasing trend through years, it implies that there is a need to construct new roads for meeting the demand. The data needed to compute road density are the trend of total road length constructed (which is collected from AACRA) and total area/population size of the Arada sub-city and dividing the two numbers give the road density of the sub-city with respect to road density per area and road density per person.

4.5.2 Proximity to Road Network

Proximity measures how many people can access the infrastructure within certain distance. It is one of the parameters that show the availability of transport infrastructure and its closeness to the end users.

4.5.3Accessibility

Accessibility is the individual's possibility to take advantage of resources with fixed location in space that requires existence. It is obvious that access to resources is restricted by distance. Accessibility can be pictured as the interaction of people with land use along certain transport mode. Accessibility is defined here as the ease or possibility of reaching a desired destination from a given point in a space by a certain mode of transport. In this research accessibility is measured based on the walking distance and travel time from point of origin to destination point (from living place to work, school, and/or CBD). For this purpose sample population is taken.

4.5.4 Road Connectivity

Connectivity refers to the directness of links and the density of connections in path or road network. A well-connected road or path network has many short links, numerous intersections, and minimal dead-ends. The connectivity in the road network of the study area was tested using Beta index of connectivity by dividing the total number of arcs or straight line roads found in the road network by nodes or junctions in the road network. To use this first the total number of nodes in the road network and the straight line roads between the nodes must be determined which is obtained manually by counting from the master road network.

As connectivity increases, travel distances decrease and route options increase, as this allowing more direct link between the origin and destination points creating a more accessible and connectivity in terms of easy movement.

4.5.5 Road performance

Road network performance is a ratio between lengths of road in stable condition with total road length. Road performance has no unit. This indicator shows the proportion of roads which are in good condition/stable condition which means they do not need maintenance and they are in a good status. The data needed to compute this indicator is total length of roads constructed in the city from AACRA and total length of roads in unstable/bad condition which means uncomfortable roads like roads in poor condition and roads in maintenance.

4.5.6 Traffic volume load

Traffic load in road transport is a ratio between total lengths of road with number of vehicles. This indicator has a unit km/no of vehicle. This indicator shows percentage usage of constructed roads by vehicles in the city. The data needed to compute this indicator are total length of road constructed in the study area from AACRA and total number of registered vehicles in the sub-city from Addis Ababa Transport Office.

4.5.7 Road safety

In recent years, safety is critical in any transport system, as many people are involved in road accidents every day, often suffering injury or death. The safety level of transport infrastructure is defined by the number of accidents on one hand, and by the impact of the accidents on the other. Using this indicator the effect of the construction of the road network and the trend how road network development affect safety was evaluated.

Road traffic safety was measured as the number of road traffic crashes and causalities resulting from crashes per time period. This indicator needs recorded accident rates in different categories with their causes which are found from Arada sub-city Police department.

A schematic presentation of the analytical framework is depicted in figure 4.2

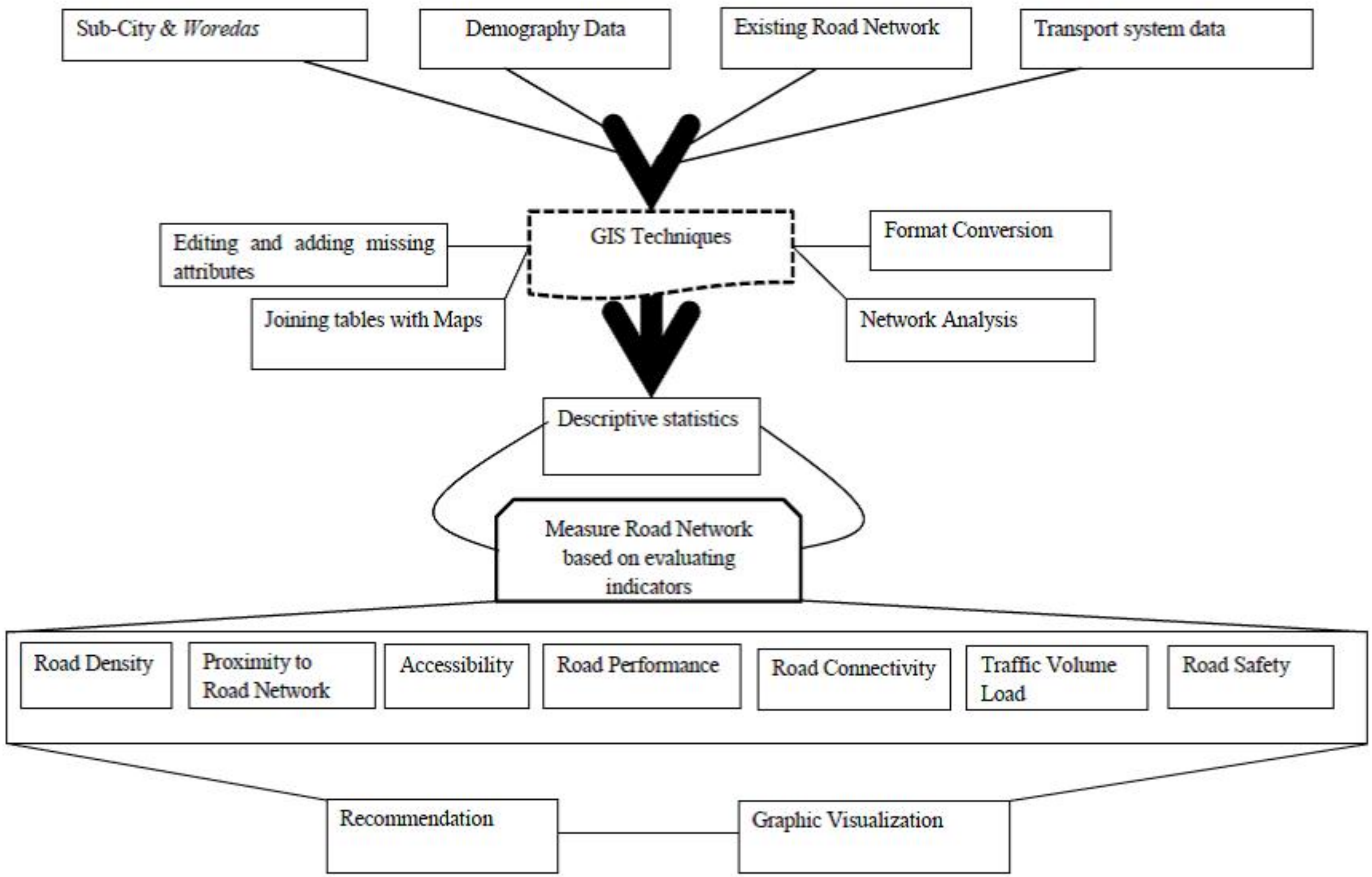


Figure 4.2 Schematic Presentation

CHAPTER FIVE

EVALUATION OF EXISTING ROAD NETWORK

In this chapter the results obtained from evaluating the existing transport network using indicators that are identified in the methodology chapter are discussed. The current performance of major road networks that are providing transportation service for Arada sub-city are evaluated based on road density, the proximity of the road, accessibility, connectivity, road performance, traffic volume load and safety. The outputs are mapped and interpreted.

Historically there has been limited data to track the performance of the road network. But, in the modern era of sustainability, performance measurement is seen as a key to measuring progress on that front and also it is now feasible to measure road network. The ultimate purpose of measuring road network performance is to improve transportation services for travellers. The road network of Arada sub-city has been important throughout history. Measuring the performance of the road network based on evaluation indicators and improving the network is essential not only for the sub-city but also for the entire city and as well as for the country.

Indicators of performance measurement that are adopted in this study have the following characteristics:

Measurability: measurable with tools and resources available.

Predictability: possible to compare future alternative projects or strategies using this measure.

Clarity: understandable to the general public.

Usefulness: relevant to further studies, planning and project design processes, their reporting and also should provide decision-makers with relevant information for their decision making processes.

These characteristics are obviously flexible. The parameter and data required for the purpose of selecting criterias were identified through intensive literature review and also potential sources of data.

In this research the evaluation is made only on the major road network of the study area, the road type which gives transport service, the asphalt road of Arada sub-city. From the data that is gained from AACRA, the total length of Asphalt road in Arada sub-city is 26.29 km.

5.1 Road Density/Availability

Road density or road availability can be measured as the ratio of the total road network in an area to the land area or to the total population in that area. Given similar network topology, in different area, higher road density (road per area) implies a higher availability of alternative routes (Jenelius, 2009). Also, this implies higher directedness and connectivity levels within the network. The road density per area investigates the network structure only considering the supply side whereas the road density per unit of population measures the availability of network distance per person.

The formula for road network density is given as:

RD = L/A

Where, RD= denotes road density

L= is the total length of transport network in study area depending on scale

A = represents the area of the sub-city

The dimensions are normally in [km/km^2] depending on scale of network.

Road Density = Total Road Length in km/Total Area in km^2

$$= 26.29km/9.51km^2$$

$$= \mathbf{2.76\ km/km^2}$$

The above result shows, the road density of Arada sub-city is increasingly significant which from the total area of $9.51km^2$, the road network cover $2.76km/km^2$. Although, the length of the major asphalt road network in Arada sub-city is seen increasing from the past 3 years. So this result means, the ratio of the area covered with road in the sub-city is increasing which in other words enhancing mobility and availability in the study area. The road density trend in Arada sub-city shows an increasing value and the total areal share of the road also shows an increasing value.

Figure 5.1(A) shows the road density in the study area. The road density per area shows higher value in the central area, but this is not true for the road density per population because of higher population density in the CBD, rather the north-west and some areas in the west have proportionally higher road density per area value.

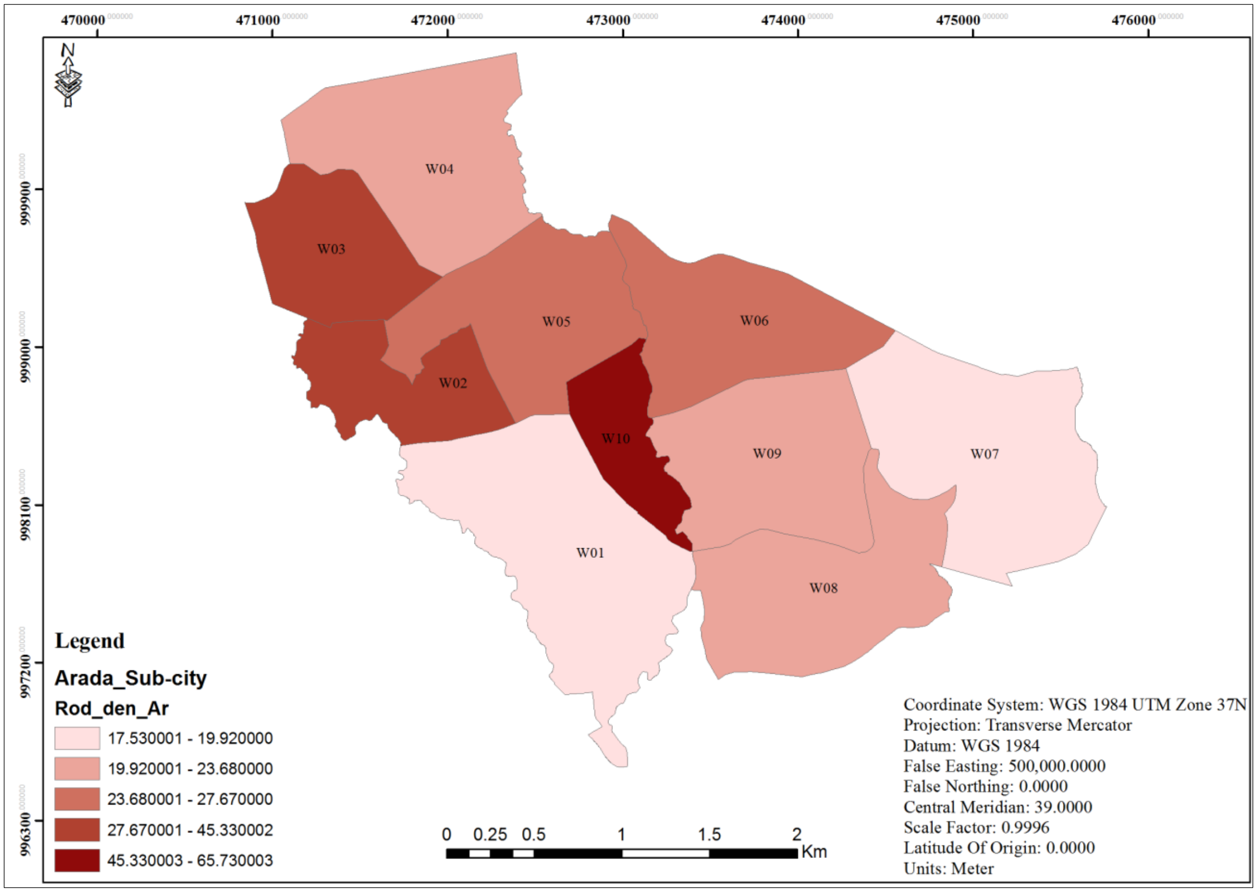


Figure 5.1(A) Road density, Road length per area (road length km/km^2)

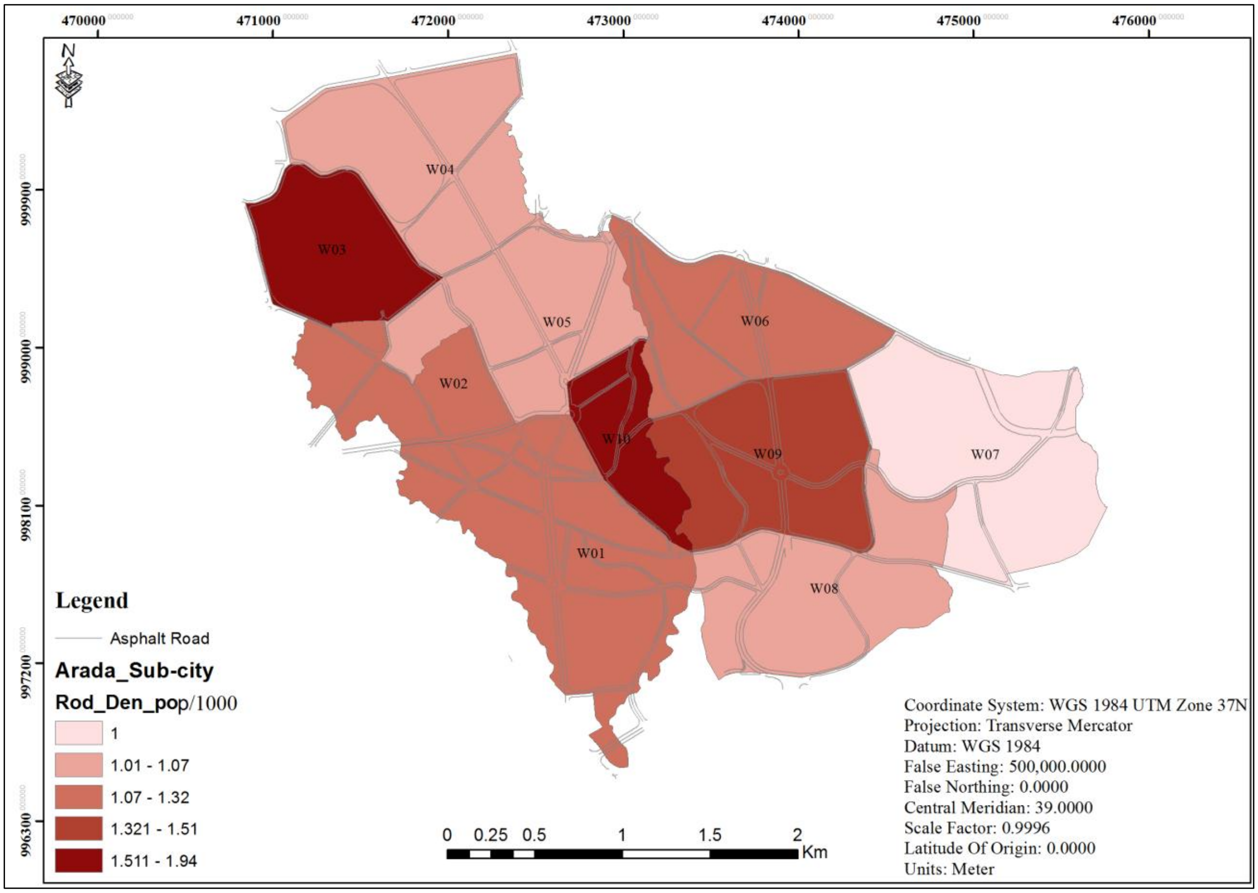


Figure 5.1(B) Road length per 1000person (road length km / total population)

The road density per unit of population shows the availability of road distance per person. Based on the result, there are areas and population suffering from road network; specially, areas that are situated at the center and north east of the study area.

Hence, road infrastructure exist in more quantities in areas where there is high population density, though the vice versa could be true. There is an area that has more infrastructure and higher population density. This implies there is high road density per population in this *Woreda*, locally known as *Piazza.* There are also areas that have lower value of road per population. These areas have relatively low population density. There is low value of road per population in *W* 07, *W*08, *W*04 and 05.

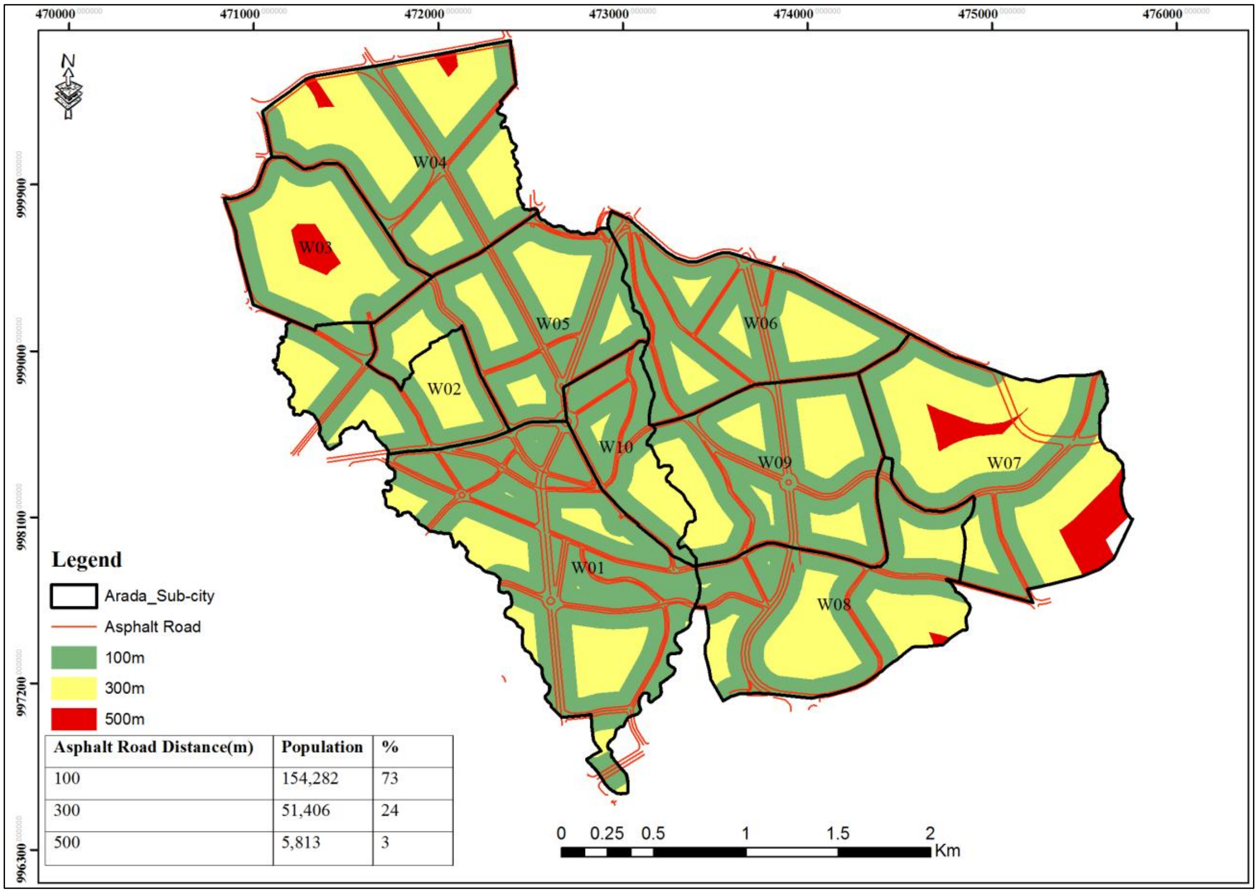
From this we can conclude that, because of they are having larger area *W*07 and *W*01 have lower road transportation infrastructure availability with respect to road density per area and per population. On other hand, *W10* and *W803* have relatively higher road infrastructure with respect to road per population. Most of areas that are found in the south-west and north have low infrastructure. When we consider spatial equity, those areas that are far away from the central part of the sub-city have low share of roads. While central part of the sub-city has considerable amount. The same is true when considering equity by the share of road density per person.

5.2 **Proximity to the Road Network**

Proximity to road network is one of the parameters that show the availability of transport infrastructure and vicinity of road network to the end users. Proximity measures how many people can access the transport infrastructure within certain distance. In the GIS environment proximity tools can be divided into two categories depending on the type of input the tool accepts: features or raster. The feature-based tools vary in the types of output they produce. For example, the buffer tool outputs polygon features which can then be used as input to overlay tools. The Near tool adds a distance measurement attribute to the input features, while the Select Layer By Location tool creates a selection set. The raster-based Euclidean distance tools measure distances from the center of source cells to the center of destination cells. The raster-based cost-distance tools accumulate the cost of each cell traversed between sources and destinations.

In the first case feature-based proximity is done to measure the proximity of the population from the infrastructure using the proximity toolset in Analyst toolbox. These tools output information with buffer features and tables. This is done by considering the total population distribution over the area, population density of the sub-city and each *Woreda* is computed.

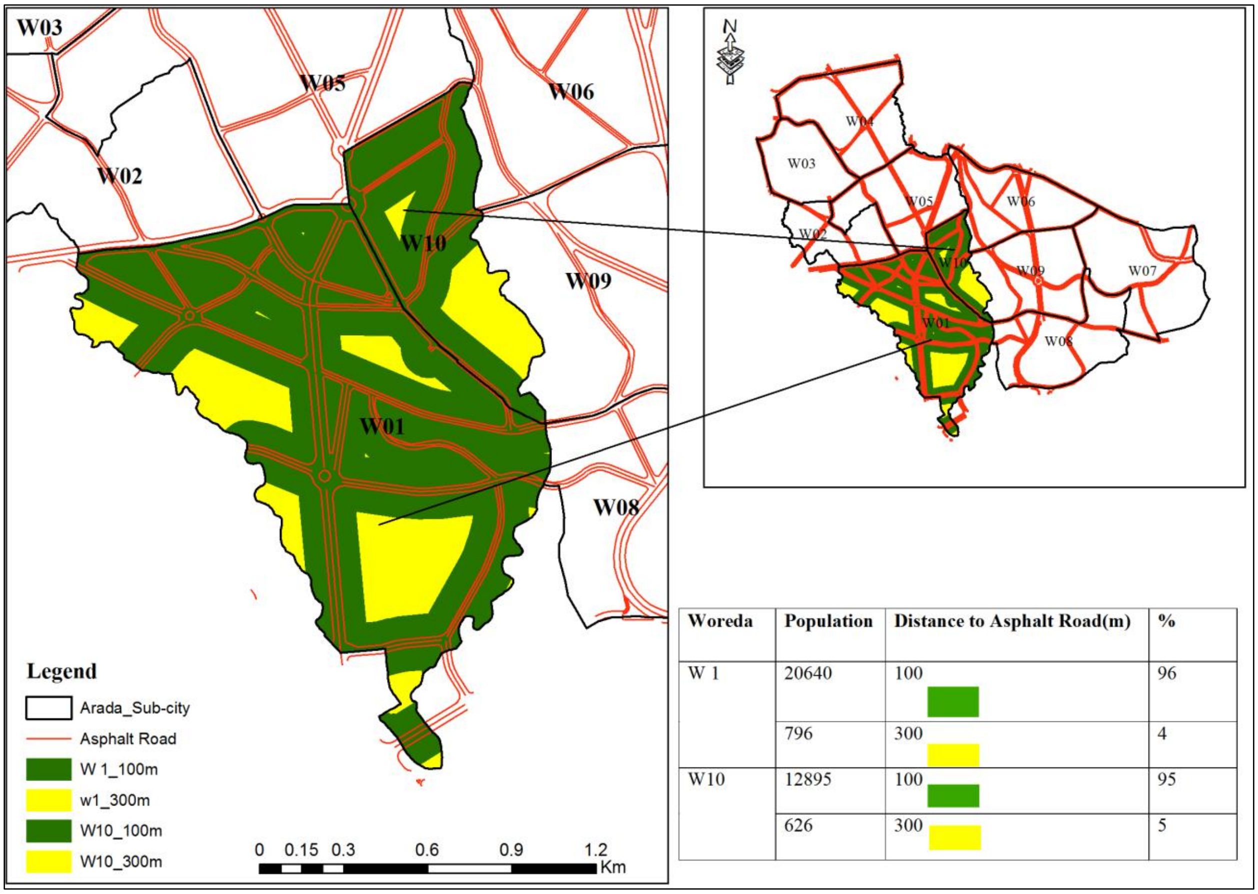
According to this analysis, 73% of the population in Arada sub-city can access to major asphalt road within 100m (refer to figure 5.2). Because of the concentration of road network and being CBD of the city, 96% of the population within *woreda* 01 can access the major asphalt road after traveling 100m distance.



Asphalt Road Distance(m)	Population	%
100	154,282	73
300	51,406	24
500	5,813	3

Figure 5.2: Proximity of major road networks in Arada sub-city

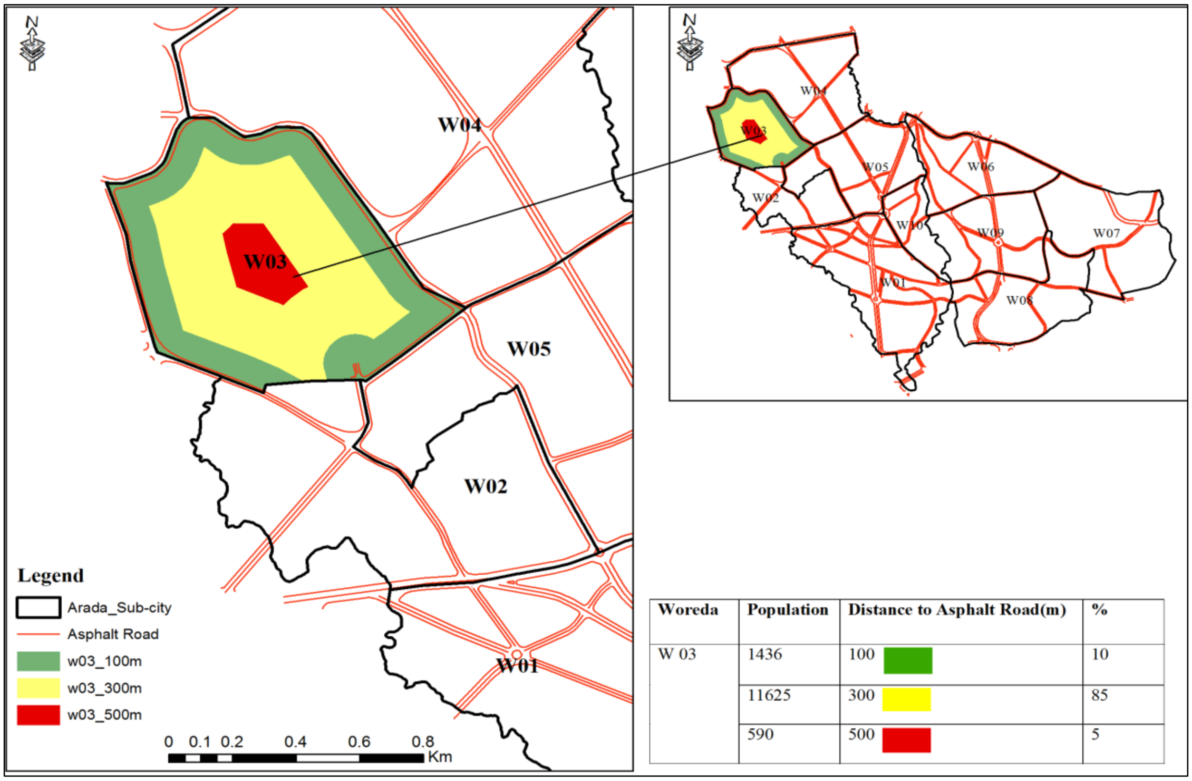
Figure 5.3 shows that, because to the dense population and concentration of major places and being the central part of the study area, 95% of the population within *woreda* 10 can access to major asphalt road after traveling 100m of distance.



Woreda	Population	Distance to Asphalt Road(m)	%
W 1	20640	100	96
	796	300	4
W10	12895	100	95
	626	300	5

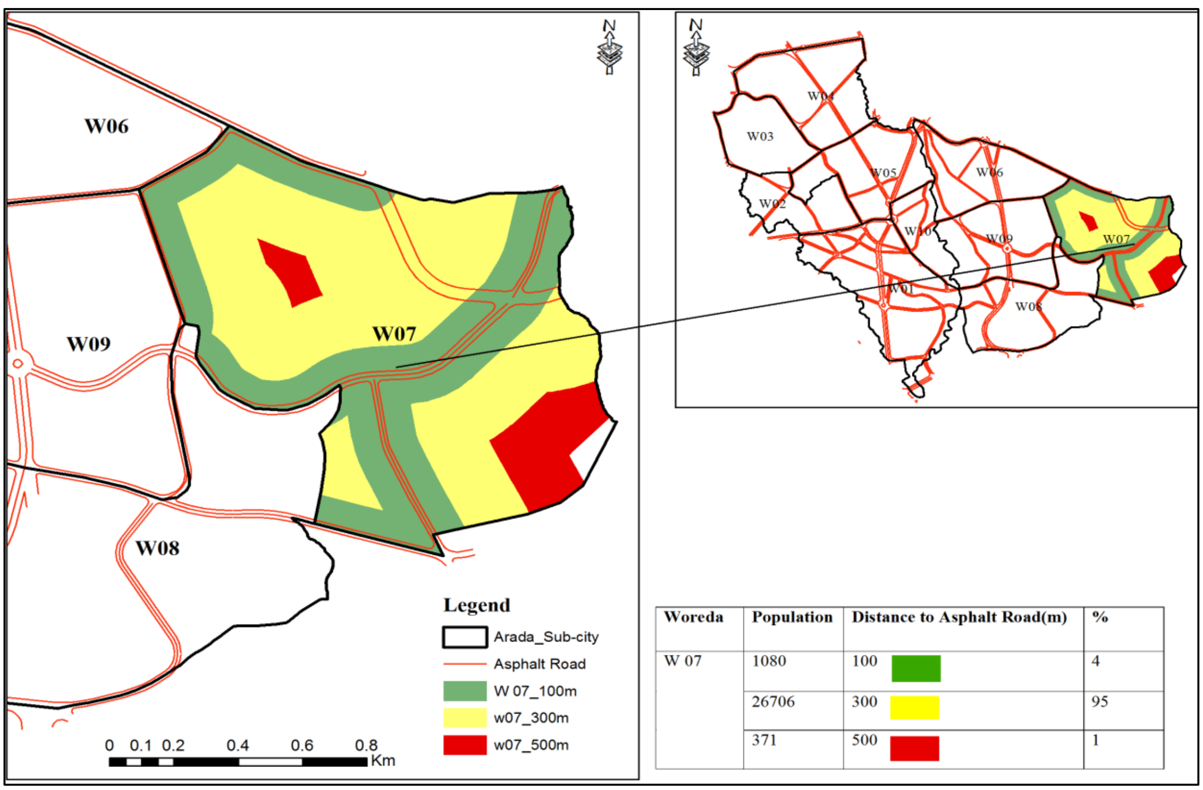
Figure 5.3: Proximity of major road network in *woreda* 01 and *woreda* 10 of Arada sub-city

The proportion of proximity of road network in some areas with Arada sub-city is poor. For instance, population within *woreda* 03 and *woreda* 07 can access any kind of major asphalt road network after 300m and more distance. Within those areas, if we assume any transportation system is available at the end of the closest major asphalt road, 83% and 95% of populations within the above *woreda* respectively can access to major asphalt road by traveling 300m and more distance. From this we can conclude that, population within those area have low level of proximity to the major asphalt road network which is essential for transportation service.



Woreda	Population	Distance to Asphalt Road(m)	%
W 03	1436	100	10
	11625	300	85
	590	500	5

Figure 5.4: Proximity of major road network in W03 of Arada sub-city



Woreda	Population	Distance to Asphalt Road(m)	%
W 07	1080	100	4
	26706	300	95
	371	500	1

Figure 5.5: proximity of major road network in W07 of Arada sub-city

Figure 5.5 shows that, because of the inadequate road network availability in W03 and W10, travelers in those are have low level of proximity to major asphalt road.

On the other hand, The Spatial Analyst extension provides several sets of tools that can be used in proximity analysis. The Distance toolset contains tools that create raster showing the distance of each cell from a set of features, or that allocate each cell to the closest feature. In this case Euclidean distance is done. Euclidean distance is straight-line distance or distance measured as the crow flies. For a given set of input feature, the minimum distance to a feature is calculated for every cell. Figure 5.6 shows the output of the Euclidean Distance tool, where each cell of the output raster has the distance to the nearest road network feature and the output is also reclassified into 5 classes.

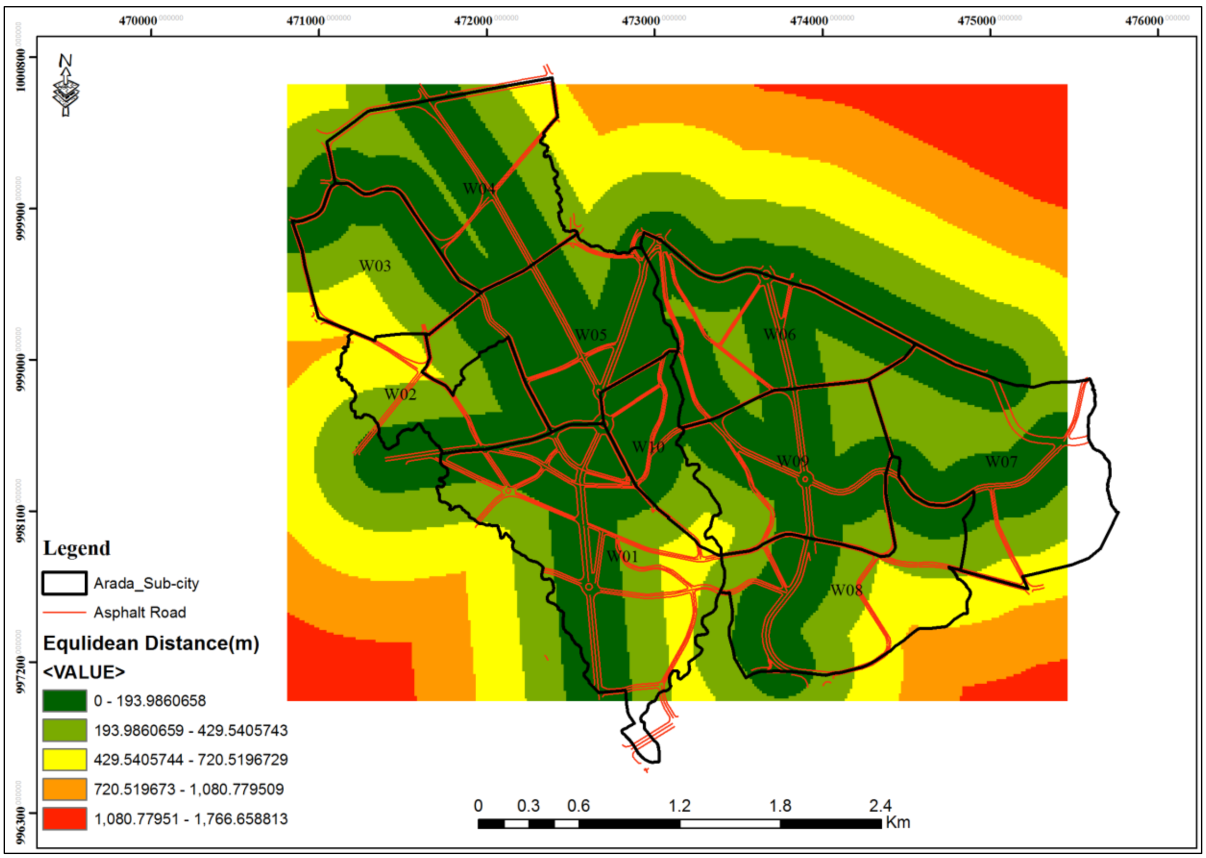


Figure 5.6: Euclidean Distance to major Road network

Figure 5.6 shows the distance of the major asphalt road network in Arada sub-city which identifies the distance (proximity) of travelers, areas and facilities to the major asphalt road in the sub-city.

Based on this result, areas within the green color are closer to the major asphalt road network. Considering the total size of the area, if one needs to access the asphalt road network from this area he/she needs to travel 0-193m of distance. There are also some areas which have low level of proximity to major asphalt road (areas in yellow color of figure 5.6). Travelers from these areas can access to any kind of major asphalt road after 429-720m distance. Because of the inadequate road network, travelers from this area have low level of proximity to the major road network.

5.3 **Accessibility**

One of the goals of transport system is to increase access to facilities. In measuring the performance of roads networks, the concept of accessibility has been employed in different forms. Even though the definition of accessibility varies depending on its presentation, based on this context, it can be generally defined as the ability of a road network to provide access to jobs, recreation, shopping, intermodal transfer points, educational institutions, health centers and other land uses, which is one of its primary purposes. Generally speaking, an accessibility increase does two things. First it increases total wealth and second, it redistributes wealth.

Measuring the performance of road network accessibility is hence an important part of quantifying the performance of the system in terms of traffic efficiency. Accessibility measures should reflect the ability of people and goods to reach different destinations. In this study accessibility is mainly concerned with the travel time of a place to another place on the road network. So, considering the available mode of public transport, the accessibility level of different area within the sub-city to reach Piazza, the CBD of the city and to 6 *kilo*/ *Yekatit* 12 square were measured.

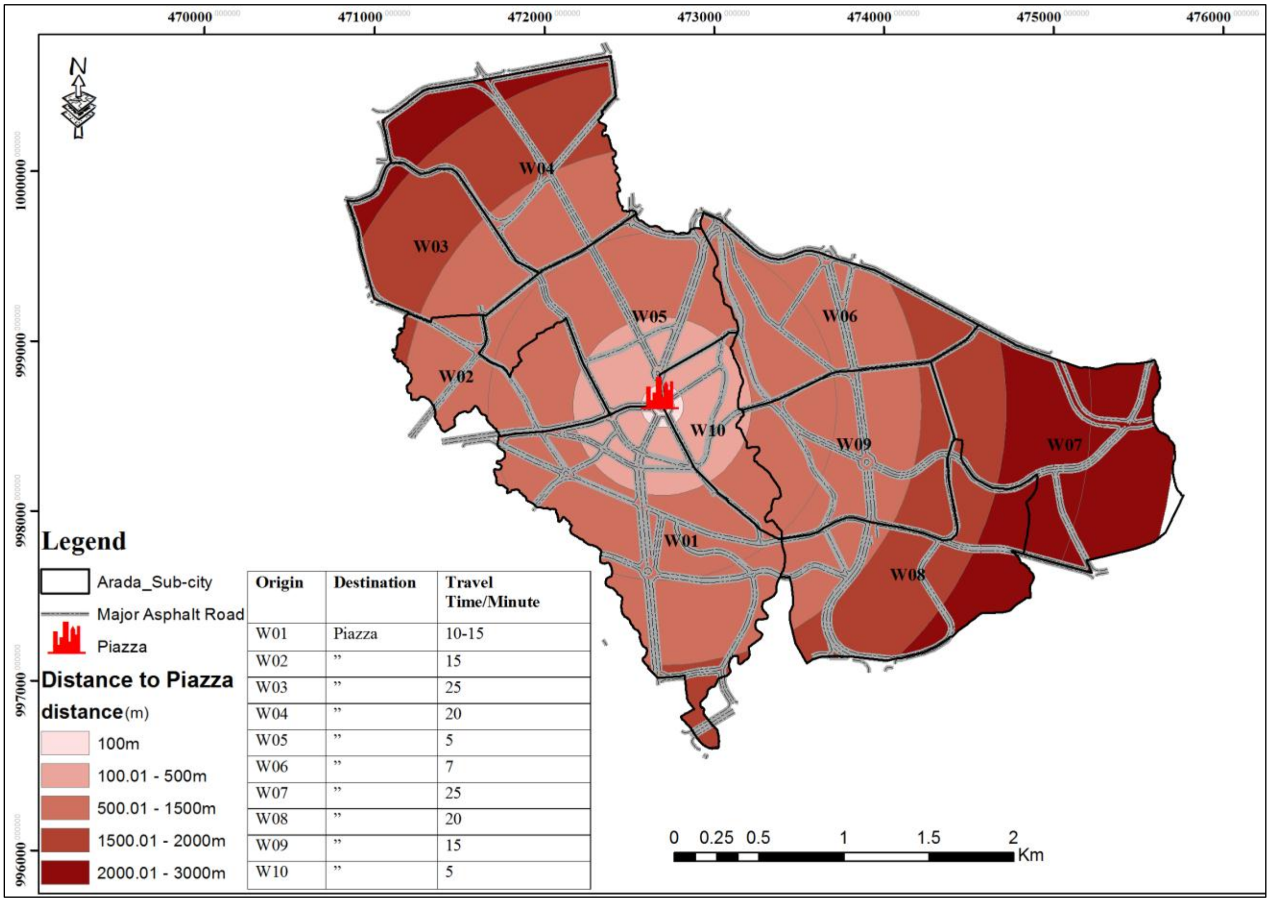
Because of being the centroid of sub-city and CBD of the city, Piazza is the busiest area. Within Piazza there are several major market places, the Municipality, recreational areas and different job opportunities that are found in this area.

Based on their accessibility result, Piazza is more accessible to travellers from *woreda* 10. As a result of sharing border and being neighbor to each other, travel time and distance from *Woreda* 10 to Piazza is less than the other *woredas*. Using the major asphalt road network which connects the two *Woreda's,* travel originated from *Woreda* 10 takes not more than 7 minutes. *Woreda* 02 also shares a common border with the *Woreda* 01. But, because of the crowdedness of the road network within the area, it might be difficult to reach in a short time. Travels that are especially from the road of the northern part of *Woreda* 02 locally known as *Atobes Tera* takes about 15 to 20 minute to reach Piazza. Most of the congestion relates to the many intersections that are linked with the major road network. Comparing with the above road network, there are also areas that are reached in short travel time to Piazza from *Woreda* 02. These areas include: areas using the road network from *Habte Giorgis* Bridge and *Taliyan sefer*.

There is also a road network within *Woreda* 05 that is accessible to reach Piazza using the major asphalt road. Using this road network traveller from *Datsun sefer*, *Gedam sefer*, *Afincho ber*, *Sebara babur* can reach Piazza within 5 minute.

Relative to those accessible areas to Piazza within short travel time, there are areas that take some minute to reach to the central part of the sub-city. Those are *Woreda* 08 and 09. Trips made from those *woredas* need at least 15- 20 minutes to reach Piazza using the major road network.

Figure 5.7 shows, trips that are made from Woreda 03, 04 and 07 within Arada sub-city to Piazza. The road network in these areas is longer in distance and take much time. As a result of lack of alternative road network which connect those areas to the central part of the sub-city, trips made from those areas commonly use only one major road network which radiates from *Addisu Gebya* (*Semen mazgaja*) to St.George. Travellers from *Semien Mazgaja*, *Enkulal Fabrika* and *Kebena* respectively reach Piazza by wasting more than 25 minutes. This is also possible if there is enough transport modes.



Origin	Destination	Travel Time/Minute
W01	Piazza	10-15
W02	”	15
W03	”	25
W04	”	20
W05	”	5
W06	”	7
W07	”	25
W08	”	20
W09	”	15
W10	”	5

Figure 5.7: Accessibility of major road networks from the 10 *woredas* to Piazza

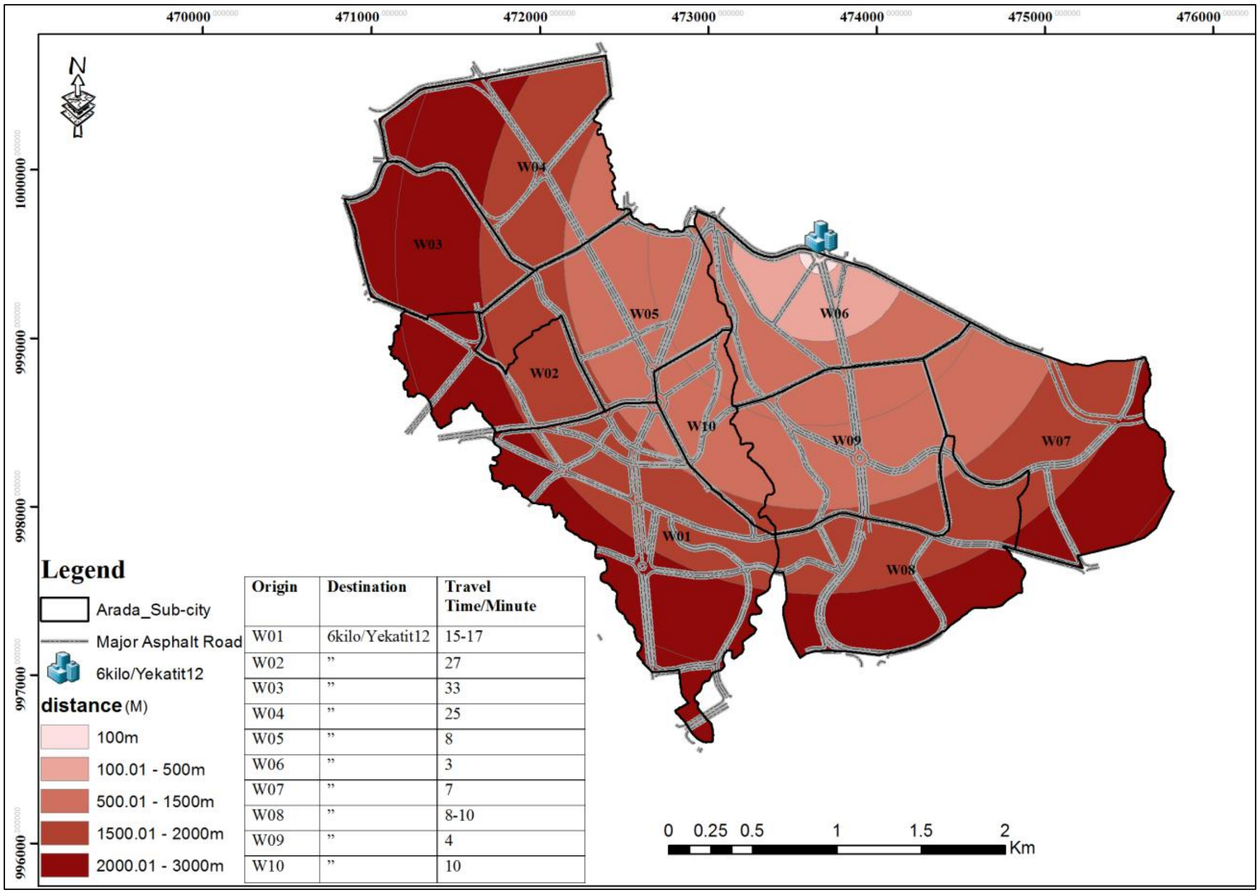
The other accessibility result is done by calculating the travel time from different parts of the sub-city to reach 6*kilo* University and *Yekatit* 12 Hospital. Trips that are made to these two places have their own purpose. It is true that if more activities are at the destination, the more valuable it is for the peoples. As the result of being the largest, famous and internationally known, there are several trips made to 6Kilo university. An interesting thing here is, 6 kilo university falls between 3 sub-cities, namely: Arada, Gulele and Yeka sub-city of Addis Ababa City Administration. For this reason, we take the travel time up to *Yekatit* 12 square, where the 2^{nd} gate of 6*Kilo* university found. On other hand, *Yekatit* 12 is one of the largest Hospitals in the city. To get the services provided by this Hospital there are thousands of people traveling from different part of the sub-city, the city and also from different parts of the country to this area.

Figure 5.8 shows the travel time from different part of the sub-city to 6kilo and/or to *Yekatit* 12. As the map shows, 6kilo and *Yekatit* 12 are accessible to trips that are made from *woreda* 05, 07, 09 and 10. Among these *woredas* 6*kilo* and/or *Yekatit* 12 is more accessible to *Woreda* 09, locally known as *Arat Kilo*. Using the major road network, travellers from *Woreda* 09 needs less than 5 minutes to reach 6*kilo* and/or *Yekatit* 12.

Woreda 05 and 10 have shortest distance to 6*kilo* and/or *Yekatit* 12 when we compare with *Woreda* 07. But they take relatively more travel time to reach at the destination. The vice versa is true. Using the major road network trips from *Woreda* 05 and *Woreda* 10 takes about 8 minutes to reach *6kilo* and /or *Yekatit* 12. The major road network within *woreda* 07 up to some kilometer is in good condition. But, from *Minilik* Hospital to *Yekatit* 12 square, the road is currently found in poor condition. Even though the road network condition is not that much efficient, most of the time road network is free. As a result trips made from this area take not more than 7 minutes to reach 6kilo and/or *Yekatit* 12.

Opposite to those accessible areas, there are areas found far away from 6*kilo* and /or *Yekatit* 12 Hospital. Those areas include; *Woreda* 02, 03 and 04. Because of the crowdedness of the major road network found in *Woreda* 02, trips made from this area take more than 25 minutes. As a result of lack of enough transport infrastructures, trips made from *woreda* 03 also take more than 30 minutes. *Woreda* 04 has only one major road network connection with different areas. Because of this and other reason trips made from this area to reach 6*kilo* and/or *Yekatit* 12 take 25 minutes.

Comparing to other *woredas*, *Woreda* 01 has more transport infrastructure. As a result of several major places found in it, road network of this *woreda* is somehow crowded. By using several road networks found in area, traveler needs to travel 15-17 minutes to reach 6*kilo* and/or *Yekatit* 12.



Origin	Destination	Travel Time/Minute
W01	6kilo/Yekatit12	15-17
W02	”	27
W03	”	33
W04	”	25
W05	”	8
W06	”	3
W07	”	7
W08	”	8-10
W09	”	4
W10	”	10

Figure 5.8 Accessibility of major road networks from the 10 *woreda's* to 6Kilo/*Yekatit* 12

5.4 **Connectivity**

The other measurement indicator which is related to the road network and the size of the area and its structure of population distribution is the level of connectivity. Connectivity refers to the density of connections in path or road network and the directness of links. The connectivity of roads network is determined by the extent to which nodes in a network are directly connected to one another. Connectivity measures the number of segments (in this case links or arcs) to which a specific segment is directly connected.

The connectivity of the road network in the study area was tested using Beta index of connectivity. This was done by dividing the total number of arcs or straight line roads found in the road network by nodes or junctions in the road network. The straight lines between the nodes must be determined which is obtained manually by counting from the master road network.

Beta index =Arc/Nodes

Where the nodes are the number of road junctions and arcs are connections (straight lines) between the nodes as straight lines.

Road connectivity = Straight lines/Road Junction (Nodes)

= 126/76

=1.66

This result shows that, on the average there is 1.66 links for each vertex of the route in the study area. However, any route with Beta index value less than 1.0 such route network is considered to have low level of connectivity and such route is not viable for adequate road network transport service.

A well-connected road or path network has many short links, numerous intersections, and minimal dead-ends. As connectivity increases, travel distances decrease and route options increase, as this allowing more direct link between the origin and destination points creating a more accessible and connectivity in terms of easy movement (Kofi, 2010).

According to the study of Kofi (2010), for an adequate connectivity, the road network should have a minimum connectivity index of 1.40. A connectivity index of 1.40 is a reasonable standard to ensure a connected roadway network. However, there are some cities that require a smaller index, sometimes as low as 1.20.

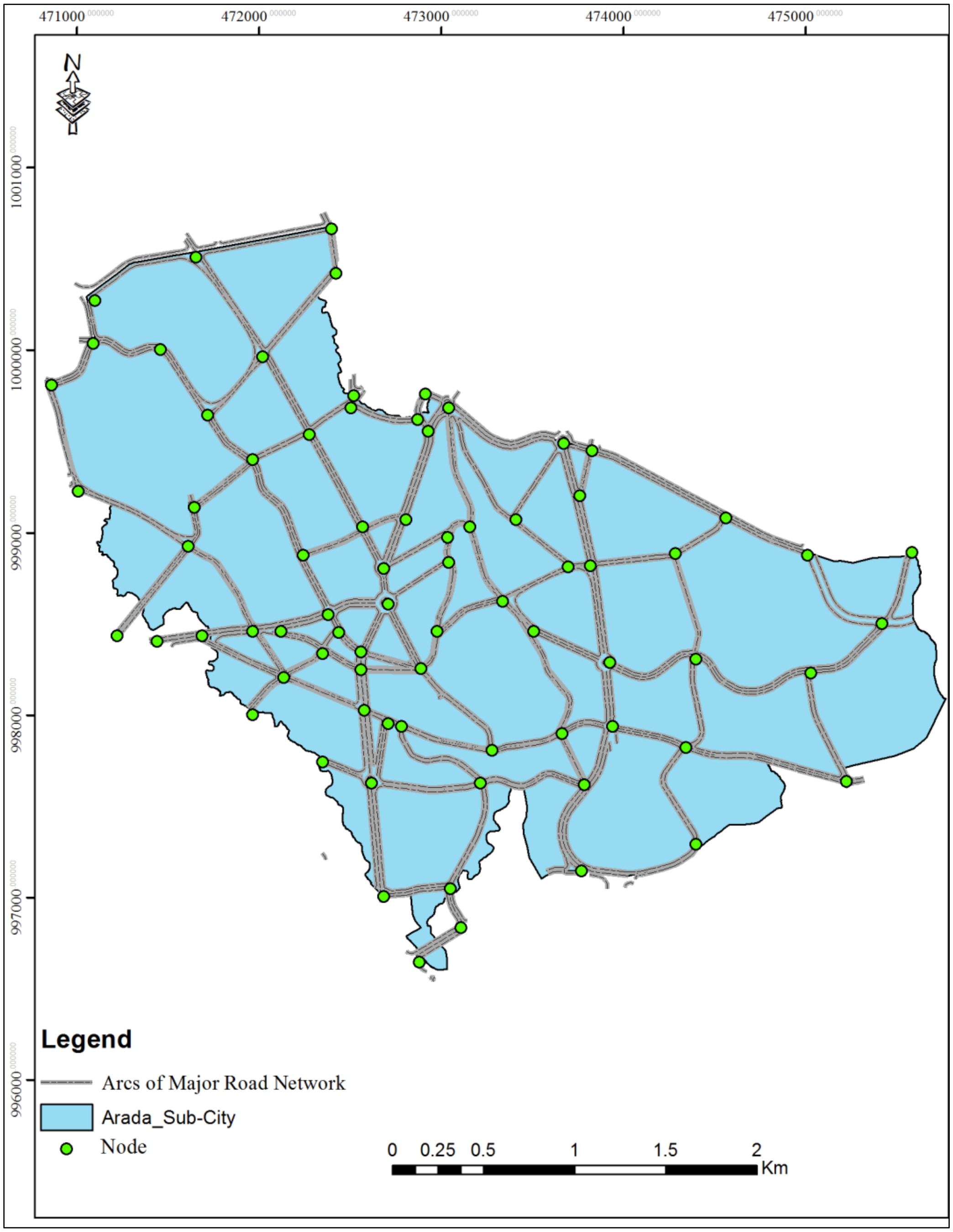


Figure 5.9 Major asphalt road network nodes and arcs in Arada sub-city

Therefore, as we can see from figure 5.9 there are 126 straight lines between 76 road junctions or nodes in Arada sub-city major asphalt road network. This implies there is better road network connectivity in this sub-city. Because, the road network of Arada sub-city have greater than one beta index, which shows a better connectivity in the sub city. As stated in the above paragraphs, as connectivity increases, travel distances decrease and route options increase, allowing more direct travel between destinations, creating a more accessible and reachable road network.

If the road authority needs to improve the connectivity level of the existing road network, there must be a simple change in design. Such as removing dead ends and connecting the street-ends to other streets can bring about significant changes in connectivity index scoring. The sub-city shall utilize the connectivity index mechanism, in addition to other qualitative measures, to determine whether transportation impact fees can be reduced within the city.

5.5 Road Performance

Road performance is a ratio between lengths of road in stable condition with total road length (Santosa, 2005). This indicator shows the proportion of roads which are in good condition/stable condition which means they do not need maintenance. This type of road network has high comfortable, high level mobility and movement of vehicles in the road network of the sub-city.

Road performance of the study area is calculated using the following formula.

Road Performance = Total Asphalt Road Length in km – Total Asphalt Road under fair and poor condition/ total length of road in km

= 26.29 – 11.45/26.29

= 14.84/26.29

= 0.56

The large number of people in Addis Ababa city travel using the motorized transportation system. The road network in the city is predominantly serving the population for their travel purpose. In Arada sub-city, there are several market places, different major governmental organization and private limited companies. Because of this and many other reasons, larger numbers of population are making trip to this area and out of this area.

Similarly to the city, motorized vehicles are the dominant means of transportation in Arada sub-city. As already indicated, the total length of major asphalt road network in Arada sub-city is about 26.29 km. From this, about 11.45 km length road network in Arada sub-city is mostly under fair and poor condition. This type of road network is not safe to ride. This means those road networks need an urgent maintenance. If the maintenance is delayed, the cost might get increased, as maintaining gravel roads needs much cost.

As the result shows, there are major areas lacking good road network condition. Figure 5.10 illustrates the condition of the road network from *Kidest Mariam* to *Arat Kilo* those are within *woreda* 06 and 09. This road network is suffering from fair condition. But, when we see the service it delivers, it is one of the very important road networks which connect major educational and governmental institutions in the sub-city.

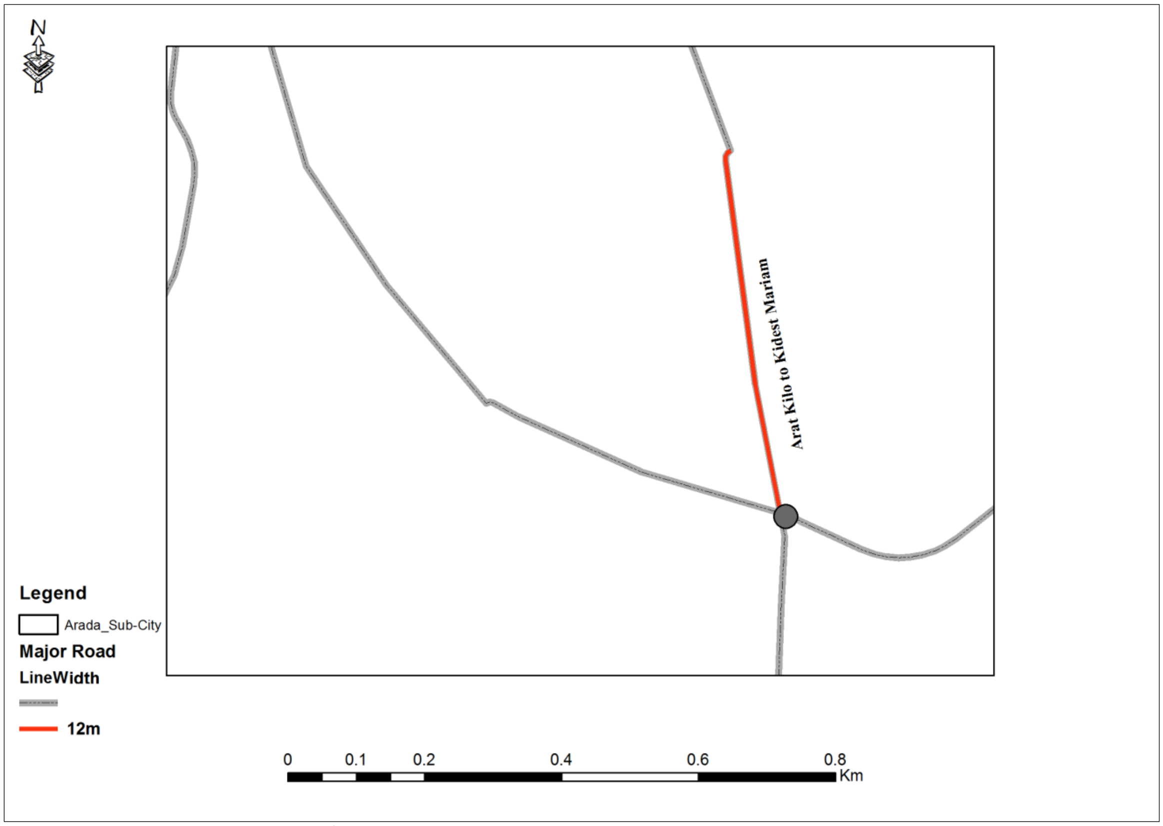


Figure 5.10: Road network from Arat kilo to Kidest Mariam in Fair condition

Figure 5.11 show the road network connecting *piazza* and *merkato*, from *Arada* building to *Kelifa* building and from *Arada* building to *Abune Petros* square and road network from *Showa* supermarket to *Kelifa* building found in fair condition. Those road networks are found on the busiest areas of the sub-city. But there is absence of good road condition. According to data gained from the road authority of the city, those roads are constructed before 1983.

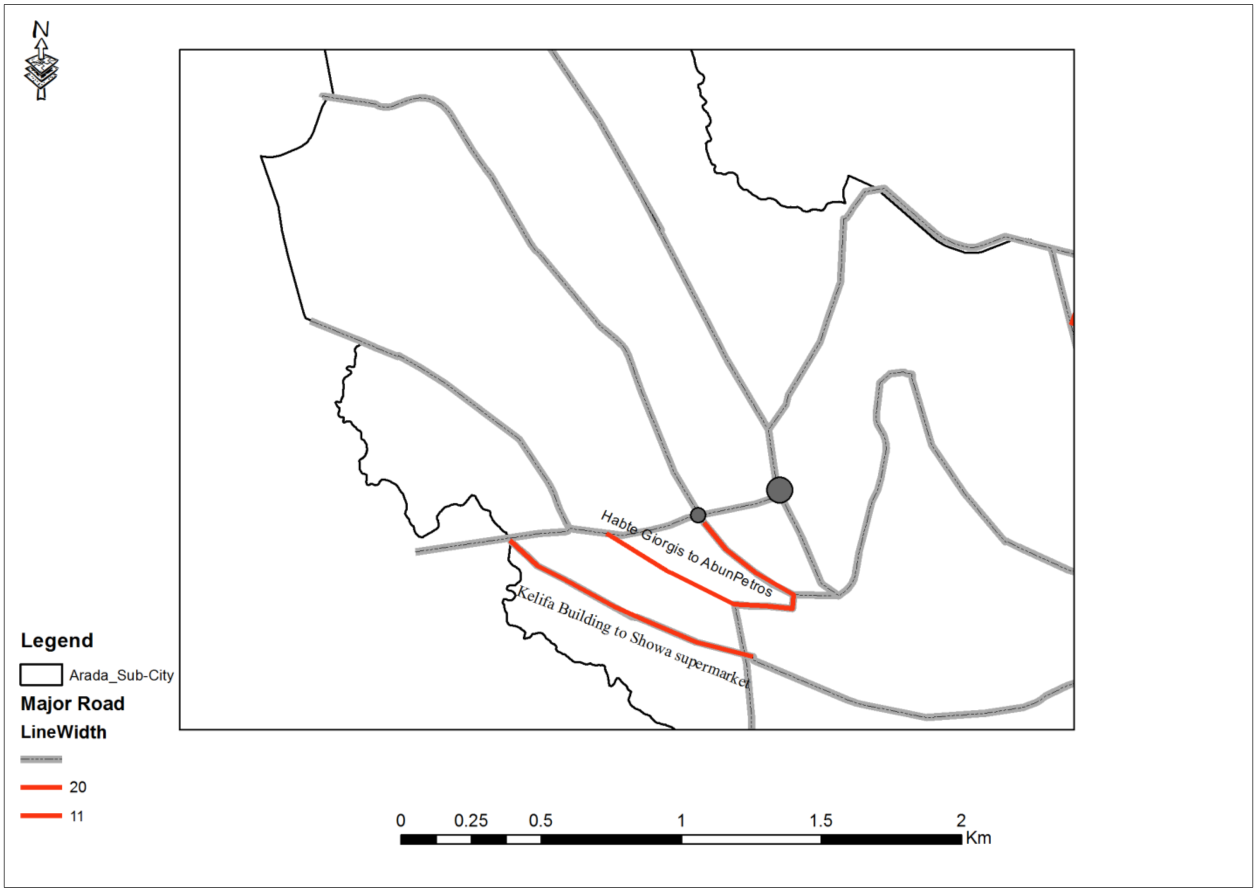


Figure 5.11 Road Network from Habte Giorgis through Arada Building to Abun Petros Mariam and Road network from Showa Supermarket to Kelifa Building found in fair condition

The road network shown on figure 5.12 is the road from Anbessa Gebi to Total gas station. This road serves as crossing route for at least three different areas, namely; Arat Kilo to Minilik, Arat Kilo to French Embassy and Arat Kilo to Bela. But it is under poor condition and providing poor transport service.

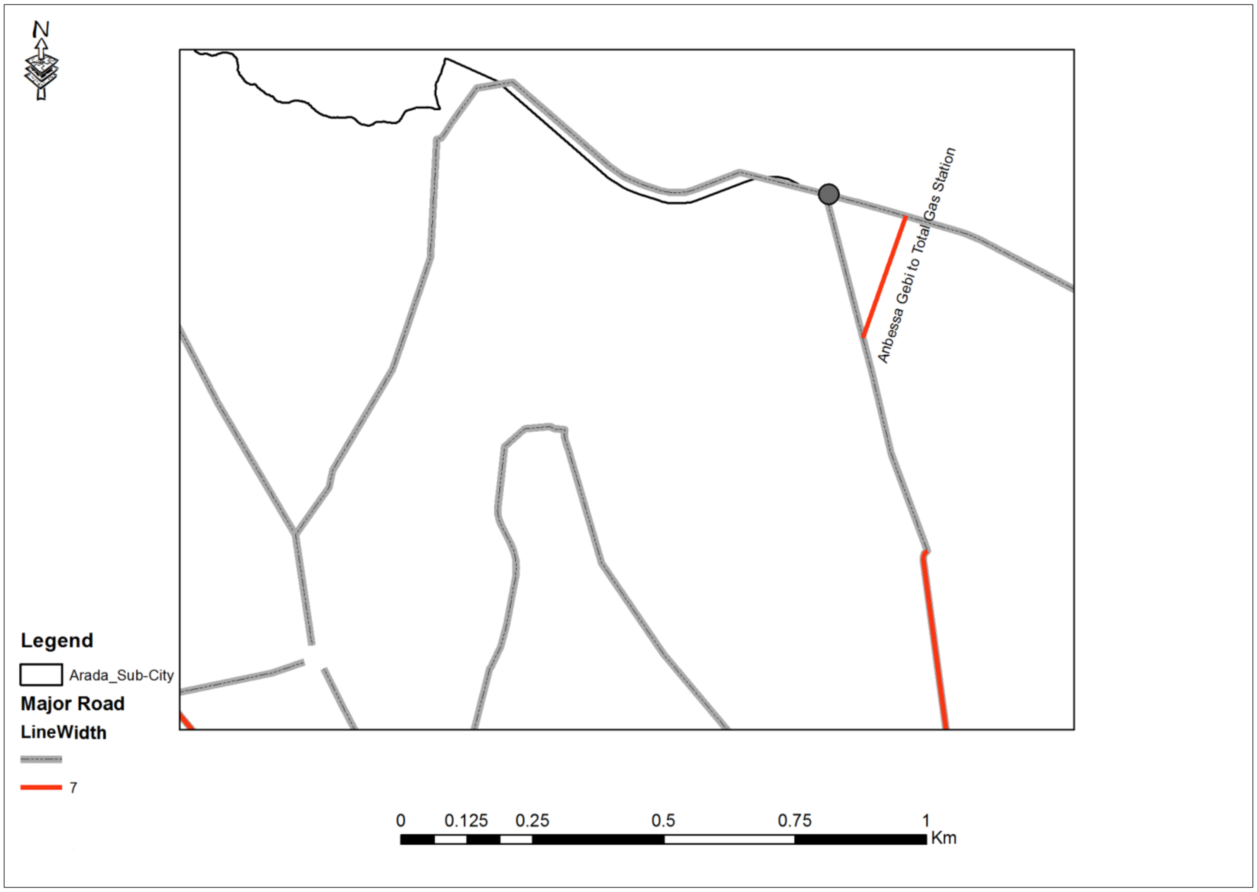


Figure 5.12: Road Network from Anbessa Gebi to Total gas Station found in poor condition

5.6 Traffic Volume Load

Traffic load is a ratio between total lengths of road with number of vehicle (Transport Association of Canada, 2006). This indicator has a unit km/no of vehicles. This shows percentage usage of constructed roads by vehicles in the area. This indicator also specifies how the numbers of vehicles are affecting the road network. So, to calculate the traffic volume load we use the following formula.

Traffic load = Total Asphalt Road length / Total number of vehicles

= 26.29/ 38851

= **0.00068 km/vehicle**

=0.68km/1000vehicle

According to the data gained from Arada sub-city Transport Office, the total number of registered vehicles under Arada sub-city accounts about 38851. The number of vehicles grows in line with the growth of the road network and population number in the sub-city. But currently in the road network of Arada sub-city, there are also vehicles that are not registered under the transport office of the sub-city, but are using the road network. Those vehicles are adding a load on the road network. Those vehicles are not considered on the evaluation of the traffic volume load of the road network of Arada sub-city.

As a result of its location situated at the central part of the city, the road networks found in Arada sub-city would carry and provide transportation service for larger portion of vehicles in the city and as well in the country too. Based on the analysis result, several roads that are found in Arada sub-city are dated many years back before they get maintained. For this and many reasons the road network of the sub-city need maintenance and reserve road networks.

5.6.1 Damaged Roads

Figure 5.13 shows pot holes in the study area which is the other entity described on the roads of the study area. Pot hole is an area or portion of the road that is damaged or a road that has needed to be maintained.

By querying out different road entities as per the duty (interest) what will be done by the road authority is possible to have a good result. In this case the researcher identified major pot holes in the sub cities. It is possible to sort out roads which damage severely with their respective location and measurement along with in which roads width these severe damages occur.

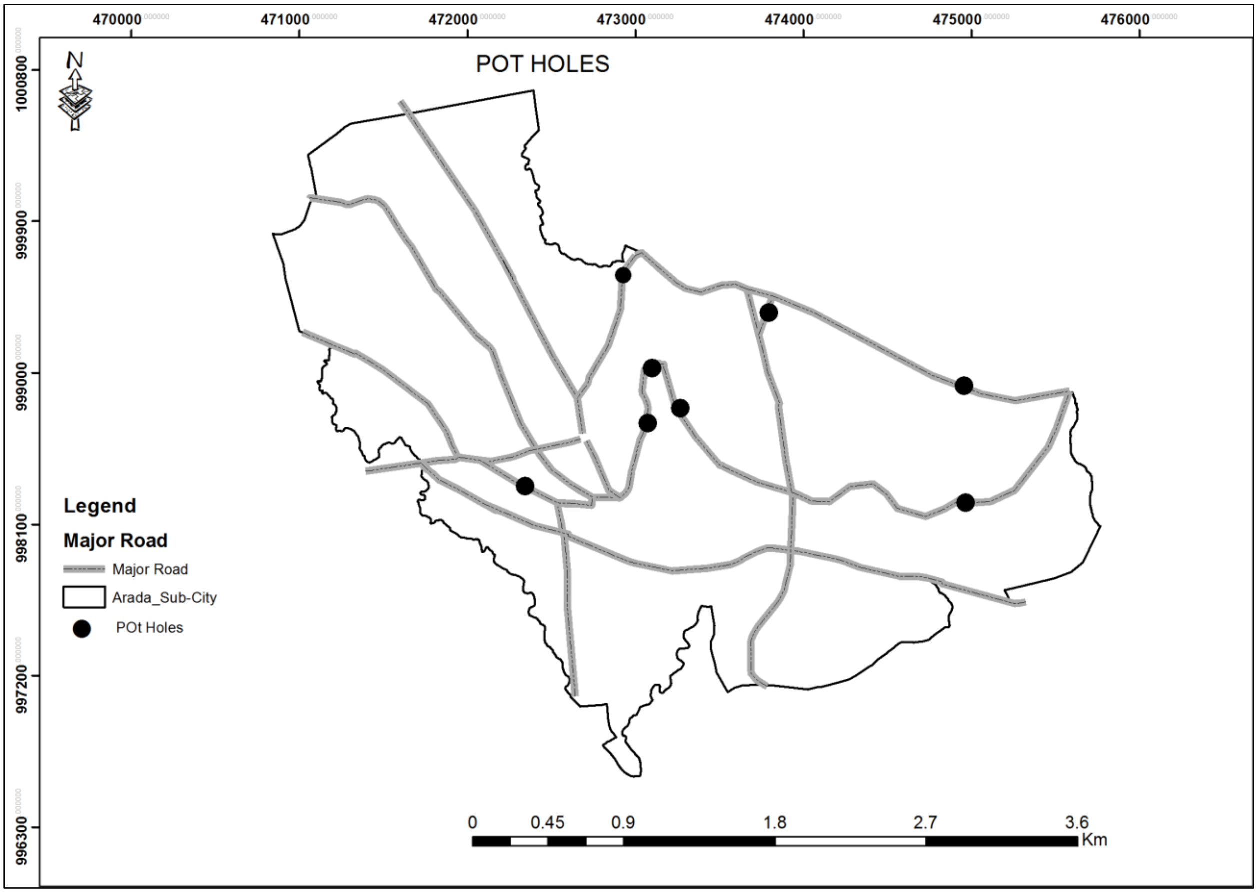


Figure 5.13: Major Pot Holes in the Road Network of Arada sub-city

5.6.2 Width of the Road Network

Figure 5.14 illustrates that the roads are segmented through a defined criterion (road width in this case). For the case of Arada sub city, the road has 7 different sizes of width (7, 11, 12, 14, 16, 20 and 21) meters. For each of the road a given road width is assigned according to their width size. Moreover, they are defined by different colors to distinguish various types of sizes of road width.

If the road authority wants to widen up the road of the sub cities to a specific road width, 7 meter and 11 meter in this case (figure 5.14), it is possible to select out the roads which have 7 meter and 11 meter width in the sub cities and based on these road width and by considering the portion of damaged road, the widening up of the roads can be done.

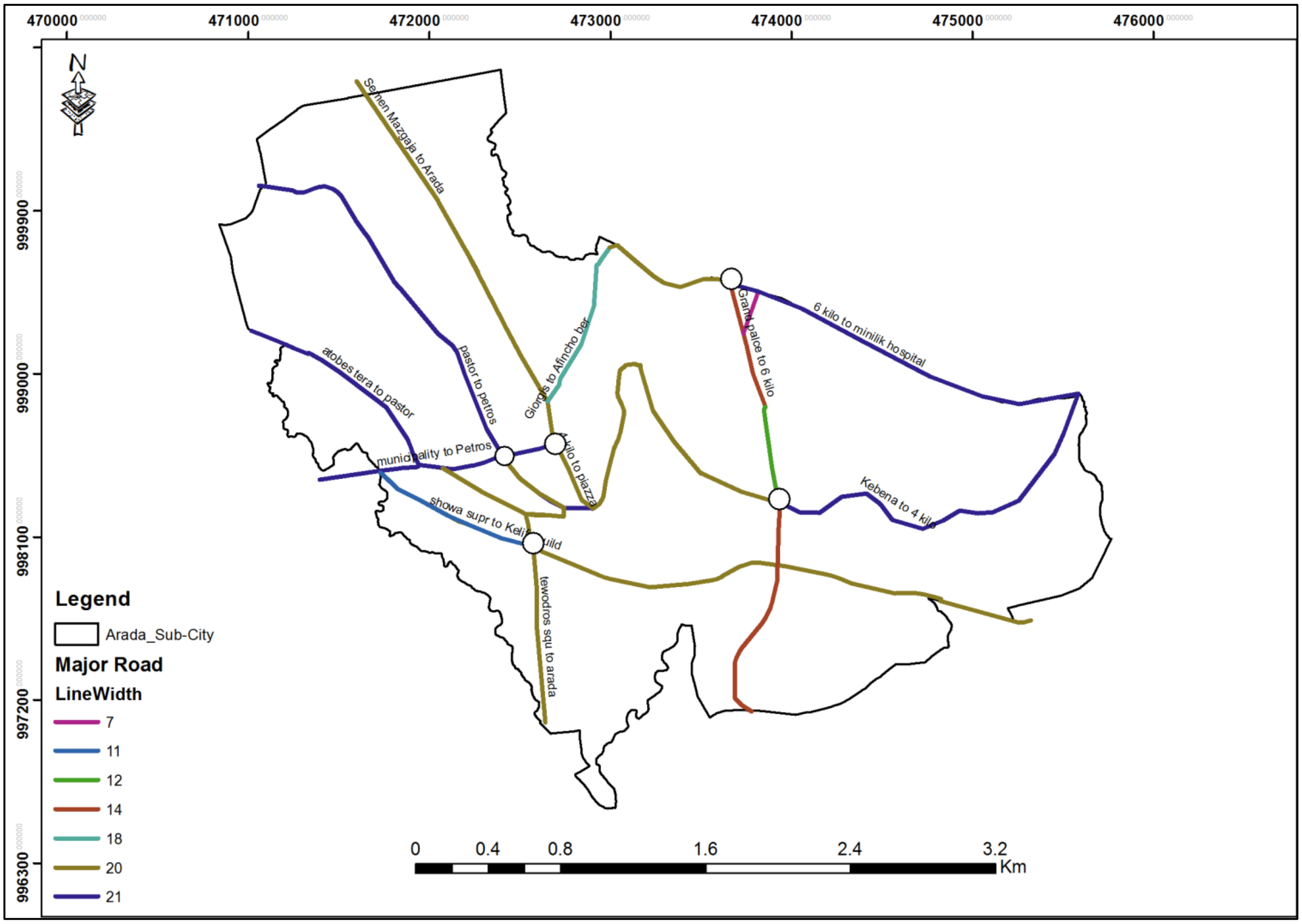


Figure 5.14 Map of Major Asphalt Road width in Arada sub-city

5.7 Road Safety

In recent years, safety is still a key issue within transport planning, as many people are contract road accidents every day, often suffering injury or death. According to WHO (2004) report, road traffic accident kills more than 1.2 million and injures between 20 and 50 million people every year. As a result, it has become the ninth most common cause of death in 2004, and remains among the most central public health problems in the world (WHO, 2004).

Safety is critical in any transport system. The safety level of transport infrastructure is defined by the number of accidents on one hand, and by the impact of the accidents on the other. Using this indicator the road network related accident was assessed. Road traffic safety is measured as the number of road traffic crashes and causalities resulting from crashes per time period. To calculate road safety we need, recorded accident rates in different categories with their causes.

For this purpose data from the Arada sub-city Police department was used. Traffic accident in the study area is categorized by the type of accident, such as property damage, slight and serious injuries and death. In Arada sub-city, for the past 6 months (*Meskerem* to *Yekatit)* 79 peoples were dead because of traffic accident, 904 property damage and 106 slight and serious injuries were recorded. From those categories and number of recorded accidents, 105 property damage and 16 slight and serious accidents were occurred as a result of the road network. According to the report of UN, by 2015, road crashes was the leading cause of death for children aged 5-14 in the developing world. The same is true here, according to our data, from the total number of death recorded in Arada sub-city, 12 deaths were occurred on primary school students.

Table 5.1 Traffic Accident occurred in Arada sub-city from *Meskerem* to *Yekatit(2015)*

Accident Type	Accident Rate	Accident Rate associated with the Road Network
Property Damage	904	105
Slight & Serious Injuries	106	16
Death	79	-
Total	**1089**	**121**

Source: Arada sub-city police department

According to the study of Bitew, (2002) which was done on the traffic accident and identified that, the main causes of traffic accidents in Addis Ababa city in general and Arada sub-city in particularl are poor road conditions, poor driving behavior, inadequate traffic management systems, and poor vehicle maintenance upkeep. We also take into account that the road users are the cause for the accident.

5.8 Network Analysis

Network Analysis toolbox extension was developed for transportation application. The ArcGIS Network Analyst extension allows us to build a network dataset and perform analysis on a network dataset. This extension is composed of a number of parts, which I go through some of them.

The ArcGIS Network Analyst extension also allows us to solve common network problems, such as finding the best route across a city, finding the closest emergency vehicle or facility, identifying a service area around a location, servicing a set of orders with a fleet of vehicles, or choosing the best facilities to open or close (ESRI, 2015). Network Analyst can find the best way to get from one location to another or to visit several locations. The locations can be specified interactively by placing points on the screen, entering an address, or using points in an existing feature class or feature layer. If you have more than two stops to visit, the best route can be determined for the order of locations as specified by the user. Alternatively, Network Analyst can determine the best sequence to visit the locations, which is known as solving the traveling salesman problem.

5.8.1 Creating Route

In GIS environment after creating dataset, the next step is to create a route for each separate road which is a pre-requisite for making route event layer. In this case we have sixteen different routes, most of which radiate from a given point to a destination point (Arada Giorgis). Each of which has a route identifier Road ID (RID) which is a unique identifier for that given road (route) which speeds up the dynamic segmentation process.

Once creating a route for the entire roads one can say that it is ready for making route event layer. In order to speed up and facilitate the linear referencing process as well as finding the best route, closest facility and finding the service area primarily creating a route is essential.

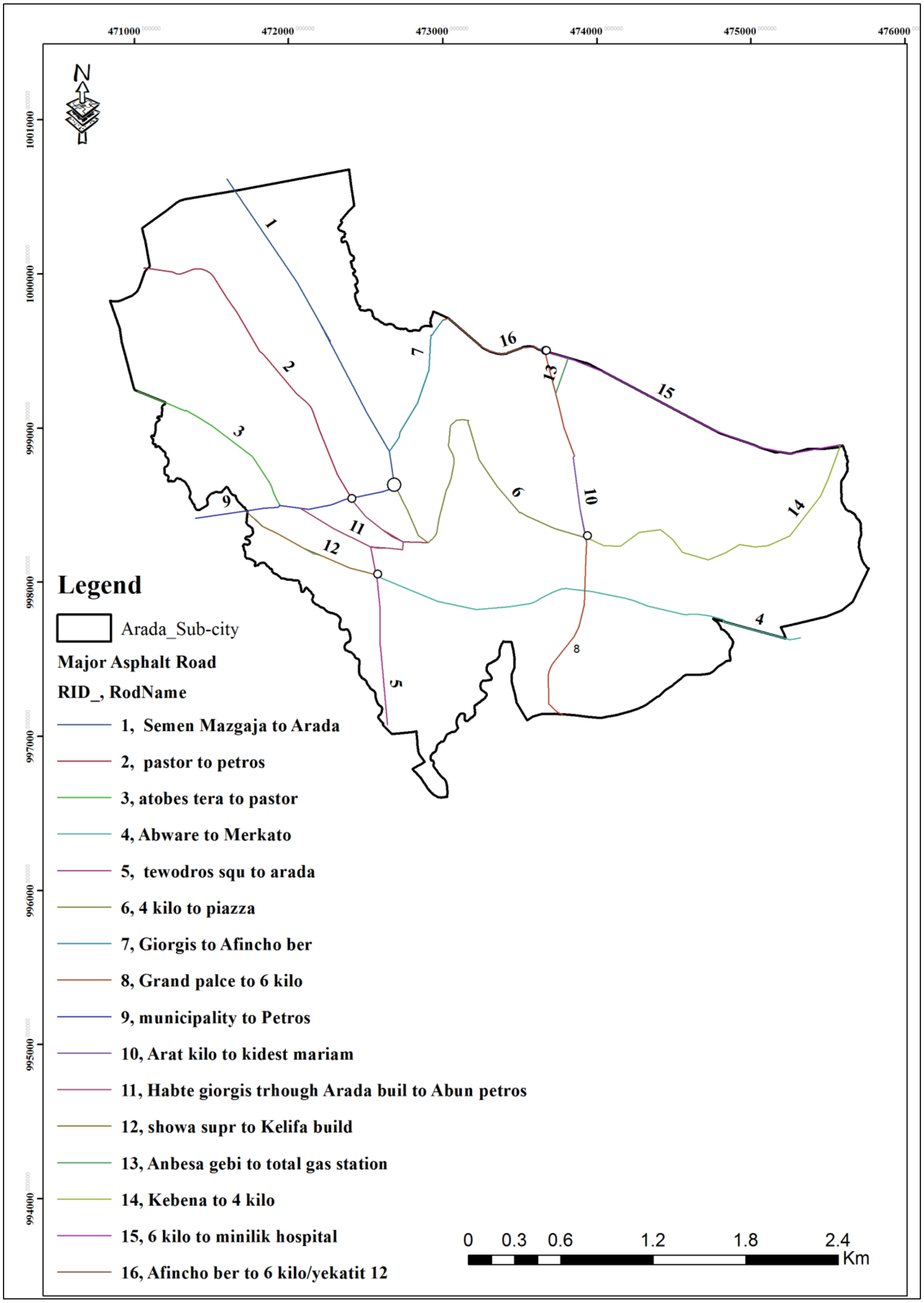


Fig 5.15 Route creation of the study area

Finally we get a given route out of different routes which makes route event layer (dynamic segmentation). In this case we have sixteen routes for each of which all the above consecutive steps are kept.

The other entity give due attention in this study is that of corridor information (illustrated on the map below). Corridor information in this case includes known institutions, religious places, and different organizations, higher institutions and others that give a reference for the other entities. Thus these entities those are found in this study area are well organized and enter in to the dataset. They are many in number and type, thus they are given a unique symbol to distinguish easily.

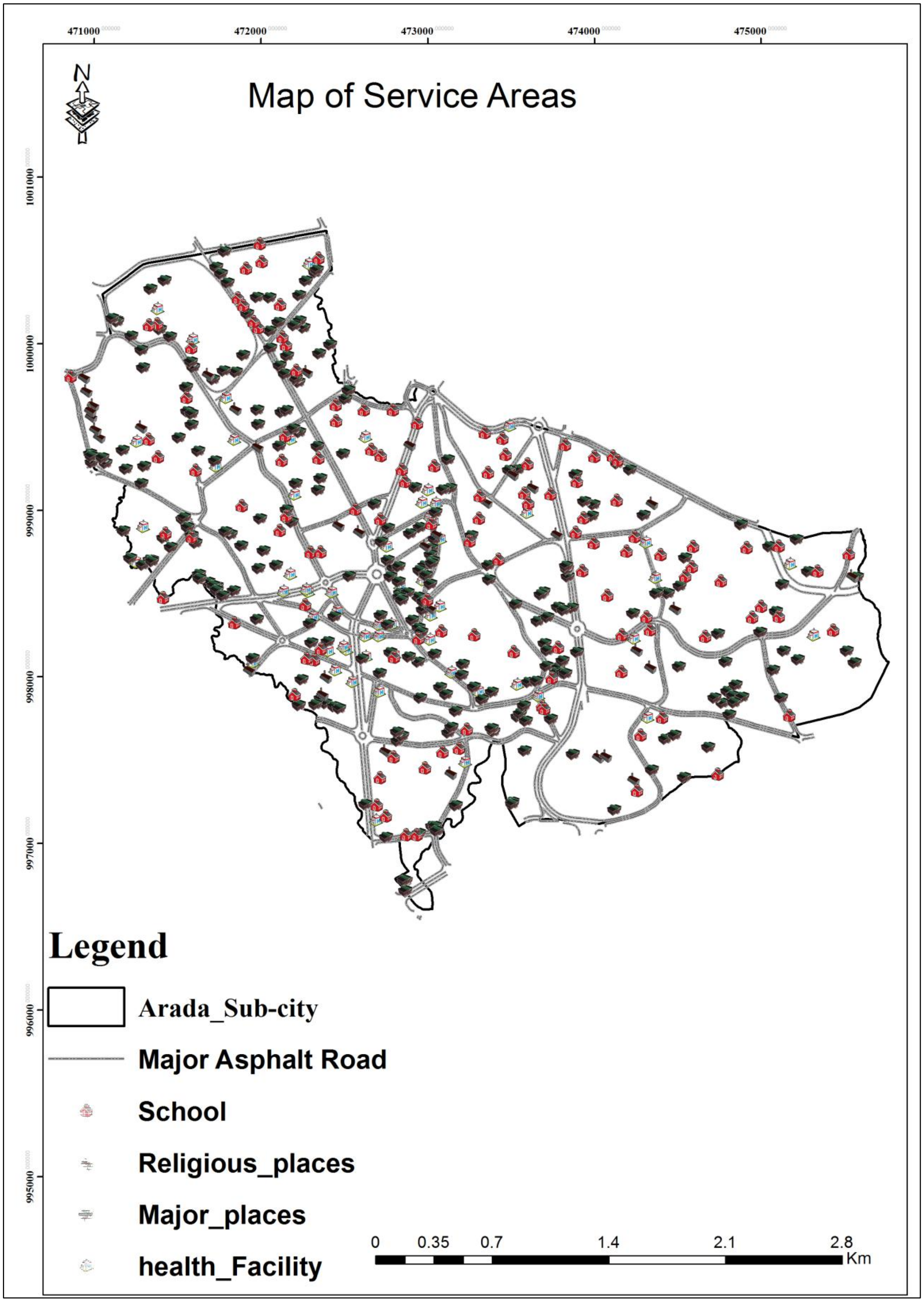


Figure 5.16: Service Places

After putting all the entities of the road in a linearly referenced network and dynamically segmented way and once the dataset is created, it is easy to manage the road and its entities in an integrated way. Since all the entities linearly referenced, one can perform all network analysis. Any worker in the authority can query and observe what happens on the road network. So it is supposed to save time, resource and above all it enhances work efficiency of the authority.

5.8.2 Finding “Best” Route

Using the network analyst in GIS techniques, one can perform all types of network analyses like that of finding best route analysis, finding closest facility, finding service area, and cost matrix analysis. Whether finding a simple route between two locations or one that visits several locations, people usually try to take the best route. But best route can mean different things in different situations. Creating the best route can mean finding the quickest, shortest, or most scenic route, depending on the impedance chosen.

If the impedance is time, then the best route is the quickest route. If the impedance is distance, then the best route is the shortest route. Hence, the best route can be defined as the route that has the lowest impedance, or least cost, where the impedance is chosen by the user. Any cost attribute can be used as the impedance when determining the best route.

One can make so many different types of best routes for a specific places depending up on the area of interest. The well-equipped network analyst gives the best out of many routes depending up on the impedances that a given person wants. For this case the best route is created from Ethiopian News Agency which is found in *woreda* 04 to *Kebena* (*woreda* 07), and the impedance taken for the analysis is that of distance in minutes. This means, by the existing road network, in order to travel from Ethiopian News Agency to Kebena using the shortest path one has to follow the figure below. Thus we can say that this is the best route from Ethiopia News Agency to Kebena.

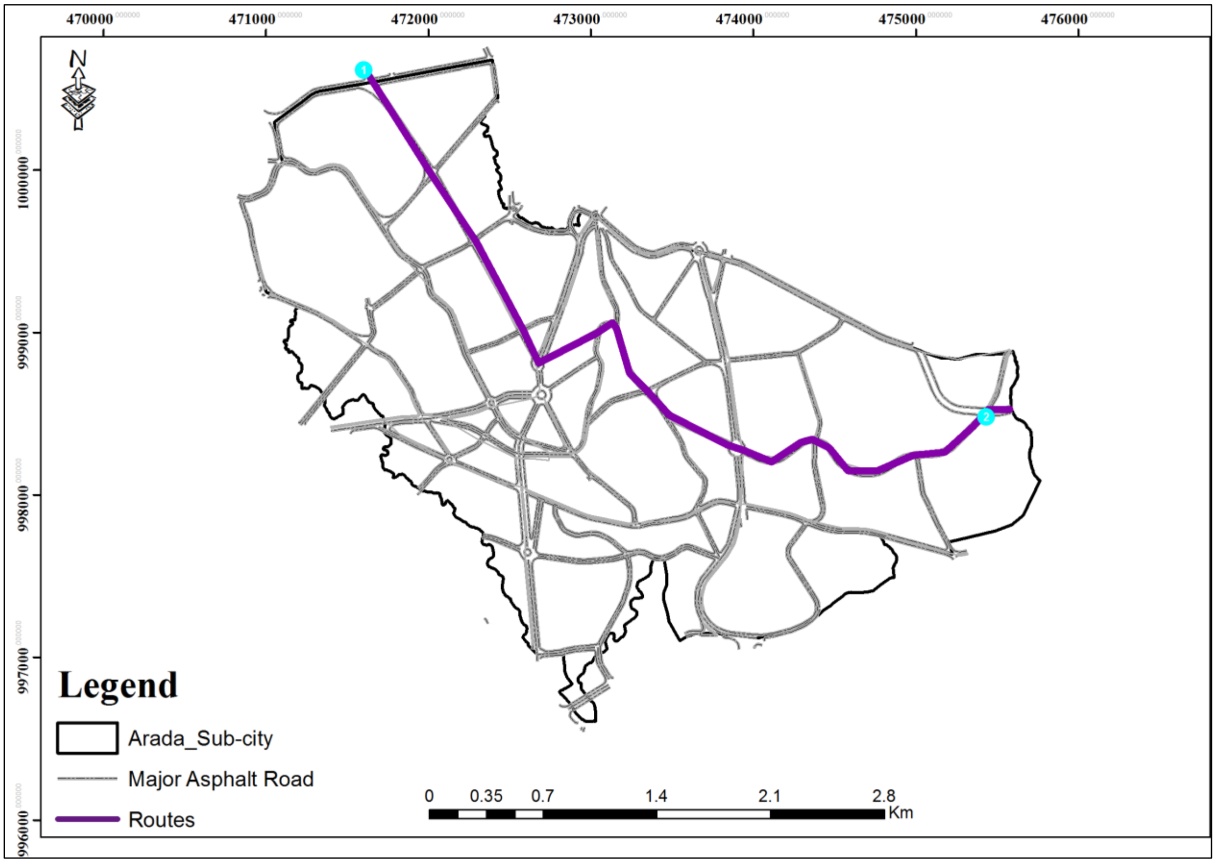
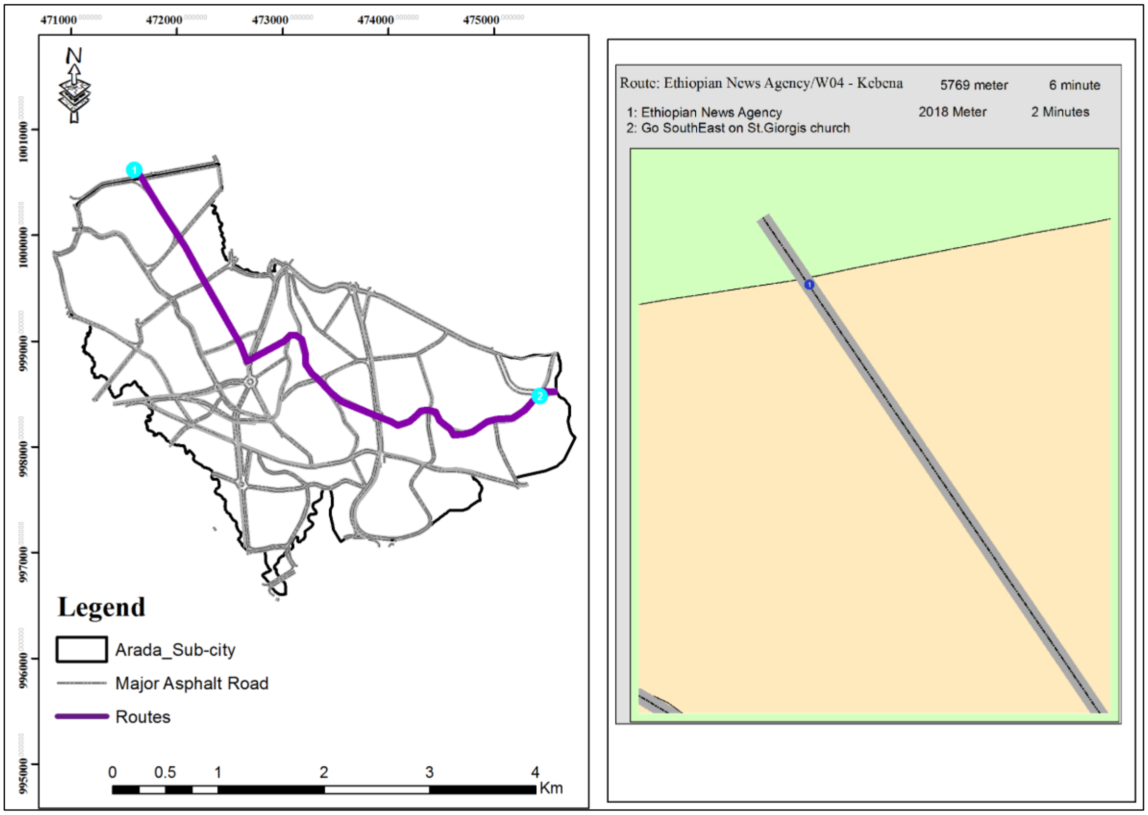
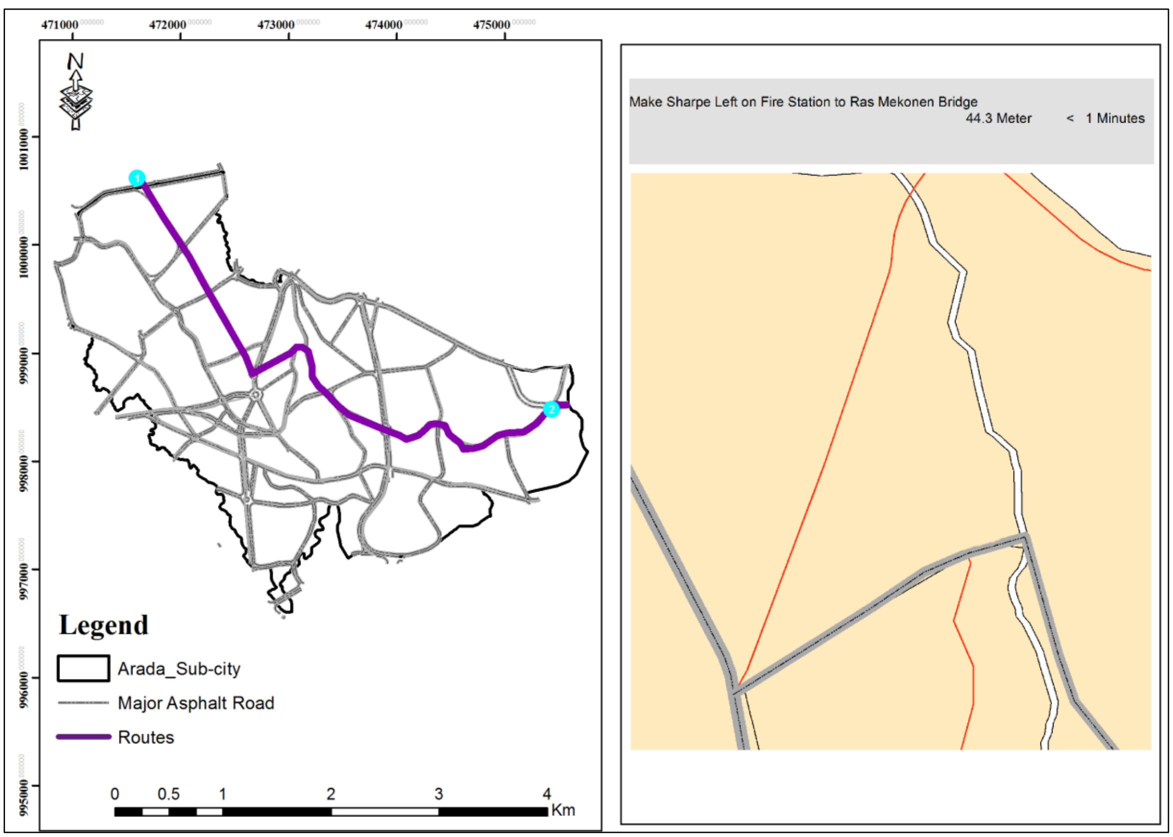


Figure 5.17: Map of Best Route from Ethiopian News Agency to Kebena



471000
472000
473000
474000
475000
1001000
1000000
999000
998000
997000
996000
995000
N
Legend
Arada_Sub-city
Major Asphalt Road
Routes
0 0.5 1 2 3 4 Km
Route: Ethiopian News Agency/W04 - Kebena
5769 meter
6 minute
1: Ethiopian News Agency
2: Go SouthEast on St.Giorgis church
2018 Meter
2 Minutes



471000
472000
473000
474000
475000
1001000
1000000
999000
998000
997000
996000
995000
N
Legend
Arada_Sub-city
Major Asphalt Road
Routes
0 0.5 1 2 3 4 Km
Make Sharpe Left on Fire Station to Ras Mekonen Bridge
44.3 Meter
< 1 Minutes

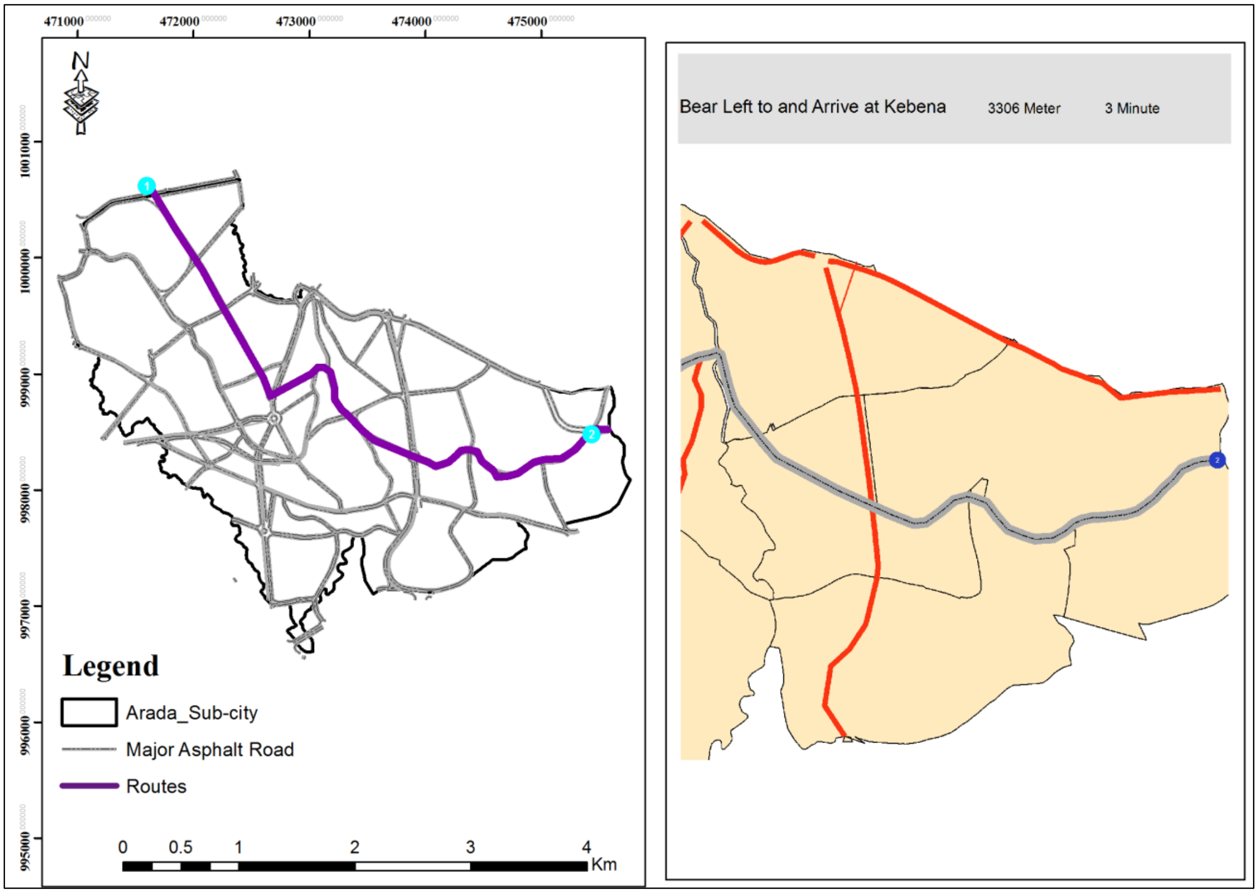


Figure 5.18: Map of Best Route from Ethiopian New Agency to *Kebena*

Network Analyst allows performing multiple closest facility analyses simultaneously. This means we can have multiple incidents and find the closest facility or facilities to each incident. So, the second best route is from Police Officers club (*woreda* 03) to Minilik II Hospital (*woreda* 07), (figure 5.19). Here the impedance is distance. Thus out of many routes from Police Officers club to Minilik II Hospital (the best route) the one seen below is selected. Thus it is the best route out of many routes for these two different locations.

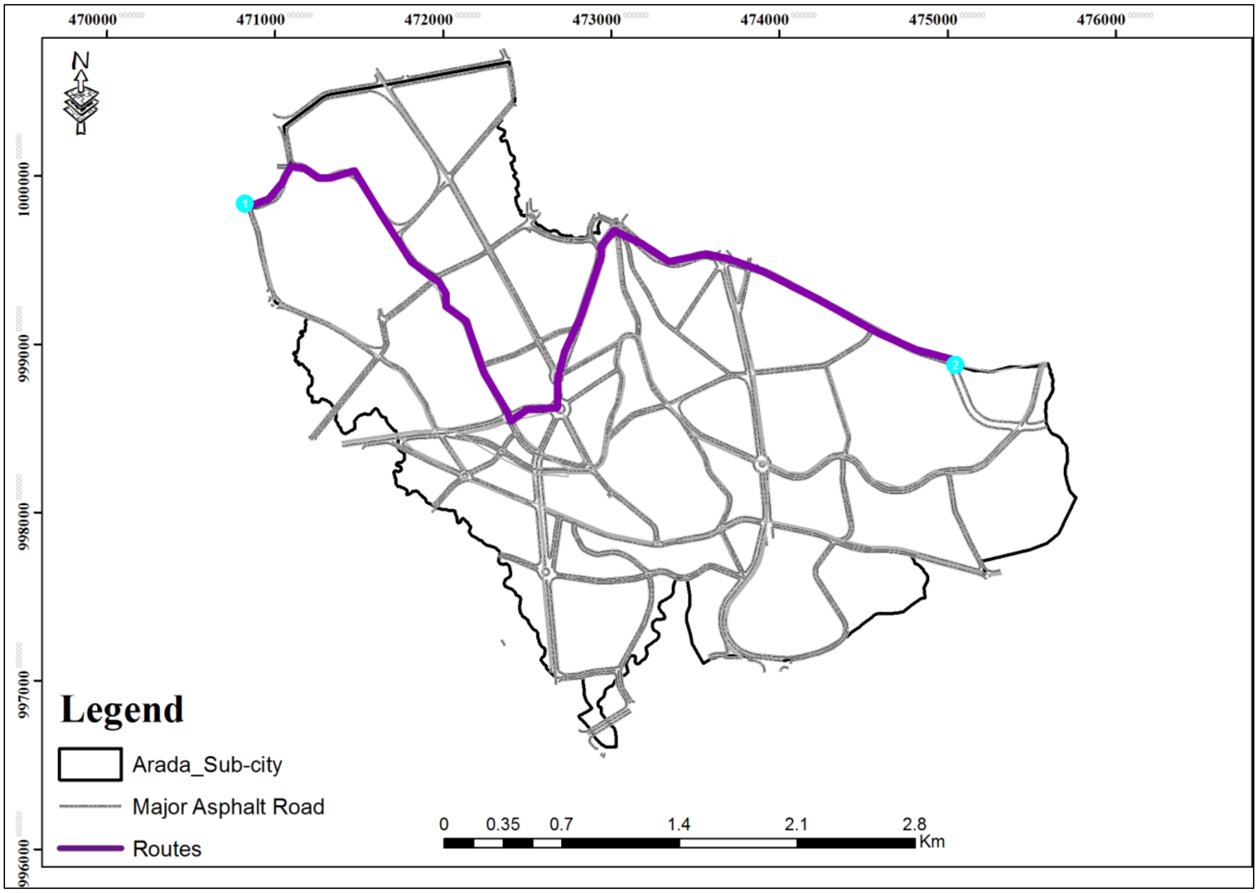
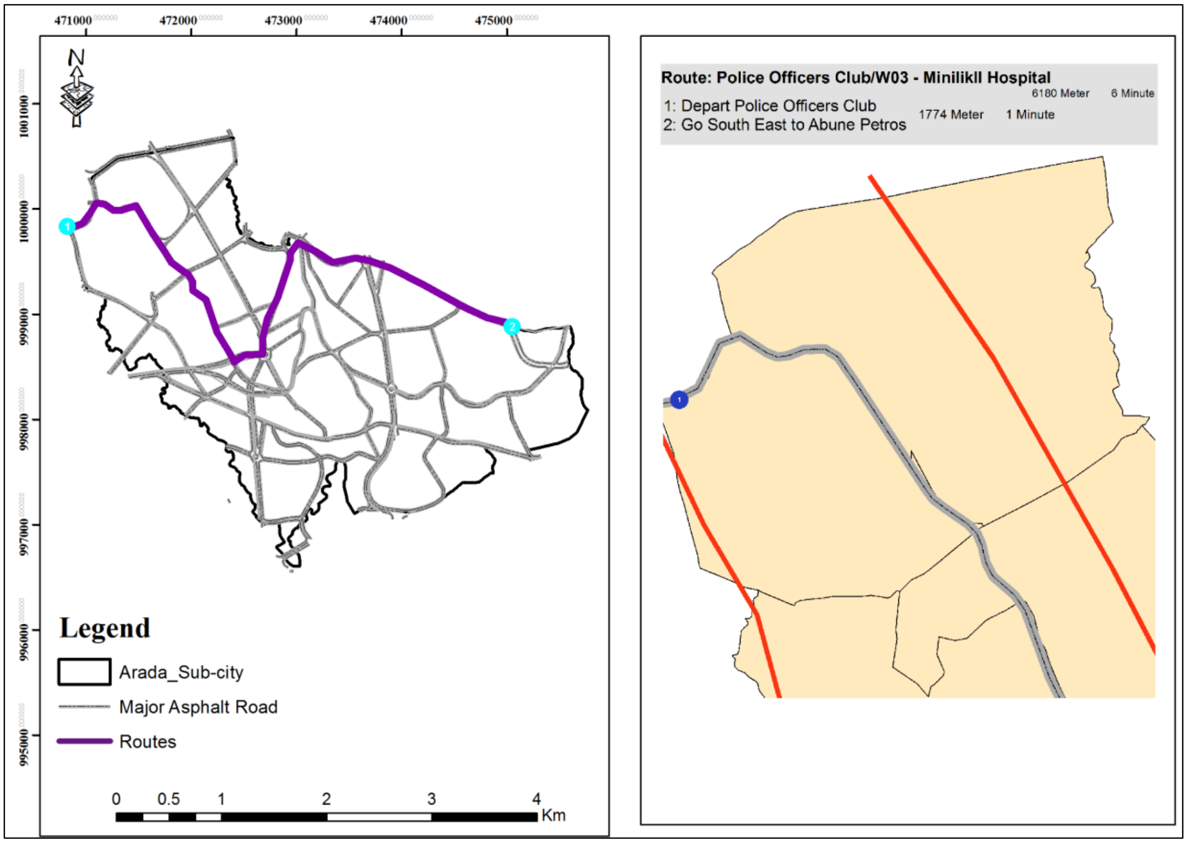
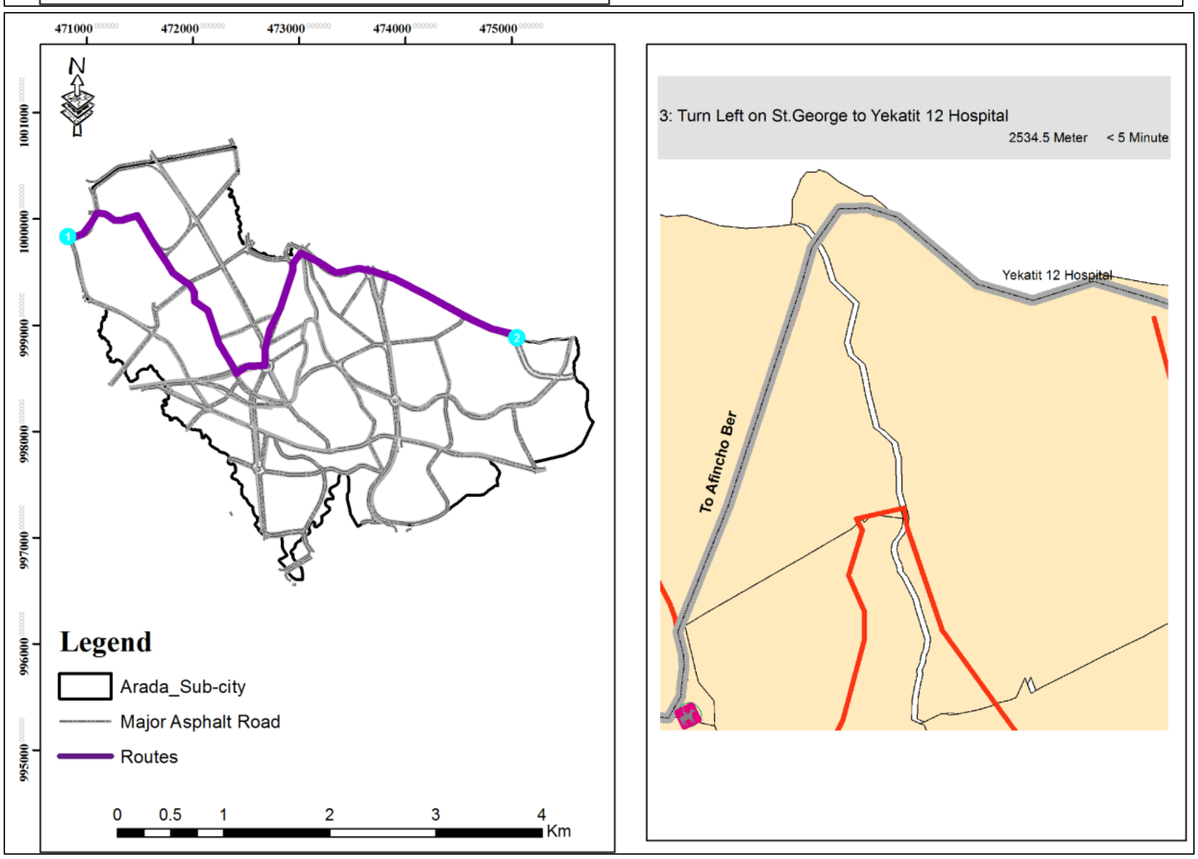


Figure 5.19: Map of Best Route from Police Officers Club to Minilik II Hospital



471000
472000
473000
474000
475000
N
Legend
Arada_Sub-city
Major Asphalt Road
Routes
0 0.5 1 2 3 4 Km
Route: Police Officers Club/W03 - Minilikll Hospital
6180 Meter 6 Minute
1: Depart Police Officers Club
2: Go South East to Abune Petros 1774 Meter 1 Minute



471000
472000
473000
474000
475000
N
Legend
Arada_Sub-city
Major Asphalt Road
Routes
0 0.5 1 2 3 4 Km
3: Turn Left on St.George to Yekatit 12 Hospital
2534.5 Meter < 5 Minute
Yekatit 12 Hospital
To Afincho Ber

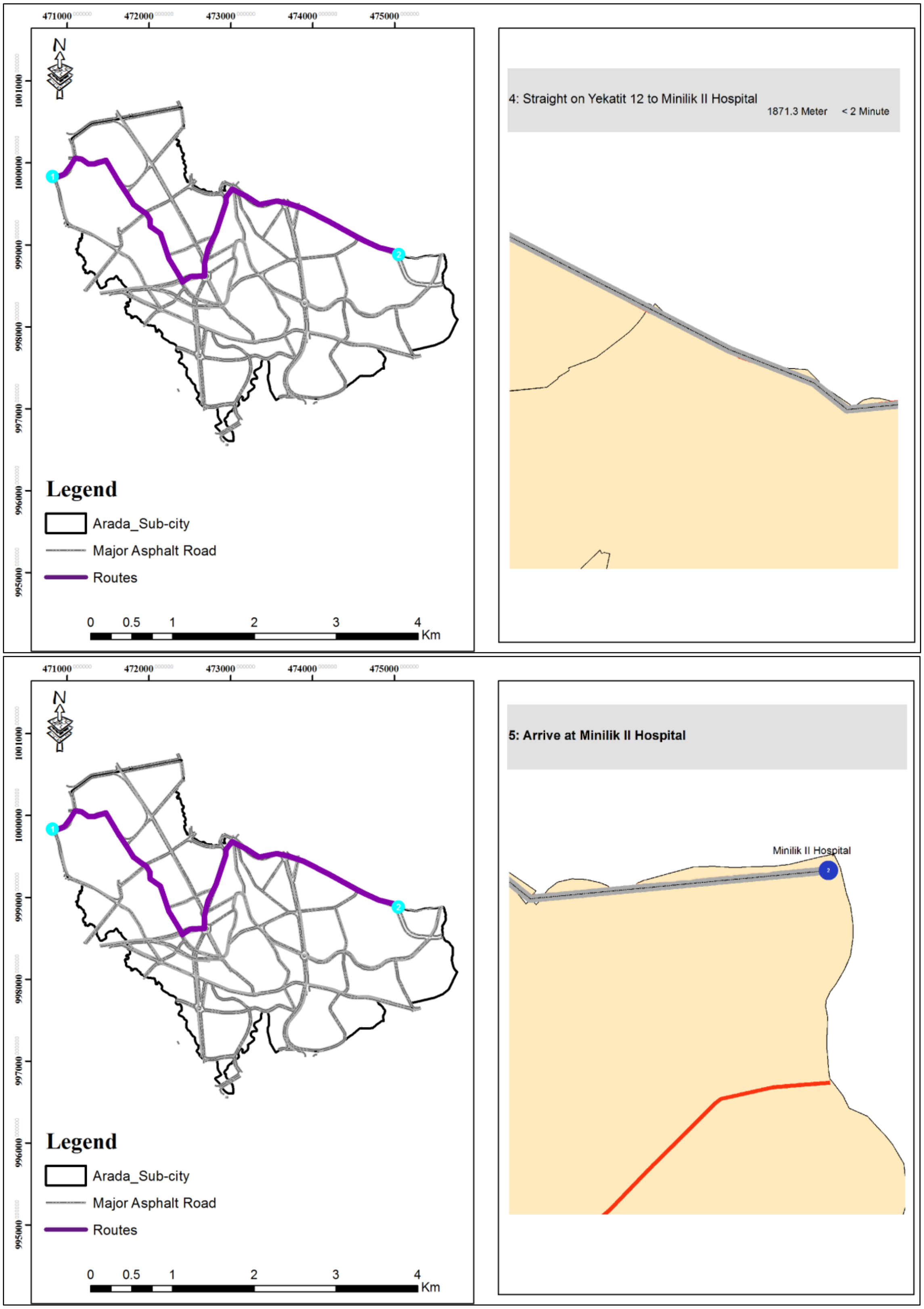


Figure 5.20 Maps show best route from Police Officers club to Minilik II Hospital

5.8.3 Service areas

With Network Analyst, one can find service areas around any location on a network. A network service area is a region that encompasses all accessible streets. Those streets are lie within specified impedance. For instance, the 10-minute service area for a facility includes all the streets that can be reached within 10 minutes from that facility.

In GIS environment, service areas created by Network Analyst toolbox which can help to evaluate accessibility of road network. Accessibility refers to how easy it is to go to a site. Accessibility can be measured in terms of travel time, distance, or any other impedance on the network. Evaluating accessibility helps answer basic questions.

It can help to identify what is near an existing business to help you make other marketing decisions. One simple way to evaluate accessibility is by a buffer distance around a point. Service networks computed by Arc GIS Network Analyst can be analyzed by identifying the accessible streets within a specified distance of a site via the road network. Once service area is created, you can use service networks to see what is alongside the accessible streets, for example, find competing businesses within a 5-minute drive or it can be used, for example, to show how many hospitals are within 5-, 10-, and 15- minute drive times of schools.

Concentric service areas show how accessibility varies with impedance. Once built, you can use service areas to identify a kind of services that a given incident area like that of market places, gas stations, government organizations, hospitals, school or anything else within the neighborhood.

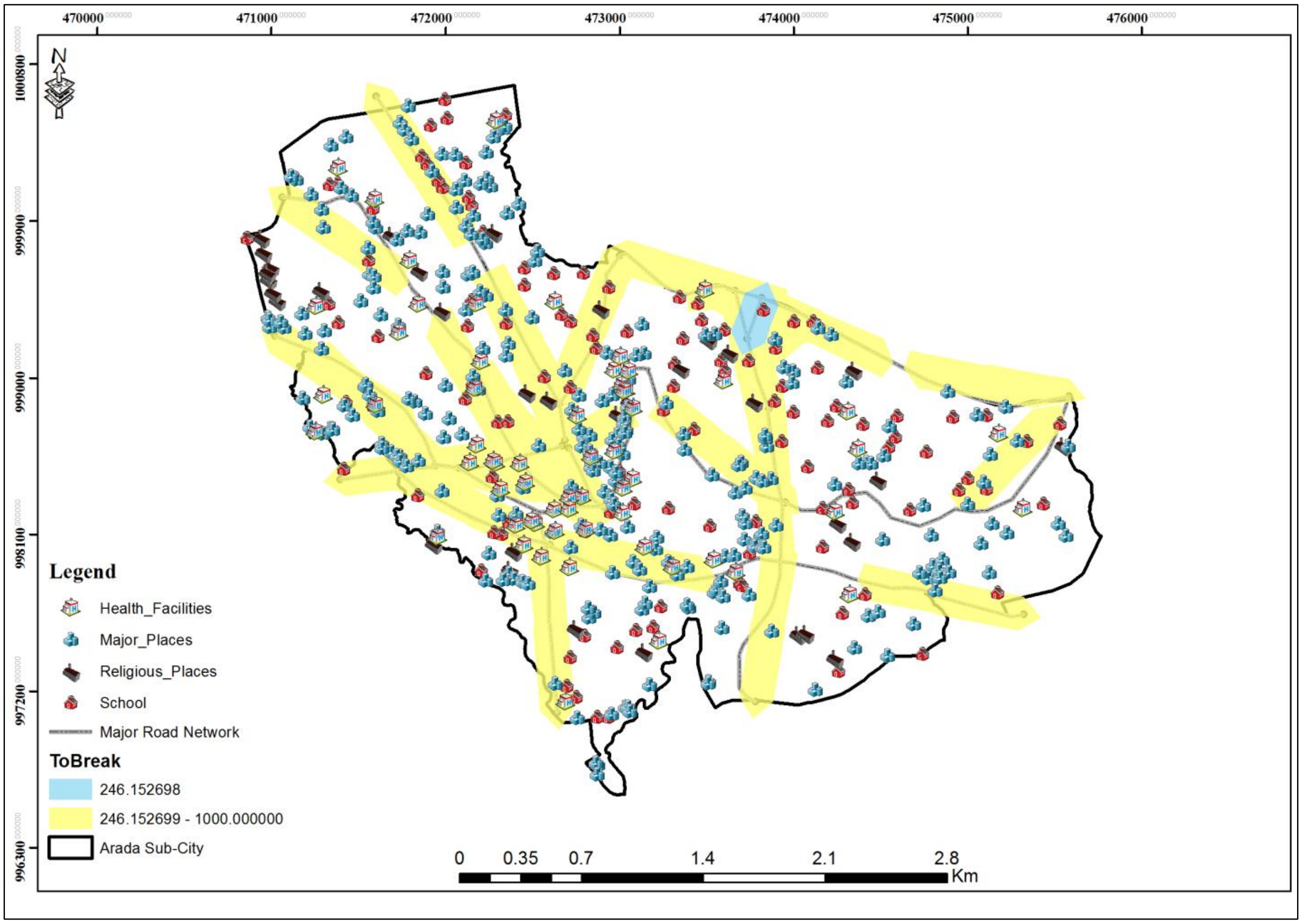


Figure 5.21: Map of Service area

Based on figure 5.21, distance of all service areas from the major road networks is computed, taking distance as the impedance. Based on the result, service areas having lower value are more accessible and needs lesser travel time.

On the other hand, service area analysis is done using the impedance distance for Health service areas those are found within the sub-city. Using five different default breaks; 223 meter, 411 meter, 549 meter, 684 meter and distance greater than 899 meter. Thus, the polygons shown in figure 5.21 illustrate the distance of available asphalt road within the service area of Health facilities.

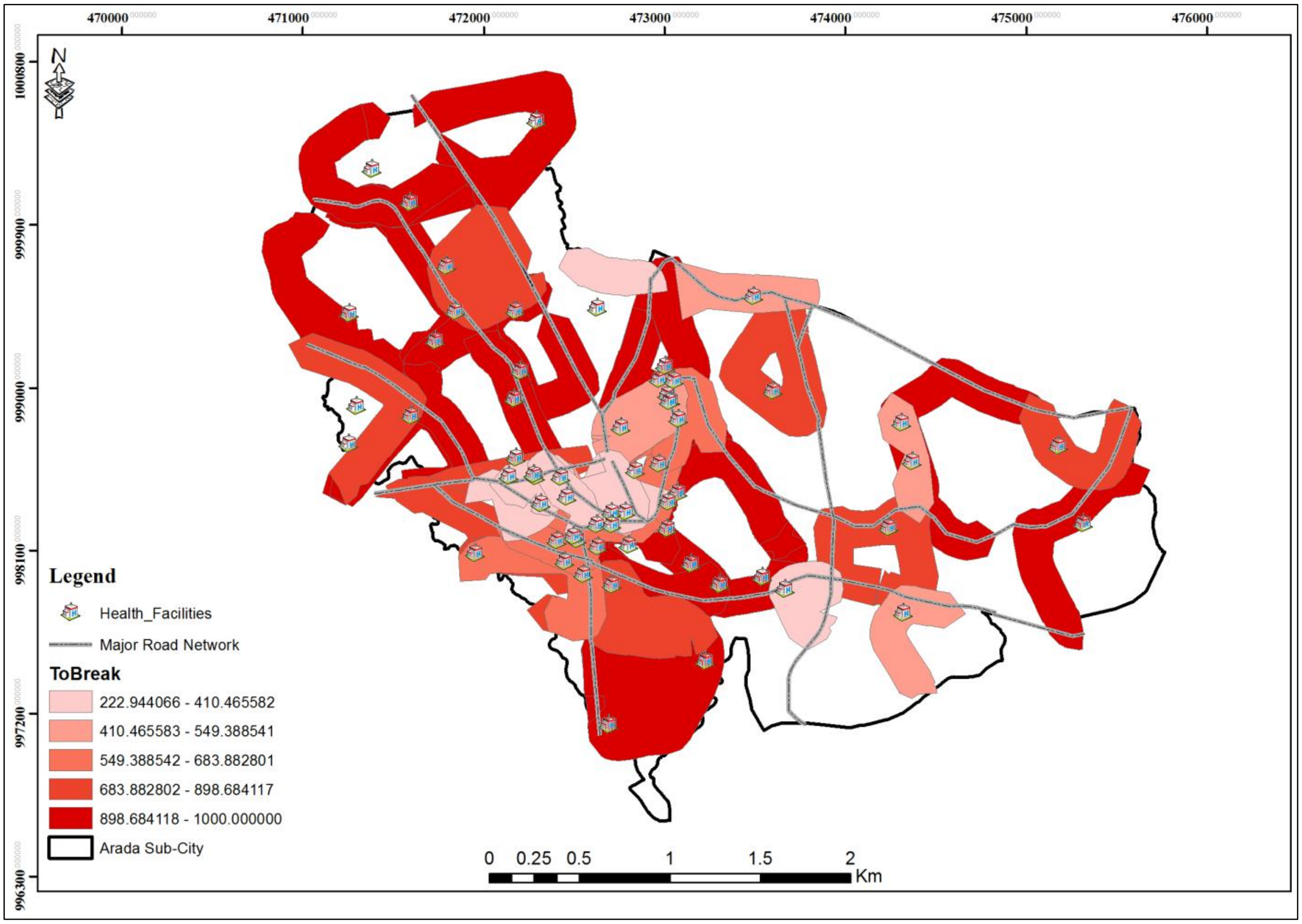


Figure 5.22 Health facility Service area map

CHAPTER SIX

QUANTIFICATION OF INADEQUACY WITHIN THE ROAD NETWORK

In this chapter based on the result obtained from the availability of the road network, inadequate road network was identified. How to set the threshold for inadequacy was discussed and the two types of inadequacies: road network with capacity limitation and missing road network was identified and discussed. By adding new road to the existing road network, the improvement of the network structure will be assessed. For fanatical purposes based on the construction cost, population they serve and connectivity they create in the network, the identified missing road networks was prioritized.

6.1 Identification of Inadequate Road Network

The effort to set a criterion that identifies a particular area as inadequate actually depends on the level of available resource. As such, a particular network structure in an area can be estimated adequate in one *woreda* is deemed inadequate in another *woreda*. However, it is still felt important to have forwarded, as part of this research, a particular method of setting acceptable range of the lower point to effectively identify observed inadequacy in the road network that can be of help to decision makers for the identification of areas with inadequate road network structure.

Based on the road density per population value, the inadequacy level is calculated from the histogram of zonal statistic (which calculates the density of road network in each *woreda*) and line density value in ArcGIS-Spatial Analyst toolbox. Essentially, lower values in the line density and zonal statistics indicate a capacity limitation due to higher demand, even though there is an existing network whereas the higher values indicate that area (*woreda*) suffers from lack of road network even though there is a demand. Hence, the weighted number of *woreda* is calculated for both sides, i.e. lower side road density and the higher side road density. Therefore, according to figure 6.1 for the particular major asphalt road density that can be considered as adequate ranges from 1.5-1.94km/1000 person.

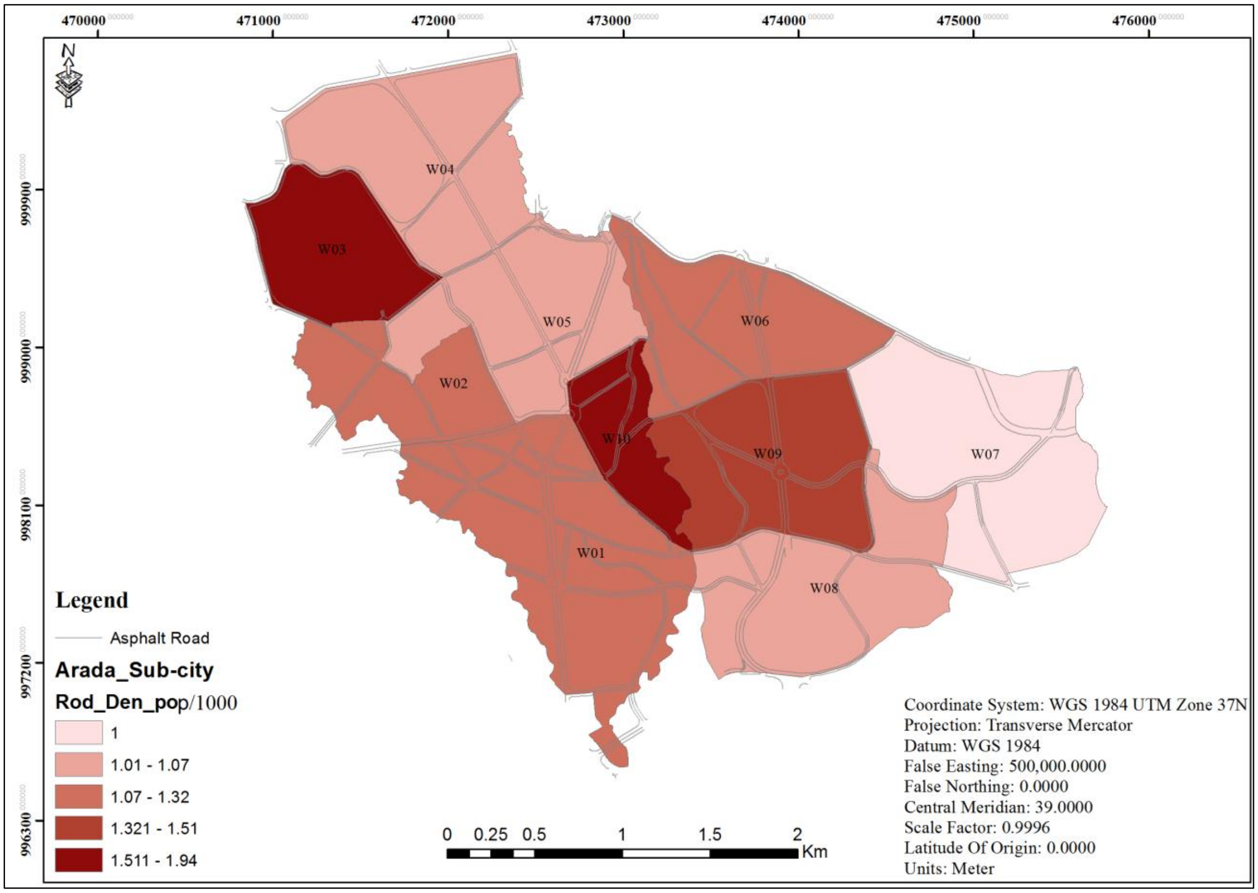


Figure 6.1: Map of Road Density per Population

In the Urban Transport Study, (2004/2006) and Addis Ababa Traffic Management Final Inception Report, (2011), there are six corridors mentioned that need immediate attention (figure 6.2). Those are:

1) Ayat – CMC – Megenegna – Leghar – Mexico – TorHailoch(the east-west corridor)
2) Urael – Grand Palace – Shiromeda
3) Kaliti – Meskel Square – Laghar – Piazza (using Debrezeit and Churchill roads, north-south corridor)
4) Menilik Square – Kolfe
5) Wingate – Abune Petros
6) Mexico Square – Mekanissa

From the above listed networks, there are four road networks found within Arada sub-city.

A. Urael – Grand Palace – Shiromeda
B. Kaliti – Meskel Square – Laghar – Piazza (using Debrezeit and Churchill roads, north-south corridor)
C. Menilik Square – Kolfe
D. Wingate – Abune Petros

In fact, the UTS, (2004/2006) recommended that Light Rapid Transit (LRT) developed in the east-west and north-south corridors and Bus Rapid Transit (BRT) in the remaining corridors identified above. However, Traffic Management Study, (2011), intimated that the traffic volume for these corridors does not merit LRT and hence, the study recommends development of BRT for all the six corridors and upgrading the road hierarch to a higher level. Those corridors that are found in the Arada sub-city is shown in figure 6.2. As it can be visualized from the map, the four corridors line up with the values of road network density within the area (*woredas* of Arada sub-city).

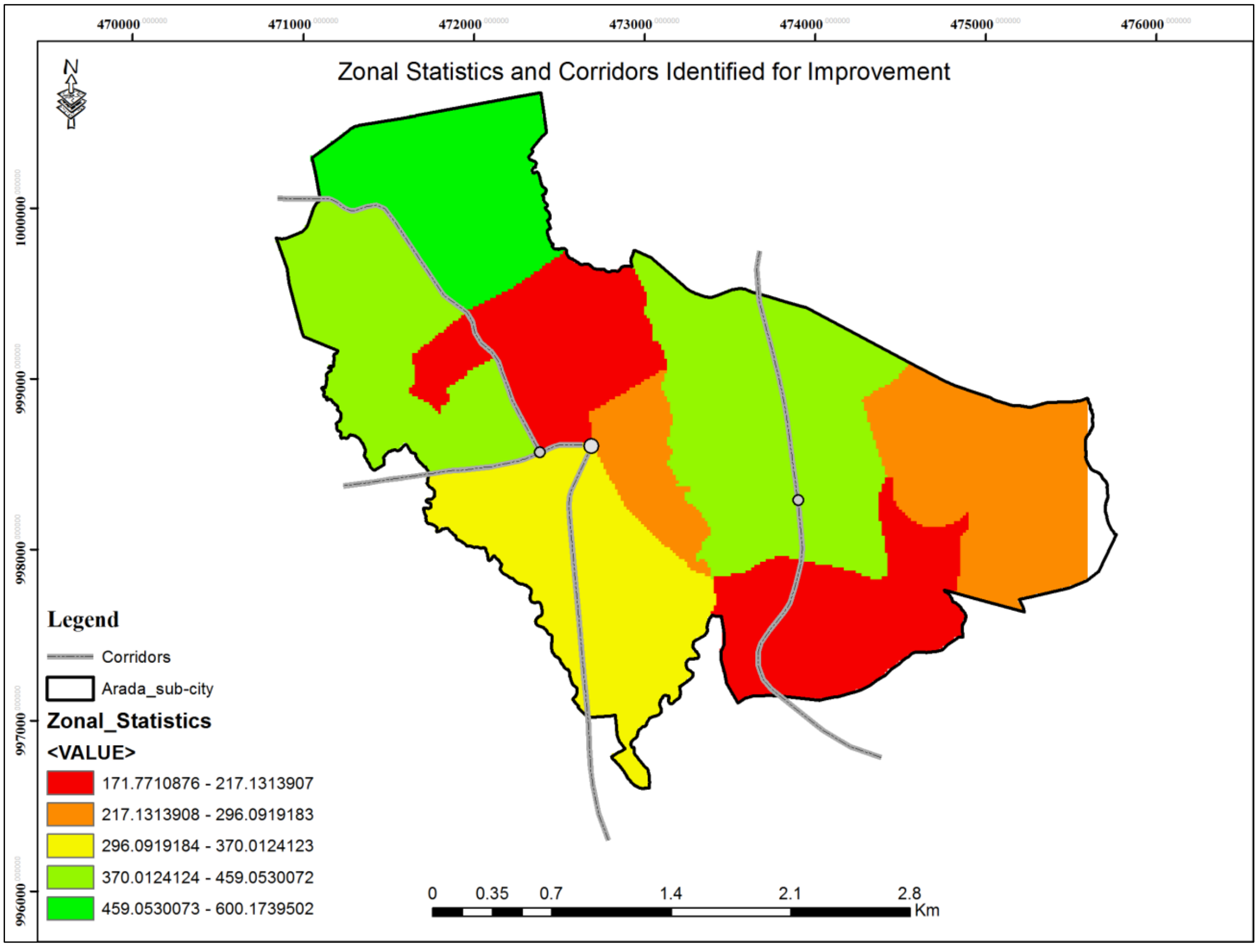


Figure 6.2: Map of Identified Road Corridors and Zonal Statistics of the Study Area

Based on the zonal statistics of the study area, lower values indicate a capacity limitation due to higher demand, even though there is an existing network. Whereas the higher value indicates, that area (*woreda*) suffers from lack of road network even though there is a demand. From figure 6.3, we can see that the already identified corridors for improvement are well mapped. However, by calculating line density of the existing road network, additional corridors are identified for future development. Spatial analyst-line density is also able to identify 8 more inadequate corridors. These extensions include road networks in the northern, north western, some networks in eastern and in the central corridors.

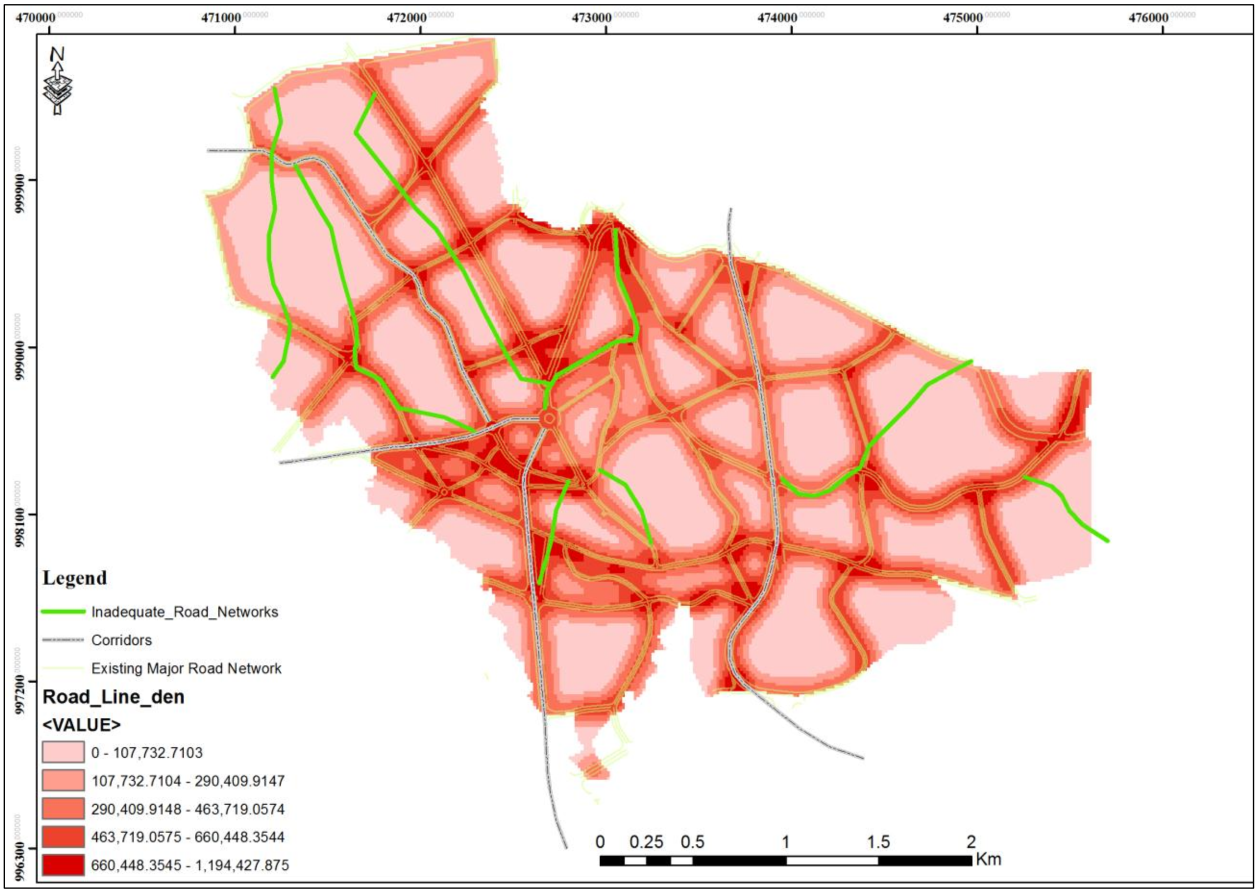


Figure 6.3: Map of Inadequate Road Networks and Value of Road Line Density

From the above map we can identify three types of inadequacy that can be manifested in the form of:

1) Areas with roads carrying more traffic loads capacity
2) Areas with roads those are not efficient because they are not the shortest paths for particular road network
3) Areas that lack road network despite the presence of demand

The first type of inadequacy is mostly observed in the central part of the sub-city. Their road line and corridor value is higher than the other networks. The second type of inadequacy can be observed in the eastern part of the sub-city. And the third type of inadequacy is exhibited in the north western part of the sub-city.

Areas where the third type of inadequacy is observed require the development of more road network. However, these links were identified by connecting population density with zonal statistics of the road network. To increase the road network connectivity the links are connected to the nearest existing road network.

The missing road links values (figure 6.4) are identified based on the corridor value and line density of the existing road network. Population served by the links depends on the link fall, length of the road and the population density of the area.

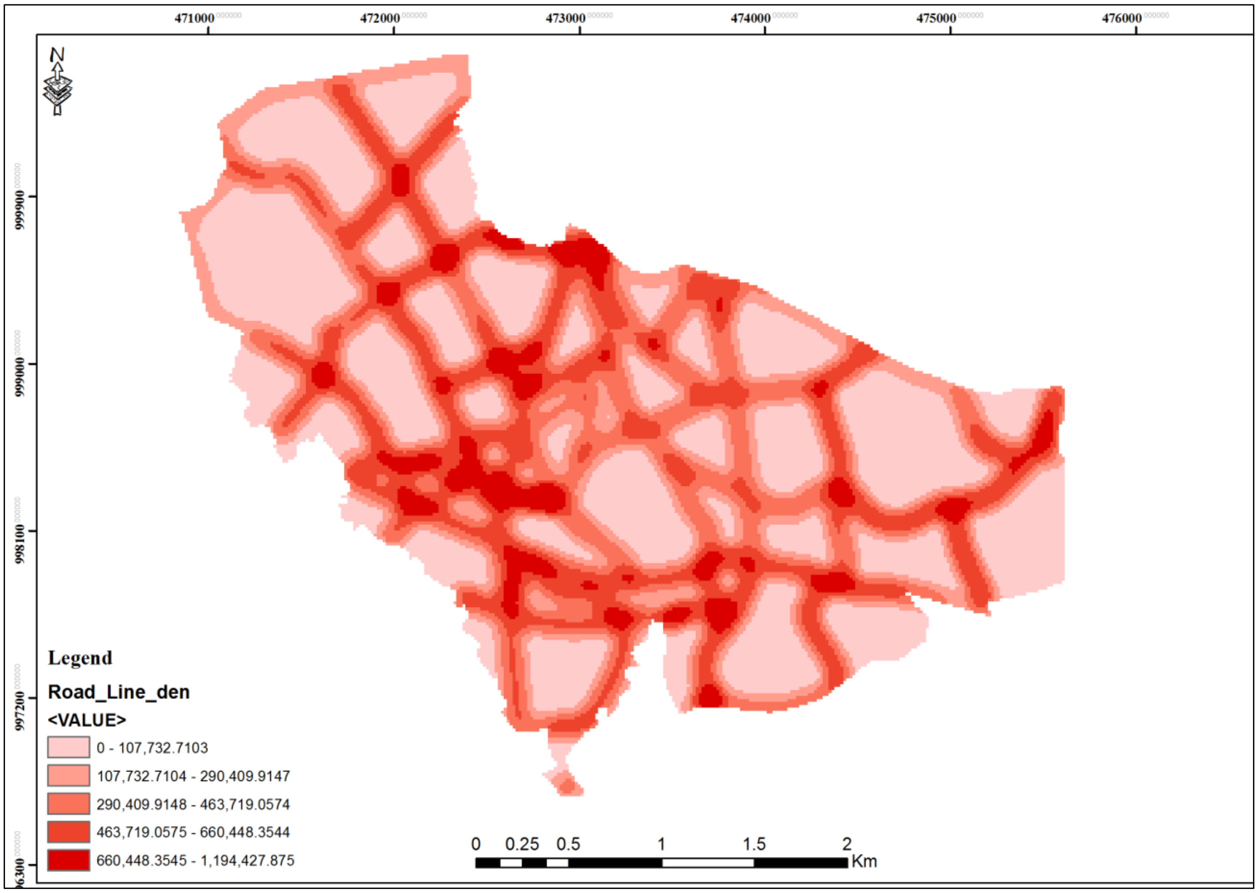


Figure 6.4: Map of Line density

Based on the line density value (which calculates the magnitude per unit area from the linear features that fall within an area) of the existing road network and the concentration of population, the density of the existing road network was computed. According to the result of the line density shows in figure 6.5, higher value (660,448-1,194,427) indicates that there are road network with high capacity limitation. These areas are found within the central part of the sub-city, where large number of population is concentrated. Hence, lower value (107732-290,409) indicates, the inadequacy of road network for the demand in the area.

CHAPTER SEVEN

CONCLUSION AND RECOMMENDATIONS

7.1 Conclusions

The world is concerned with economic strength, social equity and environmental quality which are brought to one in the opaque concept of sustainable development. Nowadays, sustainable development is widely perceived as a development pattern that improves the quality of life while protecting and enhancing the natural environment. The transport system is one of the basic components of sustainable development which integrates the economic, social and environmental needs of a city.

An effective evaluation of transportation network efficiency/performance is essential to the establishment of sustainable development in any transportation system. Based on a definition of transportation network efficiency, a quantitative efficiency evaluation method for road transportation network is proposed, which could reflect the effects of the existing road network structure of Arada sub-city.

One of the objectives of measuring road network performance was to identify the existing road network efficiency and provide information on prevailing road network structure and the demand for travel in the area. In this particular project, the researcher had evaluated the existing road network structure to estimate its efficiency and to ultimately determine the level of infrastructure that is required to support economic and social activity in the study area. Furthermore, the road network performance was calculated using some road network performance indicators.

Based on the case study for Arada sub-city, it is observed that higher road transport infrastructure is exhibited in some areas of the sub-city. These areas are having common characteristic except population number. They are commonly characterized by important socio-economic activities of the entire city including freight terminals, employment centers and higher educational institutions.

The road density, expressed by the length per area is found to be high in the central area of the sub-city. As well as, the road length per unit of person in the central areas is observed low. Proximity to the road network within the central area is not more than 100m, which allowing more people to access those road networks found in the area. However, travelers in the western and north eastern part of the sub-city have to travel 300 and more meters to access the existing road infrastructure. This result indicates the inadequacy of the road network in those areas.

This paper argues that critical problems facing many cities of the world worsening traffic congestion, air pollution, joblessness, and unaffordable housing are intimately tied to the phenomenon of accessibility. So, based on the survey result of this study, major destination points in the study area can be accessible within a maximum of 35 minutes of travel time. When we compare the travel time to reach destination point with the total area size of the sub-city, it is not satisfactory. The total area of Arada sub-city is smaller in size, even though to reach the destination point one needs to waste some of his/her time making a trip. Within the study area it is found difficult to reach the destination point by the proportional time. This is because of the congestion and inadequate road network in the area.

The road network connectivity of Arada sub-city is about 1.66 beta index. In this regard, the connectivity of the roads is allowing the sub-city to have several direct links between *woredas* and with neighbor sub-cities.

Based on the data obtained from Addis Ababa City Road Authority, the performance of most of the existing road networks were found under deprived condition. This type of road network needs more attention than before. Arada, being one of the major important sub-cities, the condition of some roads is very poor. Currently the construction of new roads and maintaining the existing ones is increasing throughout years, but still it needs more effort to gain a good road network in the sub-city.

According to the data obtained from Arada sub-city transport office, vehicles those are making a trip on the road networks of the sub-city are getting increased. For the reason of being the cities CBD, the roads of the Arada sub-city are getting burdens to provide adequate travel service for large number of cars in a day. Larger number of vehicles on a specified road network can have a negative impact. Hence, population, vehicles, road length and area have a direct and indirect relation among themselves related to road network.

According to WHO report, by 2030 the fifth most common reason for loss of health will be an injury generated within the road transport system. Among this, 90 % of the fatalities are in poor and middle income nations. In Arada sub-city there is traffic accidents occurred because of many reasons. But to curve this damages the increment of constructing new road only will not assure the safety of users rather the number and complexity of accidents increase which also has effect on road network performance. So there must be a hard work on engineering solutions on the road designs and construction to improve road safety and road network performance.

The overall result of the performance of the road network within Arada sub-city shows that, *Woreda's* that are found in the northern and southern extent of sub-city are prohibited from enjoying an acceptable road transport service. These areas have a low density of road network and people in this area have to travel longer distance to get their destination. The researcher had noted that, people have to travel more than 300 m to reach any type of road infrastructure. Opposite to this area, in the central part of the sub-city and areas that are neighbor to the central *woreda* have better road network infrastructure and they can access to transport infrastructure traveling less than 200 m.

All in all the current road transport network of Arada sub-city suffers from different road transport inadequacies and road maintenance. The low level of road network service in some part of the study area contributes to unequal spatial accessibility, limits of mobility and has negative impact on the development of the study area and also the entire city. Cost of travel, both in terms of money and time, is considerably high in some part of the sub-city. The absence of sound road network infrastructure also causes to travel unnecessary distance to reach a destination point. This restricts the level of mobility of people and goods within the study area. There is high level of road infrastructure on the central area, but the roads are characterized by poor road condition and have low capacity. These road networks need to be upgraded.

7.2 Recommendations

In the research, based on the available data, the current road network of Arada sub-city is evaluated and identified inadequate road network which need further development and improvement. The indicators used in this research consider distance as impedance. Population density is considered while computing corridor and zonal statistics to identify inadequate road network. This opens an opportunity for further studies.

Based on the result of this study, the following issues are recommended:

- ❖ Immediate actions have to be taken by the city road authority, to upgrade and construct new road network, because the population and socio-economic activities in the study area are changing dynamically.
- ❖ Despite the availability of road network in the central areas, the performance is poor. Thus to improve the performance of the road network in order to meet the mobility demand, the existing roads should have been upgraded and maintained to hold large capacity.
- ❖ Researches on performance evaluation must be conducted, since it is useful for efficient resource allocation and efficient resource management.
- ❖ The main difficult in providing road transport service is the lack of adequate and efficient road network. So for better transport service deliverance, the road network must have evaluated and improved. For this purpose a target goal should be defined in the policy for the efficiency parameters.
- ❖ Road infrastructure related safety measures offer a large potential that could be exploited for a significant reduction of road accidents and their consequences.
- ❖ Accessibility can be improved not only by increasing vehicle flow and personal mobility, but also by increasing land use clustering and mix, improving walkability. So for better road transport accessibility in the study area, increasing the land use of the road network is essential.

Generally, for effective and adequate road transport service delivery, the concerned government offices especially AACRA, and all stakeholders dealing with road transport should put their efforts toward the road transport system by evaluating the overall performance of the road network in the study area.

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APPENDIX A: Existing Major Asphalt Road

This data is obtained from Addis Ababa City Road Authority 2016

Road Name	Carriage Way Width	Length	Area	Walkway Length	Carriage Way Type	Road Conditions
From Ethiopia hotel to national palace	17.6	1170	5014	2340	Existing Asphalt	Good
From National Place to Hilton Hotel	17.6	121.7	3116	243	Existing Asphalt	
From Teodros Sq to Arada Building	20	657	4693	1314	Existing Asphalt	Good
From meskel Sq mebrate to post office	18	972	4167	1944	Existing Asphalt	Good
From Sheraton Hotel to National Palace	7.5	169	2021		Existing Asphalt	Very Good
From Teodros Sq through Mega book shop to Grand Palace	8	1161	29030	2322.4	Under Construction	
From Bis mebrate to Shewa Super-market	13	451	1484	902	Existing Asphalt	Fair
From Shewa Super-market to Banko di Roma Jun.	7	424	1211	848	Existing Asphalt	Fair
From Banko di Roma Jun to Eribekentu Jun.	11	715	2043	1430	Existing Asphalt	Fair
FromJun Eri-Bekentu bridge to Parlama	18	645	16125	1290	New Asphalt	Very Good
From Teodros Sq Mega Anfi teater to audit service Off. Building)	12	312	1337	624	Existing Asphalt	Good
From Niged printing to statistic office	7	600	1714		Existing Asphalt	Poor
From Degol Sq to Minilik Sq	20	341	1461	682	Existing Asphalt	Good
From Degol Sq to Eri-Bekentu bridge	10	560	1600	1120	Existing Asphalt	Fair
From Arada Buld. To Municipality	20	245	1050	490	Existing Asphalt	Good
From Shewa Super-market to Abune Petros	11	363	1057	726	Existing Asphalt	Good

From Degol Sq to Arada building	15	281	751	562	Existing Asphalt	Fair
From Arada Buld. To Abune Petros	20	290	1243	580	Existing Asphalt	Fair
From Degol Sq to Back of Arada Building	20	292	1044	585	Existing Asphalt	Fair
From Arada Building to Kelifa building	12	581	1637	1161	Existing Asphalt	Fair
From Anbesa Gibi to Total Gas station	7	282	1015		Existing Asphalt	Poor
From shewa supermarket through Pole Res Campany to kelifa building	11	263	857	526	Existing Asphalt	Fair
From Degol Sq. to Kideste Mariam Jun.	12	1365	3900	2730	Existing Asphalt	Fair
From Kideste Mariam Jun. to 4 kilo	14	641	2614	1220	Existing Asphalt	Fair
From Grand palace (gibi Gebriel jun.) to 6 Kilo	10.5	2686	15349	5372	Existing Asphalt	Good
From Giorgis Sq. Through fire Birgade to Ras Mekonin Bridge	7	368	1051	736	Existing Asphalt	Fair
From Afincho ber to Ras mekonin Bridge	18	645	1843		Existing Asphalt	Poor
From Giorgis Sq. to Afinchober	20	845	3621	1690	Existing Asphalt	Good
From Afencho ber to Yekatit 12 Hospital	21	804	32160	1608	New Asphalt	Very Good
From Abune PetrosSquare - paster	13	2800	84000	5600	Under Construction	Very Good
From S/t Yohanes church to Afincho Ber	20	656	13126	1313	New Asphalt	Very Good
From Giorgis through Semen Mazegaga Adisu gebeya (Total)	10	3298	14134	6596	Existing Asphalt	Good
From Afincho Ber to Shiro meda	10	1950	6964	3900	Existing Asphalt	Good
From Sidest Kilo to Menen	16	452	1291	904	Existing Asphalt	Good
From 4 Kilo to Shiro Meda (RR)	10	1982	11326	3964	Existing Asphalt	Good
From 2nd police to K/Mariam	10	494	1411	988	Existing Asphalt	Good
From K/Mariam to no 78 PAS4 junction (minilk Hosp.)	10	765	2186		Existing Asphalt	Poor

From sidist Kilo to Minilik hospital	23	1400	6000	2800	Existing Asphalt	Good
From Sidist Kilo throgh Ganmeda to keftena 12 school (RR)	18	2410	60250	4820	New Asphalt	Very Good
From Arat Kilo to Kebena bridge	21	1750	52500	3500	New Asphalt	Very Good
From Parlamente building to Lipzing Sq (German School)	18	1288	32200	2576	New Asphalt	Very Good
From National palace (Gabrel Jun.) to Hilton hotel	40	546	4680	1092	Existing Asphalt	Good
From afincho ber through nazrawi hospital to amist kilo	10	1070	16050	2140	Existing Asphalt	Fair
From yekatit 12 hospital to afincho ber amist kilo T junction	7	435	6525		Existing Asphalt	Fair
From arada police office through tele office to bherawi metal & wood work shop	7	542	10840	1084	Existing Asphalt	Fair
From CPU college to grand palace tewdros road	7	999	19980	1998	Existing Asphalt	Poor
From Afincho ber park main gate to chilot Adebabay	7	866	17320	1732	Existing Asphalt	Fair
From Afincho ber park main gate to in front of kechene medhanialem church	7	1069	21380		Existing Asphalt	Fair
From chilot to afincho ber sidist kilo junction	6	711	14220		Existing Asphalt	Poor
From Afincho-Ber -Sidist Kilo junction to behaind Ketchene church (road 75)	20	850	17000	1700	New Cobble	Very Good

APPENDIX B: CORRIDOR INFORMATION

Appendix B.1: Schools in Arada Sub-City

Table

School_ARada

OBJECTID *	Shape *	SC_NAME	SC_TYPE	SC_CODE
1	Point	K/Minilik	Primary School	2
2	Point	K/Silase	Primary School	2
3	Point	K/Silase	Higher Education	5
4	Point	Alifa	Higher Education	5
5	Point	K/Silase	Primary School	2
6	Point	Hibret	Kinder Garter	1
7	Point		Kinder Garter	1
8	Point	C.C.F.	Primary School	2
9	Point	Indian School	Primary School	2
10	Point	Yekatit 66	Primary School	2
11	Point	Sayet College	Higher Education	5
12	Point	Alkan School	Higher Education	5
13	Point	Abebech Gobena School	Primary School	2
14	Point	Africa No 2 School	Primary School	2
15	Point	Wosen Yeleshe	Kinder Garter	1
16	Point		Primary School	2
17	Point	Bruhi Tesfa	Kinder Garter	1
18	Point	Meskerem 2	Primary School	2
19	Point	Minilik 2nd Priata Sc	Primary School	2
20	Point	Hulegeb	Primary School	2
21	Point	Mehal ginfle	Primary School	2
22	Point	Dagimawi minilic	Primary School	2
23	Point		Primary School	2
24	Point	Dagimawi minilic	Primary School	2
25	Point	Sine tibeb	Higher Education	5
26	Point	Kidus yosef T.T.I	Kinder Garter	1
27	Point	Brihu tesfa	Primary School	2
28	Point	Sanj ford	Primary School	2
29	Point	Hani No- 2	Primary School	2
30	Point	Kidane mihret	Primary School	2
31	Point	Kebena	Primary School	2
32	Point	Santa Mawuz	Kinder Garter	1
33	Point	Hani	Kinder Garter	1
34	Point	Kuwina college	Higher Education	5
35	Point	A.A univeristy 4kilo	Higher Education	5
36	Point	From sis	Kinder Garter	1
37	Point	Zega bisines college	Higher Education	5
38	Point	Royal acadami	Higher Education	5
39	Point	Kinder garter	Kinder Garter	1
40	Point	Royal akadami	Higher Education	5
41	Point	Mus ik	Higher Education	5

0 (0 out of 118 Selected)

School_ARada

Table

School_ARada

OBJECTID *	Shape *	SC_NAME	SC_TYPE	SC_CODE
42	Point	Nazret	Primary School	2
43	Point	Bherawi Bete W	Primary School	2
44	Point	Brhan Ethiopia	Primary School	2
45	Point	Horn Africa	Primary School	2
46	Point		Kinder Garter	1
47	Point		Kinder Garter	1
48	Point	PoliTeknik	Primary School	2
49	Point	Atse Naod	Primary School	2
50	Point	Belay Zeleke	Primary School	2
51	Point	Ayneswuran	Primary School	2
52	Point	Maylk Kingergarden	Primary School	2
53	Point	Super Holiver	Primary School	2
54	Point	Barat Ashkerkariwoch	Primary School	2
55	Point	Adis Abeba Dhre Mreka	Primary School	2
56	Point		Kinder Garter	1
57	Point	Zewuditu Tif sera	Primary School	2
58	Point		Primary School	2
59	Point		Higher Education	5
60	Point	Kiya Medical Colge	Higher Education	5
61	Point	Selam School	Kinder Garter	1
62	Point	Tebeb Edegat School	Primary School	2
63	Point	Mariya Roza School	Primary School	2
64	Point	Dagem Berehan	Primary School	2
65	Point		Kinder Garter	1
66	Point	Ethiopia Tekedem School	Primary School	2
67	Point	Kieme Werk School	Primary School	2
68	Point	Emperiyal Acadami	Kinder Garter	1
69	Point	Feature Hope School	Kinder Garter	1
70	Point	Arbegnoch School	Junior Secondary School	3
71	Point	Atsefacil School	Primary School	2
72	Point	Ethiopia Adis	Kinder Garter	1
73	Point	Kedest Kelara School	Kinder Garter	1
74	Point	Atlas Teath Medical School	Higher Education	5
75	Point	Keylkokob	Primary School	2
76	Point		Kinder Garter	1
77	Point	Alturas	Kinder Garter	1
78	Point	Agaziya	Primary School	2
79	Point	A.A univerity	Higher Education	5
80	Point		Kinder Garter	1
81	Point	Computer traning senter	Primary School	2
82	Point	Taliyan	Primary School	2

0 (0 out of 118 Selected)

School_ARada

APPENDIX B: CORRIDOR INFORMATION

Appendix B.1: Schools in Arada Sub-City

Table

School_ARada

OBJECTID *	Shape *	SC_NAME	SC_TYPE	SC_CODE
1	Point	K/Minlik	Primary School	2
2	Point	K/Silase	Primary School	2
3	Point	K/Silase	Higher Education	5
4	Point	Alifa	Higher Education	5
5	Point	K/Silase	Primary School	2
6	Point	Hibret	Kinder Garter	1
7	Point		Kinder Garter	1
8	Point	C.C.F.	Primary School	2
9	Point	Indian School	Primary School	2
10	Point	Yekatit 66	Primary School	2
11	Point	Sayet College	Higher Education	5
12	Point	Alkan School	Higher Education	5
13	Point	Abebech Gobena School	Primary School	2
14	Point	Africa No 2 School	Primary School	2
15	Point	Wosen Yeleshe	Kinder Garter	1
16	Point		Primary School	2
17	Point	Bruhi Tesfa	Kinder Garter	1
18	Point	Meskerem 2	Primary School	2
19	Point	Minlik 2nd Priata Sc.	Primary School	2
20	Point	Hulegeb	Primary School	2
21	Point	Mehal ginfle	Primary School	2
22	Point	Dagimawi minilic	Primary School	2
23	Point		Primary School	2
24	Point	Dagimawi minilic	Primary School	2
25	Point	Sine tibeb	Higher Education	5
26	Point	Kidus yosef T.T.I	Kinder Garter	1
27	Point	Brihu tesfa	Primary School	2
28	Point	Senj ford	Primary School	2
29	Point	Hani No- 2	Primary School	2
30	Point	Kidane mihret	Primary School	2
31	Point	Kebena	Primary School	2
32	Point	Santa kawuz	Kinder Garter	1
33	Point	Hani	Kinder Garter	1
34	Point	Kuwina college	Higher Education	5
35	Point	A.A univeristy 4kilo	Higher Education	5
36	Point	From sis	Kinder Garter	1
37	Point	Zega biznes college	Higher Education	5
38	Point	Royal acadami	Higher Education	5
39	Point	Kinder gerter	Kinder Garter	1
40	Point	Royal akadami	Higher Education	5
41	Point	Mus it	Higher Education	5

0 (0 out of 118 Selected)

School_ARada

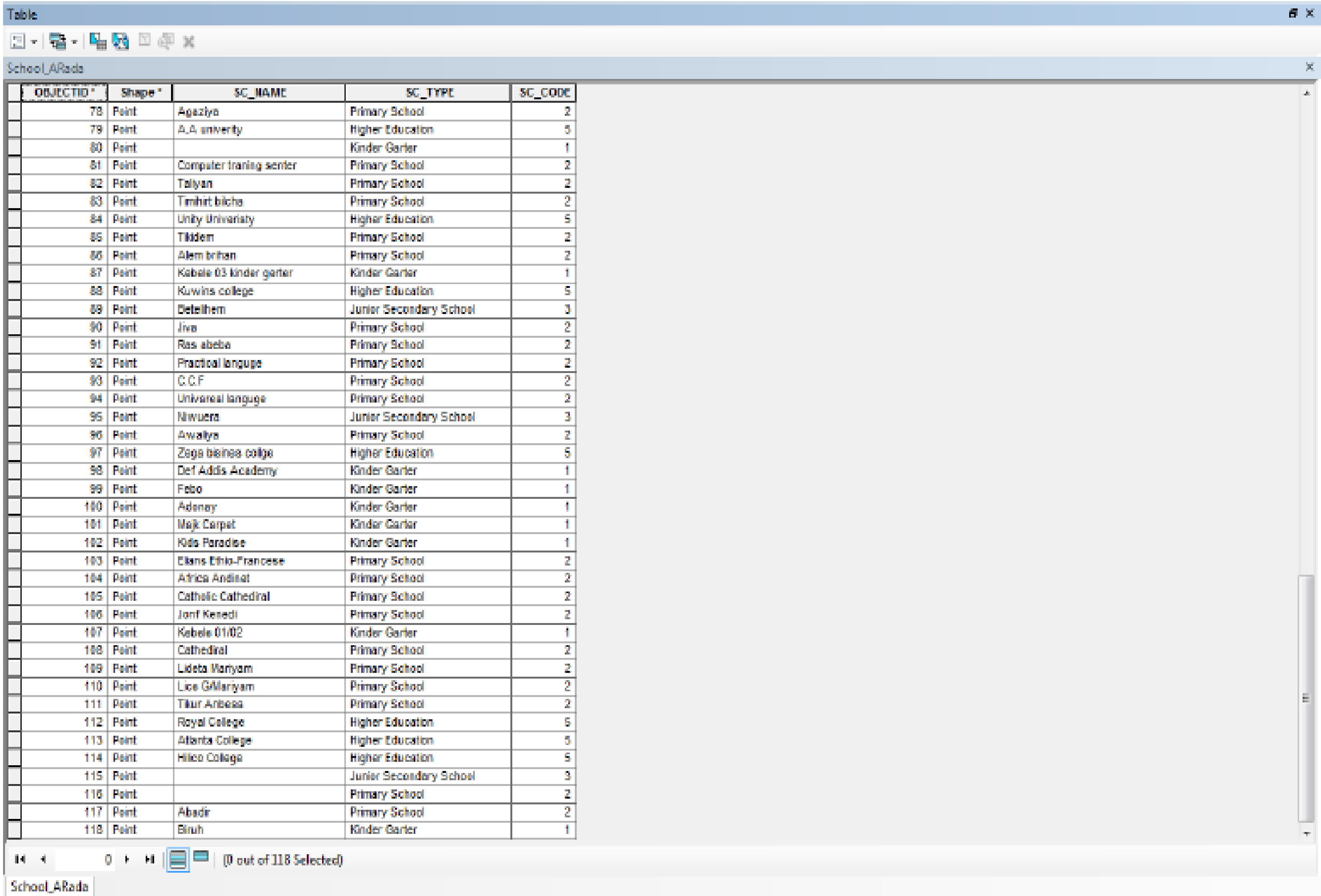
Table

School_ARada

OBJECTID *	Shape *	SC_NAME	SC_TYPE	SC_CODE
42	Point	Nazret	Primary School	2
43	Point	Bherawi Bete W	Primary School	2
44	Point	Brhan Ethiopia	Primary School	2
45	Point	Horn Africa	Primary School	2
46	Point		Kinder Garter	1
47	Point		Kinder Garter	1
48	Point	Poli/Teknik	Primary School	2
49	Point	Atse Naod	Primary School	2
50	Point	Belay Zeleke	Primary School	2
51	Point	Ayneswuran	Primary School	2
52	Point	Maylk Kingergarden	Primary School	2
53	Point	Super Holiver	Primary School	2
54	Point	Barat Ashkerkariwoch	Primary School	2
55	Point	Adis Abeba Dhre Mreka	Primary School	2
56	Point		Kinder Garter	1
57	Point	Zewuditu Tif sera	Primary School	2
58	Point		Primary School	2
59	Point		Higher Education	5
60	Point	Kiya Medical Colge	Higher Education	5
61	Point	Selam School	Kinder Garter	1
62	Point	Tebeb Edaget School	Primary School	2
63	Point	Mariya Roza School	Primary School	2
64	Point	Dagem Berehan	Primary School	2
65	Point		Kinder Garter	1
66	Point	Ethiopia Tekadem School	Primary School	2
67	Point	Kleme Werk School	Primary School	2
68	Point	Emperiyal Acadami	Kinder Garter	1
69	Point	Feature Hope School	Kinder Garter	1
70	Point	Arbegnoch School	Junior Secondary School	3
71	Point	Atsefacil School	Primary School	2
72	Point	Ethiopia Adis	Kinder Garter	1
73	Point	Kedest Kelara School	Kinder Garter	1
74	Point	Atlas Teath Medical School	Higher Education	5
75	Point	Keyikokob	Primary School	2
76	Point		Kinder Garter	1
77	Point	Alturas	Kinder Garter	1
78	Point	Agaziya	Primary School	2
79	Point	A.A univerity	Higher Education	5
80	Point		Kinder Garter	1
81	Point	Computer traning santer	Primary School	2
82	Point	Taliyan	Primary School	2

0 (0 out of 118 Selected)

School_ARada



OBJECTID *	Shape *	SC_NAME	SC_TYPE	SC_CODE
78	Point	Agaziya	Primary School	2
79	Point	A.A univerty	Higher Education	5
80	Point		Kinder Garter	1
81	Point	Computer traning senter	Primary School	2
82	Point	Taiyan	Primary School	2
83	Point	Timhirt bilcha	Primary School	2
84	Point	Unity Univeristy	Higher Education	5
85	Point	Tikdem	Primary School	2
86	Point	Alem brihan	Primary School	2
87	Point	Kebele 03 kinder garter	Kinder Garter	1
88	Point	Kuwins college	Higher Education	5
89	Point	Betelhem	Junior Secondary School	3
90	Point	Jiva	Primary School	2
91	Point	Ras abeba	Primary School	2
92	Point	Practical languge	Primary School	2
93	Point	C.C.F	Primary School	2
94	Point	Universal languge	Primary School	2
95	Point	Niwuera	Junior Secondary School	3
96	Point	Awaliya	Primary School	2
97	Point	Zega bisines collge	Higher Education	5
98	Point	Def Addis Academy	Kinder Garter	1
99	Point	Febo	Kinder Garter	1
100	Point	Adenay	Kinder Garter	1
101	Point	Majk Carpet	Kinder Garter	1
102	Point	Kids Paradise	Kinder Garter	1
103	Point	Elans Ethio-Francese	Primary School	2
104	Point	Africa Andinet	Primary School	2
105	Point	Catholic Cathedral	Primary School	2
106	Point	Jonf Kenedi	Primary School	2
107	Point	Kebele 01/02	Kinder Garter	1
108	Point	Cathedral	Primary School	2
109	Point	Lideta Mariyam	Primary School	2
110	Point	Lice G/Mariyam	Primary School	2
111	Point	Tikur Anbesa	Primary School	2
112	Point	Royal College	Higher Education	5
113	Point	Atlanta College	Higher Education	5
114	Point	Hilco College	Higher Education	5
115	Point		Junior Secondary School	3
116	Point		Primary School	2
117	Point	Abadir	Primary School	2
118	Point	Biruh	Kinder Garter	1

Appendix B.2: Religious Places in Arada sub-city

Table

ReligionPlac_Arada

OBJECTID *	Shape *	ID	RL_NAME	RL_TYPE	RL_CODE
1	Point	0	K/Mariyam	Church	1
2	Point	0	K/Silase	Church With Cemetery	2
3	Point	0	B/Weld	Church With Cemetery	2
4	Point	0	Grice Ortodoks	Church	1
5	Point	0	Cherch Of God	Church	1
6	Point	0	T.P.E.L.Betel	Church	1
7	Point	0		Mosque	4
8	Point	0		Mosque	4
9	Point	0		Muslim Cemerery	6
10	Point	0		Muslim Cemerery	6
11	Point	0		Muslim Cemerery	6
12	Point	0		Muslim Cemerery	6
13	Point	0		Muslim Cemerery	6
14	Point	0		Muslim Cemerery	6
15	Point	0	Kidane Mheret	Church	1
16	Point	0	Bata Mariam	Church	1
17	Point	0	Gebreal	Church	1
18	Point	0	Genet protestant	Church	1
19	Point	0	Kidus mateyos anjulican	Church	1
20	Point	0	K/hywet	Church	1
21	Point	0	M/Wengel	Church	1
22	Point	0	M/Yesus	Church	1
23	Point	0	Katolik Gedam	Church	1
24	Point	0	Katolic Gebreal Church	Church	1
25	Point	0	Luteran Meshion	Church	1
26	Point	0	Meserete Krestos	Church	1
27	Point	0	Giyorgis	Church	1
28	Point	0		Church With Cemetery	2
29	Point	0	Yohanis	Church	1
30	Point	0	Adis kristyan	Church	1
31	Point	0	Meserete Kiristos	Church	1
32	Point	0	Addis Hawariyat	Church	1
33	Point	0	Meher Yegzer	Church	1
34	Point	0	Mulu Wangel	Church	1
35	Point	0	Amanueal Baptist	Church	1

1 (0 out of 35 Selected)

ReligionPlac_Arada

Appendix B.3: Major Institutions in Arada sub-city

Table

Major_places_arada

OBJECTID *	Shape *	ID	CN_NAME	CN_TYPE	CN_CODE
1	Point	0		Bridge	7
2	Point	0		Floor Mill	1
3	Point	0		Market Place	2
4	Point	0		Floor Mill	1
5	Point	0	Public Telepon	Telecommunication	12
6	Point	0	Kebele 14/21	Administration Office	3
7	Point	0	Menafesha	Hotel	5
8	Point	0		Police Station	17
9	Point	0	Tikmit	Hotel	5
10	Point	0		Gas Station	10
11	Point	0		Gas Station	10
12	Point	0		Floor Mall	1
13	Point	0		Floor Mall	1
14	Point	0		Bridge	7
15	Point	0		Bridge	7
16	Point	0		Police Station	17
17	Point	0		Telecommunication	12
18	Point	0	Awash	Bank	9
19	Point	0		Post Office	13
20	Point	0	Sibse	Bank	9
21	Point	0		Infrastructure Office	11
22	Point	0	Arada K/Ketema	Administration Office	3
23	Point	0		Factory	4
24	Point	0	Seyif Gillariyam	Hotel	5
25	Point	0		Floor Mill	1
26	Point	0		Floor Mill	1
27	Point	0		Floor Mill	1
28	Point	0		Administration Office	3
29	Point	0		Floor Mill	1
30	Point	0	Turist	Hotel	5
31	Point	0		Bank	9
32	Point	0	Tsedey	Hotel	5
33	Point	0	Bizani	Hotel	5
34	Point	0	Ejerisa Goro	Hotel	5
35	Point	0	Saylent	Hotel	5
36	Point	0	Firid Bet	Administration Office	3
37	Point	0	Iset Adega Mekelakeya	Administration Office	3
38	Point	0	Hager Fiker	Administration Office	3
39	Point	0		Hotel	5
40	Point	0	Nashonal Matemia Bet	Administration Office	3
41	Point	0	Master Sun	Hotel	5

0 (0 out of 263 Selected)

Major_places_arada

Table

Major_places_arada

OBJECTID *	Shape *	ID	CN_NAME	CN_TYPE	CN_CODE
42	Point	0	Bekal	Hotel	5
43	Point	0		Administration Office	3
44	Point	0	Wegagen	Bank	9
45	Point	0	Tikur Abay	Hotel	5
46	Point	0	Inter Langano	Hotel	5
47	Point	0	British Counsel	Administration Office	3
48	Point	0	Hibret	Bank	9
49	Point	0	Tinsae	Hotel	5
50	Point	0	Shewa	Hotel	5
51	Point	0	Abay Chomen	Hotel	5
52	Point	0	Sanshine	Hotel	5
53	Point	0	Dehab	Hotel	5
54	Point	0		Flour Mill	1
55	Point	0		Gas Station	10
56	Point	0	K. Giorgis	Hotel	5
57	Point	0	Colla	Hotel	5
58	Point	0	Afrika	Hotel	5
59	Point	0	CMB	Bank	9
60	Point	0	Yirgalem	Hotel	5
61	Point	0	Dashen	Bank	9
62	Point	0	Kidus Giorgis	Hotel	5
63	Point	0	Nib	Bank	9
64	Point	0	Artistic Matemia	Administration Office	3
65	Point	0	Fasiledus	Hotel	5
66	Point	0		Flour Mill	1
67	Point	0	Jamayeka Shuse	Factory	4
68	Point	0	Fekadu Hotel	Hotel	5
69	Point	0		Administration Office	3
70	Point	0	Eyerusalem Hotel	Hotel	5
71	Point	0	Elpa Office	Administration Office	3
72	Point	0		Flour Mill	1
73	Point	0		Bridge	7
74	Point	0		Bridge	7
75	Point	0		Bridge	7
76	Point	0		Bridge	7
77	Point	0		Flour Mill	1
78	Point	0		Flour Mill	1
79	Point	0		Flour Mill	1
80	Point	0		Bridge	7
81	Point	0		Flour Mill	1
82	Point	0	Abowa Hotel	Hotel	5

0 (0 out of 263 Selected)

Major_places_arada

Table

Major_places_arada

OBJECTID *	Shape *	ID	CN_NAME	CN_TYPE	CN_CODE
82	Point	0	Abowe Hotel	Hotel	5
83	Point	0	Alem Buna	Factory	4
84	Point	0		Telecommunication	12
85	Point	0		Flour Mill	1
86	Point	0		Flour Mill	1
87	Point	0		Flour Mill	1
88	Point	0		Flour Mill	1
89	Point	0		Flour Mill	1
90	Point	0		Flour Mill	1
91	Point	0		Flour Mill	1
92	Point	0		Flour Mill	1
93	Point	0		Flour Mill	1
94	Point	0		Market Place	2
95	Point	0		Market Place	2
96	Point	0		Administration Office	3
97	Point	0	Palac	Administration Office	3
98	Point	0	Sosoaty Office	Administration Office	3
99	Point	0	Senay Ethiopia Assoation Offi	Administration Office	3
100	Point	0	Kurtena	Hotel	5
101	Point	0	Arat kilo	Hotel	5
102	Point	0	Assela	Hotel	5
103	Point	0	Samson	Hotel	5
104	Point	0		Bridge	7
105	Point	0		Bridge	7
106	Point	0		Bridge	7
107	Point	0		Bridge	7
108	Point	0		Bridge	7
109	Point	0		Bridge	7
110	Point	0		Bridge	7
111	Point	0		Flour mill	1
112	Point	0	Kabale 13/14	Administration Office	3
113	Point	0		Bridge	7
114	Point	0		Flour mill	1
115	Point	0		Flour mill	1
116	Point	0	Mahiberawi ajenai	Administration Office	3
117	Point	0		Bridge	7
118	Point	0	Mothers &Childrn office	Administration Office	3
119	Point	0		Flour mill	1
120	Point	0		Flour mill	1
121	Point	0		Flour mill	1
122	Point	0	Hind imbasi	Administration Office	3

0 (0 out of 263 Selected)

Table

Major_places_arada

OBJECTID *	Shape *	ID	CN_NAME	CN_TYPE	CN_CODE
122	Point	0	Hind imbasi	Administration Office	3
123	Point	0		Flour mill	1
124	Point	0		Flour mill	1
125	Point	0		Market Place	2
126	Point	0	Qana Oil&Duqet Factory	Factory	4
127	Point	0		Flour mill	1
128	Point	0		Flour mill	1
129	Point	0		Flour mill	1
130	Point	0		Flour mill	1
131	Point	0	Kidane mihret katolic	C-llective Quarter	44
132	Point	0	Ras amba	Hotel	5
133	Point	0	Beleler	Hotel	5
134	Point	0	3B Hotel	Hotel	5
135	Point	0		Collection Qurater	45
136	Point	0		Flour Mill	1
137	Point	0		Administration Office	3
138	Point	0		Gas Station	10
139	Point	0		Flour Mill	1
140	Point	0		Flour Mill	1
141	Point	0		Flour Mill	1
142	Point	0		Flour Mill	1
143	Point	0		Collection Qurater	48
144	Point	0		DA Office	24
145	Point	0		Bridge	7
146	Point	0		Administration Office	3
147	Point	0	Hedaja Wendemu	Flour Mill	1
148	Point	0		Bridge	7
149	Point	0	Anwar Sugebaa	Flour Mill	1
150	Point	0		Bridge	7
151	Point	0	Alemayhu	Flour Mill	1
152	Point	0	Mehamad	Flour Mill	1
153	Point	0	Getachew Demese	Flour Mill	1
154	Point	0		Micro Weve Station	55
155	Point	0	America Ambase	Administration Office	3
156	Point	0	Burkinafaso Ambase	Administration Office	3
157	Point	0		Administration Office	3
158	Point	0	Shemanewoch Mahaber	Administration Office	3
159	Point	0	Recration	Hotel	5
160	Point	0	Kestedemena	Hotel	5
161	Point	0	Enterjem Sport Cleb	Administration Office	3
162	Point	0	Debebe Hotel	Hotel	5

0 (0 out of 263 Selected)

Table

Major_places_arada

OBJECTID *	Shape *	ID	CN_NAME	CN_TYPE	CN_CODE
163	Point	0	Karyahun Hotel	Hotel	5
164	Point	0	Jemal Yesuf	Flour Mill	1
165	Point	0	Rahel Hotel	Hotel	5
166	Point	0	Felan	Flour Mill	1
167	Point	0	Ayeredin Juhar	Flour Mill	1
168	Point	0		Polis Station	17
169	Point	0	Ethiopia Zena Agelgelot	Administration Office	3
170	Point	0	Chora	Hotel	5
171	Point	0	Josi Cafe	Hotel	5
172	Point	0	Buruk	Hotel	5
173	Point	0	Barlona	Hotel	5
174	Point	0		Post Office	13
175	Point	0	Gini Ambasi	Administration Office	3
176	Point	0	Kiraye Betoch	Administration Office	3
177	Point	0	Katolic Haregawiyan	C-llective Quarter	44
178	Point	0	Adem Abubeker	Flour Mill	1
179	Point	0		C-llective Quarter	44
180	Point	0	Gulele Capasity Bulding	Administration Office	3
181	Point	0	Fede ral Tena office	Administration Office	3
182	Point	0			1
183	Point	0		Market Place	2
184	Point	0	Uk office	Administration Office	3
185	Point	0			1
186	Point	0	Halima keramela	Factory	4
187	Point	0			1
188	Point	0	women office	Administration Office	3
189	Point	0		Flour mill	1
190	Point	0	Kebele 04/05	Administration Office	3
191	Point	0		Flour mill	1
192	Point	0	Yang office	Administration Office	3
193	Point	0		Market Place	2
194	Point	0		Bridge	7
195	Point	0		Bridge	7
196	Point	0		Bridge	7
197	Point	0	Balezaf areqe	Dense Forest	4
198	Point	0		Flour mill	1
199	Point	0	Zeyi	Dense Forest	4
200	Point	0			1
201	Point	0	C.C.F	Administration Office	3
202	Point	0			1
203	Point	0			1

0 (0 out of 263 Selected)

Major_places_arada

Table

Major_places_arada

OBJECTID *	Shape *	ID	CN_NAME	CN_TYPE	CN_CODE
204	Point	0			1
205	Point	0	A.A water& Suplay Office	Infrastructure Office	11
206	Point	0	A.A police commision	Police Station	17
207	Point	0			1
208	Point	0			1
209	Point	0			1
210	Point	0	Uk office	Administration Office	3
211	Point	0			1
212	Point	0		Bridge	7
213	Point	0		Flour Mill	1
214	Point	0		Flour Mill	1
215	Point	0		Flour Mill	1
216	Point	0		Flour Mill	1
217	Point	0		Flour Mill	1
218	Point	0		Flour Mill	1
219	Point	0		Market Place	2
220	Point	0	Addis Ababa Municipality	Administration Office	3
221	Point	0	AddisAbaba Social Affairs	Administration Office	3
222	Point	0	National Lotery	Administration Office	3
223	Point	0	Kebele 01/02	Administration Office	3
224	Point	0	CSA	Administration Office	3
225	Point	0	National Lotery	Administration Office	3
226	Point	0	CSA	Administration Office	3
227	Point	0	Egypt Air Lines	Administration Office	3
228	Point	0	Commercial Printing Press	Administration Office	3
229	Point	0	Hope Interprise	Administration Office	3
230	Point	0	Tana Plastic	Dense Forest	4
231	Point	0	Paulo Bricks	Dense Forest	4
232	Point	0	Afro German Chemical	Dense Forest	4
233	Point	0	Debre Zeyt Food Industry	Dense Forest	4
234	Point	0	Kangaro	Hotel	5
235	Point	0	Aduls	Hotel	5
236	Point	0	Zecave	Hotel	5
237	Point	0	Elega	Hotel	5
238	Point	0		Bridge	7
239	Point	0		Bridge	7
240	Point	0		Bridge	7
241	Point	0	Commercial Bank	Bank	9
242	Point	0	Commercial Bank	Bank	9
243	Point	0	Nib Bank	Bank	9
244	Point	0		Gas Station	10

0 (0 out of 263 Selected)

Major_places_arada

Table

Major_places_arada

OBJECTID *	Shape *	ID	CN_NAME	CN_TYPE	CN_CODE
223	Point	0	Kebele 01/02	Administration Office	3
224	Point	0	CSA	Administration Office	3
225	Point	0	National Lotery	Administration Office	3
226	Point	0	CSA	Administration Office	3
227	Point	0	Egypt Air Lines	Administration Office	3
228	Point	0	Commercial Printing Press	Administration Office	3
229	Point	0	Hope Interprise	Administration Office	3
230	Point	0	Tana Plastic	Dense Forest	4
231	Point	0	Paulo Bricks	Dense Forest	4
232	Point	0	Afro Germen Chemical	Dense Forest	4
233	Point	0	Debre Zeiyt Food Industry	Dense Forest	4
234	Point	0	Kangaro	Hotel	5
235	Point	0	Adulis	Hotel	5
236	Point	0	Zecaire	Hotel	5
237	Point	0	Elege	Hotel	5
238	Point	0		Bridge	7
239	Point	0		Bridge	7
240	Point	0		Bridge	7
241	Point	0	Commercial Bank	Bank	9
242	Point	0	Commercial Bank	Bank	9
243	Point	0	Nib Bank	Bank	9
244	Point	0		Gas Station	10
245	Point	0		Telecommunication	12
246	Point	0		Telecommunication	12
247	Point	0	Construction Bank	Bank	9
248	Point	0	Addis Ababa	Hotel	5
249	Point	0		Post Office	13
250	Point	0		Sawmill	16
251	Point	0		Police Station	17
252	Point	0		Animal Husbandary	26
253	Point	0	Tena Hotel	Hotel	5
254	Point	0		Bridge	7
255	Point	0		Flour Mill	1
256	Point	0		Bridge	7
257	Point	0		Flour Mill	1
258	Point	0	Exitrim	Hotel	5
259	Point	0		Bridge	7
260	Point	0		Bridge	7
261	Point	0		Bridge	7
262	Point	0	Harambe	Hotel	5
263	Point	0		Bridge	7

0 (0 out of 263 Selected)

Major_places_arada

Appendix B.4: Health Facilities in Arada sub-city

Table

health_Facility_Arada

OBJECTID *	Shape *	ID	HF_NAME	HF_TYPE	HF_CODE
1	Point	0	Beriges	Clinic	2
2	Point	0	K/Silase	Clinic	2
3	Point	0	Arada	Health Center/Tena Tabiya	3
4	Point	0	Miklas Dental Clinic	Clinic	2
5	Point	0	K.Giorgis Dental Clinic	Clinic	2
6	Point	0	Spring	Pharmacy	6
7	Point	0	Birhan Dental Clinic	Clinic	2
8	Point	0		Clinic	2
9	Point	0	Betel Higher Clinic	Clinic	2
10	Point	0	K.Mihiret Higher Clinic	Clinic	2
11	Point	0	Arsho Laboratory	Clinic	2
12	Point	0	Kamira Clinic	Clinic	2
13	Point	0	K.Mariam Clinic	Clinic	2
14	Point	0	Kal Higher Clinic	Clinic	2
15	Point	0		Health Center/Tena Tabiya	3
16	Point	0	Sehate Brehan	Clinic	2
17	Point	0	Bata	Clinic	2
18	Point	0	Arat Kilo	Clinic	2
19	Point	0	Addis Mother&Children	Hospital	4
20	Point	0	Surahayin higher	Clinic	2
21	Point	0	Kebena tena tabiya /Health cen	Health Center/Tena Tabiya	3
22	Point	0	Kidane mihiret	Clinic	2
23	Point	0		Hospital	4
24	Point	0		Hospital	4
25	Point	0	Polis	Clinic	2
26	Point	0		Clinic	2
27	Point	0	Ethiopia	Clinic	2
28	Point	0	Rasdesta Hospital	Hospital	4
29	Point	0	Medical	Clinic	2
30	Point	0	Brhan	Clinic	2
31	Point	0		Clinic	2
32	Point	0	Abune petros	Clinic	2
33	Point	0	Ananiya	Clinic	2
34	Point	0	Kebele 03	Clinic	2
35	Point	0	Medan	Clinic	2
36	Point	0	Tibebu general hospital	Hospital	4
37	Point	0	Walmo layon etho	Veterinary	5
38	Point	0	Selam Dental	Clinic	2
39	Point	0	Kulubi Gebriel Dental	Clinic	2
40	Point	0	Adkit Tera	Clinic	2
41	Point	0	Dr.Nigatu	Clinic	2

1 (0 out of 61 Selected)

health_Facility_Arada

Table

health_Facility_Arada

OBJECTID *	Shape *	ID	HF_NAME	HF_TYPE	HF_CODE
21	Point	0	Kebena tena tabiya /Health cen	Health Center/Tena Tabiya	3
22	Point	0	Kidane mihiret	Clinic	2
23	Point	0		Hospital	4
24	Point	0		Hospital	4
25	Point	0	Polis	Clinic	2
26	Point	0		Clinic	2
27	Point	0	Ethiopia	Clinic	2
28	Point	0	Rasdesta Hospital	Hospital	4
29	Point	0	Medical	Clinic	2
30	Point	0	Brhan	Clinic	2
31	Point	0		Clinic	2
32	Point	0	Abune petros	Clinic	2
33	Point	0	Ananiya	Clinic	2
34	Point	0	Kebele 03	Clinic	2
35	Point	0	Medan	Clinic	2
36	Point	0	Tibebu general hospital	Hospital	4
37	Point	0	Walmo layon etho	Veterinary	5
38	Point	0	Selam Dental	Clinic	2
39	Point	0	Kulubi Gebriel Dental	Clinic	2
40	Point	0	Adkit Tera	Clinic	2
41	Point	0	Dr.Nigatu	Clinic	2
42	Point	0	Denden Dental	Clinic	2
43	Point	0	Piasa Liyu Dental	Clinic	2
44	Point	0	Tadese Asfaw	Clinic	2
45	Point	0	Tesfa	Clinic	2
46	Point	0	Abay Liyu Dental	Clinic	2
47	Point	0	Dadbin Dental	Clinic	2
48	Point	0	Konjit Dental	Clinic	2
49	Point	0	Shewa Liyu Dental	Clinic	2
50	Point	0	Central	Clinic	2
51	Point	0	Gujeb	Clinic	2
52	Point	0	Mariyam	Clinic	2
53	Point	0	Universal	Clinic	2
54	Point	0	Marry Stop	Clinic	2
55	Point	0	Cathedral	Clinic	2
56	Point	0	Kibir	Clinic	2
57	Point	0	Awash	Clinic	2
58	Point	0	Hailu Digelu	Veterinary	5
59	Point	0	Anbesa	Veterinary	5
60	Point	0		Clinic	2
61	Point	0		Pharmacy	6

1 (0 out of 61 Selected)

health_Facility_Arada

APPENDIX C: Road Network Data

Appendix C.1: Result of Road Density Equation

Woreda	Area/ha	Population	Road density/area	Road density/pop
01	150.04	21436	17.53	0.00123
02	58.02	22010	45.33	0.00119
03	65.59	13669	39.83	0.00192
04	110.84	25305	23.68	0.00104
05	95.15	24725	27.67	0.00106
06	90.59	19861	26.56	0.00132
07	131.98	28157	19.92	0.001
08	107.97	24627	23.68	0.00107
09	99.66	17394	23.68	0.00151
10	39.54	13521	65.73	0.00194

Appendix C.2: Result of Distance to the nearest Road Network Equation

No	Distance/m
1	147
2	388
3	699
4	1058
5	1499

Appendix C.3: Result of Zonal Statistics data

No	Corridor Value
1	10.50
2	279.42
3	570.75
4	985.33
5	1803.28

Table

ZonalSt_shp3

OBJECTID *	Woreda	POP	COUNT	AREA	MIN	MAX	RANGE	MEAN	STD	SUM
5	W 01	21436	1499	433211	5.253902	808.8748	803.6209	296.3591	201.7886	444242.3
6	W 02	22010	338	97682	11.01594	993.5678	982.5519	435.5153	277.7133	147204.2
2	W 03	13669	246	71094	6.873454	993.5678	986.6943	370.6151	337.2833	91171.33
9	W 04	25305	615	177735	6.175252	1433.869	1427.694	600.174	443.044	369107
8	W 05	24725	770	222530	10.5404	567.746	557.2056	216.1321	126.7229	166421.7
4	W 06	19861	797	230333	6.287215	1389.722	1383.435	458.5969	420.9401	365501.7
10	W 07	28157	549	158661	11.93929	1389.722	1377.783	289.2846	296.097	158817.3
7	W 08	24627	701	202589	10.5435	808.8748	798.3313	171.7711	120.5622	120411.5
3	W 09	17394	687	198543	6.354314	1141.446	1135.092	446.9118	350.973	307028.4
1	W 10	13521	323	93347	9.574182	582.7915	573.2173	217.7993	146.2385	70349.19

APPENDIX D: INTERVIEW QUESTIONS

GIS-Based Evaluation of Road Transport Network Structure; A Case Study of Arada sub-city

By: Paulos Birhanu

MA. In GIS and Remote Sensing, College of Social Science, Department of Geography and Environmental Studies, Addis Ababa University

The research is mainly concerned about evaluating the existing road network structure of Arada sub-city using network based indicators. It is expected that this research will contribute to realize the vision of the city 'affordable transport, enhanced access and mobility'.

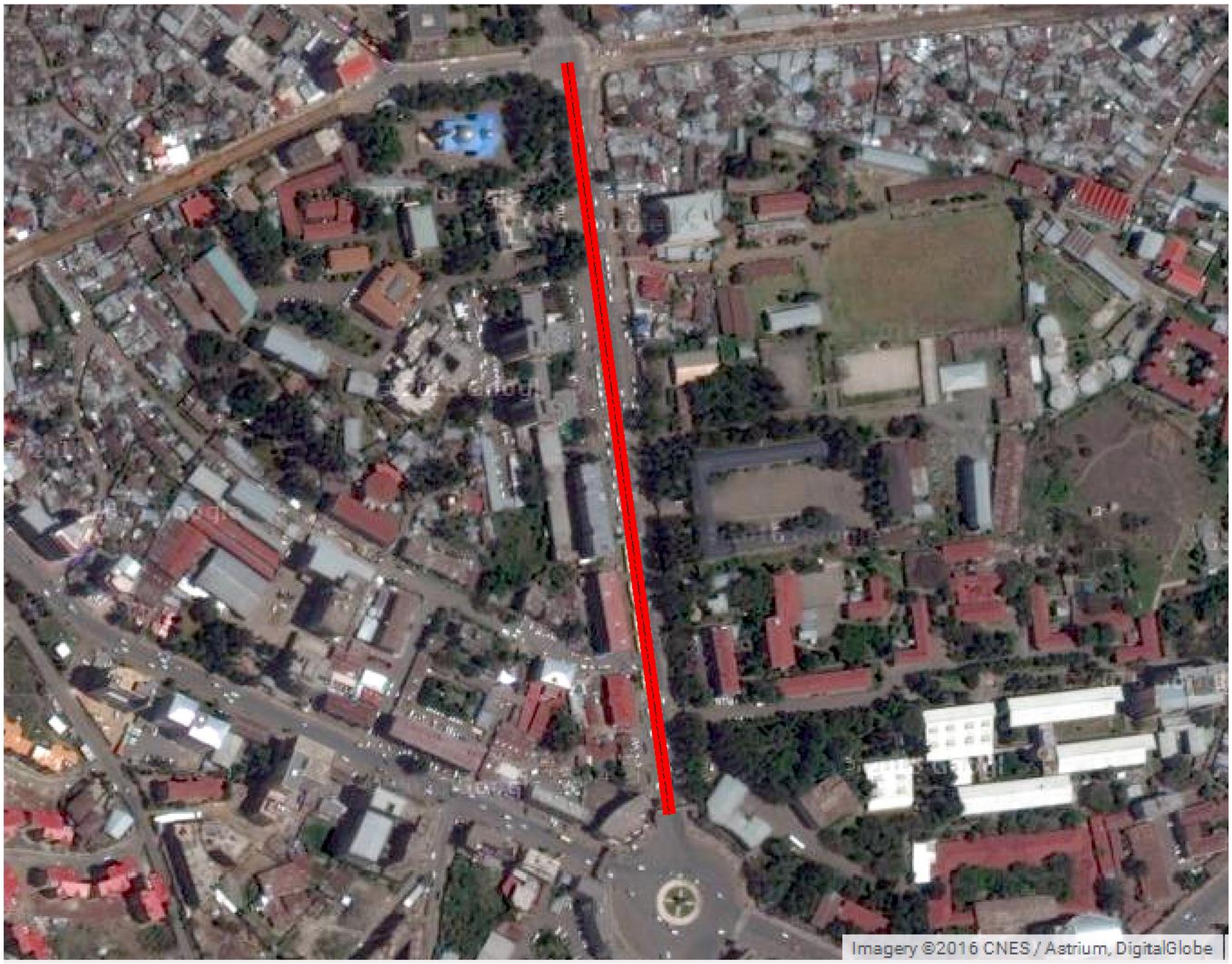
Interview questions

1. How do you define effective road network?
2. Is the existing road network structure effectively serving the demand for transport?
3. Are there studies conducted to evaluate the road transport network structure of the sub-city? If there are, what are the criterions used?
4. What are the problems occurred due to the road network?
5. Which part of the sub-city is not well served by the road network?
6. The number of vehicles in the sub-city (types of vehicles)?
7. The road network structure of the sub-city?
8. The condition of the existing road network?
9. The performance of the existing road network (for how many peoples and vehicles did the road network gives service in a day or how many trips does the road network gives in a day)?

10. The connectivity of road network?
11. Is the road network accessible for the different types of population in the sub-city (in terms of time, cost)?
12. What is the average distance between point of origin and point of destination in every route of the road network? And how long time it takes to get the destination point?
13. Where are the areas that have highest number of road network user?
14. Is there a road network that serves without maintenance in the sub-city?
15. How do you decide to construct new road or upgrade the existing road? What are the criterions (such as accessibility, connectivity, availability and etc.) used?
16. Accidents rate and their relation with road network in the sub-city?

APPENDIX E: Google image of Road Network Condition

Appendix E.1 Road Network from *Arat Kilo* to Kidest Mariam



Road network From arat kilo to Kidest Mariam

Appendix E.2: Road network from Habte Giorgis through Arada Building to Abune Petros

Road network From Habte Giorgis through Arada building to Abune Petros

Appendix E.3: Road Network from Showa supermarket to *Kelifa* building

Road network From Showa Super market to Kelifa building

Appendix E.4: Road Network from Anbessa Gebi to Total Gas Station

Road network From Anbessa Gebi to Total gas station