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SCHOOL OF CIVIL AND ENVIROMENTAL ENGINEERING

Accessibility and Suitability Analysis of Light Rail Station Location by using (AHP) and GIS: Case study on Existing and Future Expansion of Addis Ababa LRT Respectively

A thesis in Railway Engineering Center

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The undersigned have examined the thesis entitled **'ACCESSIBILITY AND SUITABILITY ANALYSIS OF LIGHT RAIL STATION. LOCATION BY USING (AHP) AND GIS: Case Study on Existing and Future Extension of Addis Ababa LRT respectively'** presented by **GOMEJU TAYE,** a candidate for the degree of **Master of Science** and hereby certify that it is worthy of acceptance.

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Abstract

Addis Ababa city metropolitan constructed phase one light rail transit line aiming to solve current transport problem. This Light Rail Transit is assumed to transport 80,000 passengers per hour per direction. For the system to hit the targeted objective on the proposed line, stations have to be positioned at a place where it can attract maximum users which enable the system to solve the problem and to be independent of subsidies. This is all about integrating Light rail system with other transport modes in Addis Ababa.

This paper examines the existing station sites accessibility to other transportation modes or access mode, and adopts Geographic Information Systems and Multi-Criteria Evaluation technique to carry out suitability mapping of station locations for phase two light rail transit route in Addis Ababa. For the station suitability analysis, eleven different criteria were identified and each criterion was weighted using Analytical Hierarchy Process AHP. The output of Analytical hierarchy process was used as an input for geographic information system GIS special analysis. Finally, based on these criteria requirements using overlaying, Euclidean distance calculation, Rasterisation, buffering reclassification and weighted overlay analysis, the station site suitability map was generated. The map revealed five classifications as: “less suitable”, “suitable”, “moderately suitable”, highly suitable and “extremely suitable”.

Key words: *Accessibility, AHP, GIS, LRT, Station, Suitability and Super Decision.*

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List of Acronyms

AACRA	Addis Ababa City Road Authority
AACPPO	Addis Ababa City Planning Project Office
AHP	Analytical Hierarchy Process
BRT	Bus Rapid Transit
CBD	Central Business District
GIS	Geographic Information System
LRT	Light Rail Transit
MRT	Metro Transit
Park-n-ride	Park and ride
TOD	Transit Oriented Development
VMT	Vehicle Meter Traveled
MCDM	Multi-criteria decision making

CHAPTER 1

1 INTRODUCTION

1.1 General

Transport planning is crucial in planning sustainable developments and ensuring accessibility to passengers, goods and services. One of the key elements in sustainable transport planning is to minimize the distance passengers travel and goods hauled; and if longer distances required, then, good network connections should be provided. Cities shall create walk-able environment by providing pedestrian barrier free network, a cycle-friendly community and private, public and non-motorized transport must functionally complement each other by forming balanced intermodal systems or intermodal network.

Hence, all urban transportation components; public (mass transit) and private transport should be integrated to easily and efficiently connect downtown urban areas with low density areas or suburbs areas. Therefore, parking should be provided at light rail transit stations in such a way that, buses, taxis and passenger cars should feed passengers from suburbs to downtown light rail transit system.

As stated by Ahmad Muhammad et al, (2006), in order to bring this connection, it is extremely important to devise an effective policy on the planning, management and operation of the public transportation system including such as light rail transit (LRT). However, the main problems usually identified are the aspect of integration that is, mistakes in integrating LRT route or alignment and station or the failure in taking into account surrounding land uses, or the linkages between other public transportation modes that are not properly planned. The lack of integration often creates problems, such as minimum usage of the LRT services contributing to the financial loss incurred by the rail operators which intern makes transit subsidy dependent.

One objective of modern transportation is changing and promoting single mode usage to intermodal transportation by combining strengths and offset weaknesses of various transportation options. The major goal of intermodal passenger transport is to reduce dependence on automobile as major mode of surface transportation and increase use of public transport such as LRT and Bus Rapid Transit (BRT). To assist and encourage such trips, Light railway transit stations have to be sited at optimum locations where it can be accessible and easily integrated with other modes for passenger transfer and enhance easy walk in traffic. To develop active urban transportation, metro, light rail transit (tram and LRT) and bus transit are being used worldwide.

"Public transport systems are more likely to be regarded as attractive alternatives to private car if they operate in a joined-up, integrated way. Integration involves co-ordination between the services, physical proximity allowing ease of interchange at stations, and through ticketing and widespread availability of passenger information about routes, fares and timetables. Passengers consider the level of integration to be the least satisfactory aspect of light rail system. Integration with bus services has been poor to moderate on many lines and bus and light rail services have been in competition with one another on the same routes" (UK Tram, 2012).

For railway industry, in order to be economically efficient and capable of handling current and projected travel demand of the cities, routes and station locations have to be planned and constructed based on existing and planned urban land use, inter connectivity with road networks, opportunity it can bring to the surrounding areas, minimum right-of- way cost, constructability and its operability.

Historically, most transportation corridors have been developed for a single mode, with the purchase of only the right-of-way required to accommodate a particular transportation improvement. The future emphasis in corridor planning will be multiuse and multimodal, as new transportation modes and communication facilities are implemented in and retrofitted into existing corridors. To optimize the limited rights-of-way available, LRT will increasingly be designed in joint or shared use with other facilities. The emphasis will be on person capacity per travel lane or track.

The rail transit stations are located to provide convenient linkages between users' origins and destinations in such a way that, access and transfer time is minimized. The planning of rail transit station location requires understanding of demographics, land use, topography of an area. Light rail transit station should be optimally located by considering these factors, to increase the usage of rail transit services.

A light rail transit lightweight metropolitan electric railway system is characterized by its ability to operate single cars or short trains along exclusive right-of-way at street level. These vehicles are usually powered by overhead electrical wires and offer frequent, fast, reliable, comfortable and high quality services that is environmentally sustainable (Boorse, 2000:443).

Light rail transit is often identified by its right-of-way and vehicle weight and size; when compared with a regional railway or metro system. However, when compared with modern low-floor trains, LRT is heavier because the vehicles are usually wider or there are two to three vehicles coupled together. The terms 'heavy' or 'light' do not solely refer to weight, but also to the flexibility of a system to deal with different types of right-of-ways and to the ability to be integrated into a variety or urban streetscapes (Topp, 1999).

In many developed cities today, transportation is characterized by the dominance of the car and high auto-dependency in travel. And this causes congestion and steals billions of hours a year.

Therefore, for a city to provide active transportation system there should be public transport domination and good transport links. Light Rail Transit (LRT), Metro, tram and Bus Rapid Transit (BRT) are modern public mass transport designed to resolve congestions in global cities.

Light rail transit station location planning where it provides maximum links between transport modes and walk-in traffic is component of active transport system planning. And urban transport planning is a foundation for creating easily accessible and economically well-built city. And good station planning is essential to maximize new rail line ridership and to help provide the right amount of parking at stations along the line (Burger and Byrne, 2008).

Many researchers have conducted study on how to plan railway station location using different methodologies. Some of which are explained as follow. Scott A. Burger and Bill Byrne (2008) acknowledged three station location planning elements:

- **Determine station Locations**: Select the number of stations using technology dependent spacing guidelines and qualitative community factors. Land availability, highway access, proximity to key land uses, shared parking possibilities and transit oriented development (TOD) potential are key considerations.
- **Parking Supply**: Obtain parking demand input from a travel demand model. Establish the required overall corridor parking supply, considering factors such as the capital construction budget, expected passenger trip types and station access modes. Determine the parking distribution across the stations. Provide larger lots towards the end of the line.

- **Assess Traffic Impacts**: Determine trip production rates for parking spaces, preferably from local experience. Define traffic impact guidelines, in conjunction with affected agencies. Select intersections in close proximity to the station areas to assess traffic operations and identify needed improvements.

According to Metropolitan Council (2012), station location planning elements are:

(i.) Major travel patterns (including location of major activity centers)

(ii.) Population and employment density

(iii.) Auto ownership

(iv.) Trip purpose (e.g., commuters, students, shoppers, other)

(v.) Existing transit ridership

(vi.) Commuter market analysis (geographic market area, existing and future demand, and facility and service competition or reinforcement)

Urban railway transit line selection and station location is a challenging problem. This is because; there are many factors that should be considered at a time to select optimum route and station location i.e. railway alignment and station selection is multi-criteria problem.

In view of the foregoing, this research focuses on light rail transit (LRT) optimal station location planning based on factors that can simultaneously determine the station location because, planning of the railway station locations in integrated passenger transport is a multi-criteria problem. Therefore, multi-criteria decision making process is integrated with GIS to develop station site suitability map.

Multi-criteria optimization, precisely multi-criteria decision-making (MCDM) is the process of simultaneously optimizing two or more conflicting objectives subject to certain constraints. This can be found in various fields, for example in an engineering design as well as in financial topics of an organization, precisely wherever optimal decisions need to be taken in the presence of trade-offs between the conflicting objectives. In each case, we are looking for a solution that has optimized each objective in such a way that if we try to optimize the solution any further, then, as the result, the other objective(s) will suffer. When setting up and solving a multi-criteria optimization problem, the goal is to find a solution, and to quantify how much it is better than any other solution.

1.2 Why Analytic Hierarchy Process (AHP)

The Analytic hierarchy process (AHP) is a method that helps the decision maker in evaluating the complicated problems and issues. Furthermore, this method contributes in identifying numerical values for the objective stimuli related to the given problem through conducting comparisons between the various criteria that affect the problem directly. This method is crucial since it assists the decision makers in observing the continuous interaction between the elements of the complicated problem. However, this in turn assists them in defining the problem's elements and setting its priorities depending on their relevant knowledge and experiences as well as the desired goals (Satty, 1990).

1.3 Research Identification

1.3.1 Research Problem

Addis Ababa's concentric land use pattern, service and administrative institutions are concentrated at the center. This in turn resulted in traffic congestion.

Another cause of traffic congestion in Addis Ababa is the rapid urban development and high population inflows from different part of the country for high employment opportunities as a result of booming construction. Poor traffic management also contributes to congestion in Addis Ababa.

Current problems of Addis Ababa City Transport are identified as follows:

- Increasing traffic congestion;
- Declining attractiveness of road-based public transport in quality and quantity;
- Increasing high costs of travel and journey times;
- High levels of road accidents;
- Due to increased road vehicles high exhaust emissions;
- The existing public transport system in Addis Ababa is critically inadequate to provide service for the existing travel demand;
- The number of mini-bus taxis is not sufficient;
- Increasing demand for parking;
- Low affordability;
- Non-motorized transport such as carts and cycles are operating at the periphery of the City unlicensed and without respecting traffic rules; etc. (Tefera, 2013)

As a result of devastated current transportation activities in the city and to lessen the problem, light rail transit system for mass transportation is being constructed. Although LRT is a system by itself, it is a combination of sub-systems such as, track, station and rolling stock. Railway can be an effective tool for facilitating urban growth, if planned and designed appropriately and properly tied in with urban development.

In order to meet the targeted aim, there should be inter-connection between LRT system and other modes; so that, the rail transit should not result in traffic congestion. For the rail transit not to cause traffic congestion, its stations and terminals should be located where they can be integrated with other modes of transportation.

So in this research an attempt was made to identify optimal LRT station locations where it can be integrated with other transport modes and surrounding land-use. This integration has a vital role in attracting large amount of passengers and revenue for transit system.

1.3.2 **Research Objectives**

The general objective of this research is to develop a method that enables analysis of LRT station site suitability and accessibility to other transportation modes users by integrating AHP and GIS Spatial Analysis Tool.

In this regard, three sub-objectives have been arranged step by step that function subsequently. The following are the three sub-objectives:

(i) To develop a method for LRT station location accessibility analysis.

(ii) To develop LRT station site suitability map building model

1.3.3 **Research Questions**

For each sub-objective, a question has been put forward to guide the research. These questions will be answered accordingly in this thesis. Consequently, a conceptual framework is introduced to illustrate how those questions have been organized to achieve specific research objectives. The following are the research questions:

(i.) What factors should be considered when analyzing station site accessibility? This helps to identify input criteria in developing a method for existing Addis Ababa LRT station accessibility analysis.

(ii.) What criteria should be considered and how these criteria used in developing station site suitability map? This helps to identify station location determining criteria (iii.) How GIS and AHP be integrated to identify potential LRT station sites? This helps to identify suitability map for LRT station locations.

1.3.4 Conceptual Framework

Urban light rail transit stations are gateways for travelling public to access rail services. Passenger stations comprise functional elements that support arrivals and departures of passengers that include: platforms, station buildings, pickup and drop off areas, and intermodal connections. These elements have a significant impact on attracting passengers (Northern New England Intercity Rail Initiatives, 2014). Figure 1.1 illustrates conceptual framework.

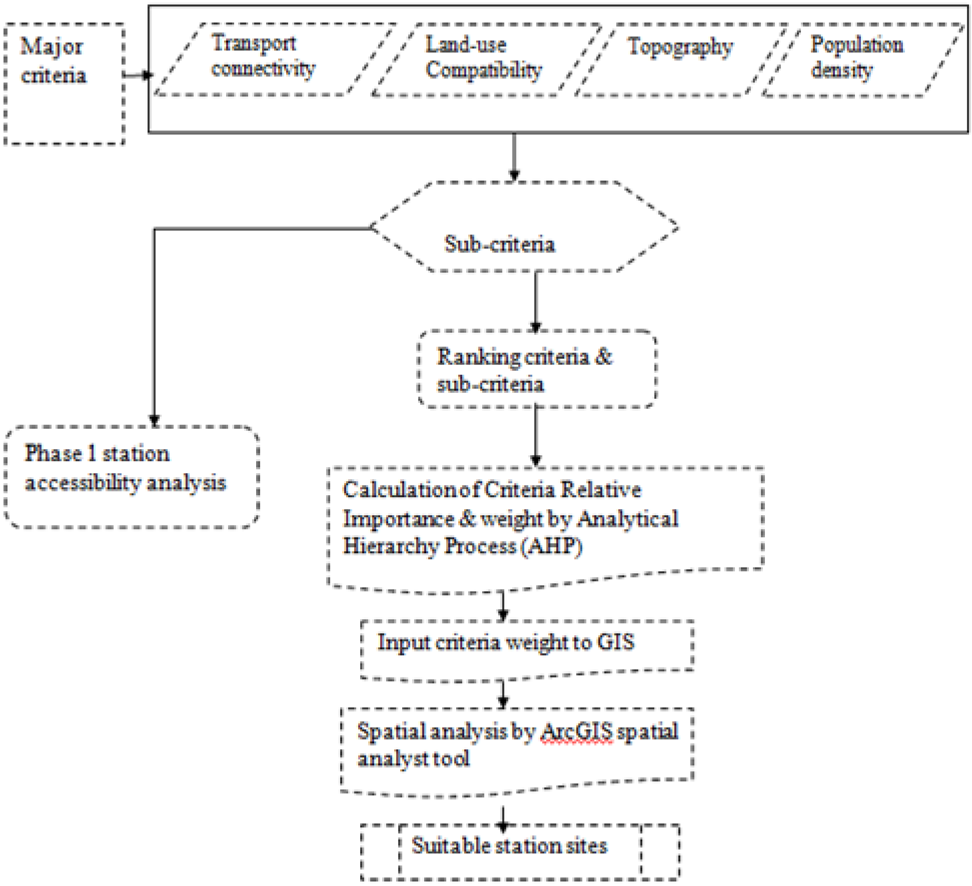

Figure 1.1: Conceptual frameworks

1.3.5 Thesis Organization

The research is comprised of eight chapters and several sub-sections. Chapter one deals with introduction followed by Chapter two which covers literature review; Chapter three deals with methodology; Chapter four deals with study area background; Chapter five deals with station accessibility analysis; Chapter six deals with station site Suitability analysis; Chapter seven forwards conclusions and recommendations and finally Chapter eight presents future research areas.

1.3.6 Research Design

The general steps of conducting this research are shown in figure1. 2.

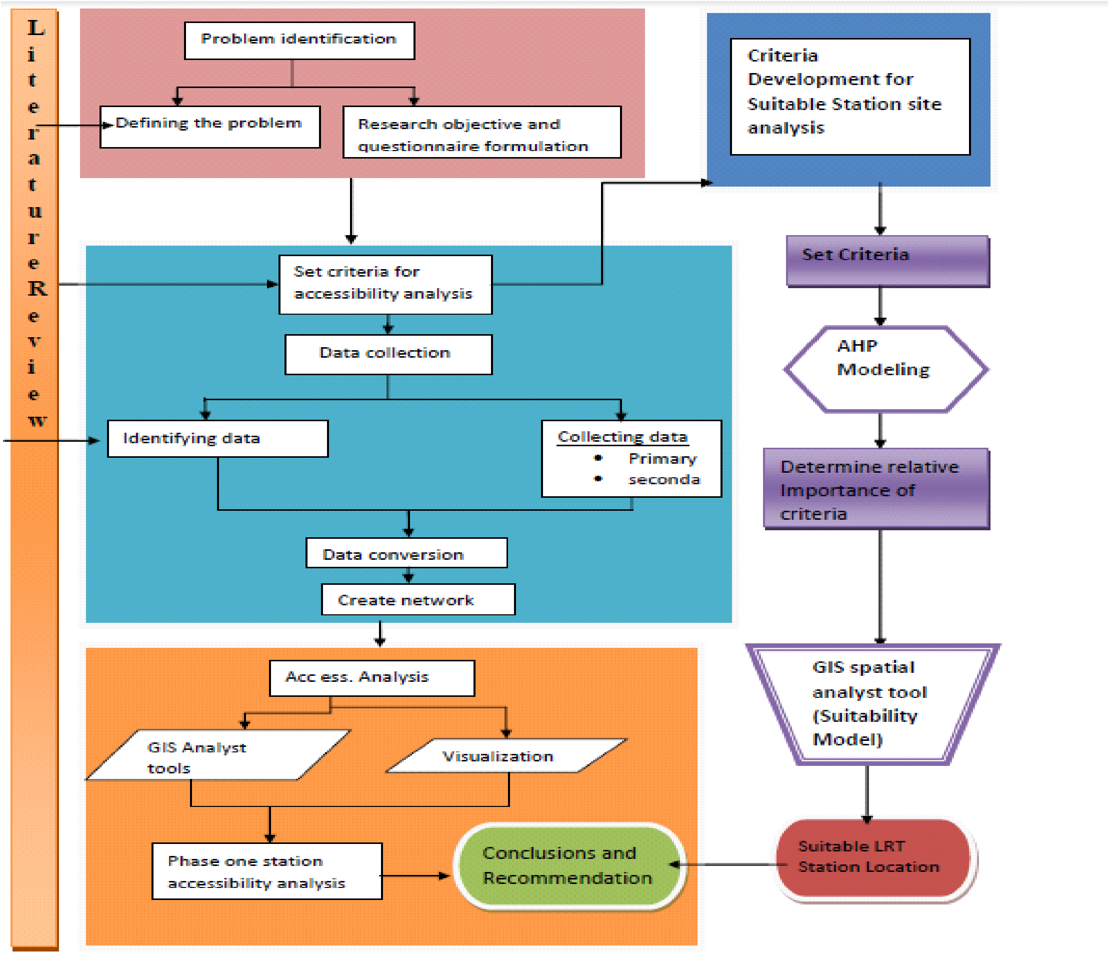

Figure 1.2: Research Structure

CHAPTER 2

2 LITERATURE REVIEW

2.1 General

The literature review chapter of this thesis consists of two sections based on the main objective: (i) accessibility analysis of stations and; (ii) research associated with suitability Map development for light rail transit stations. Section one inspects studies on accessibility of rail transit station while inspects analytical methods for determining urban rail transit station suitable sites and selection criteria.

2.2 Introduction

Locating and selection of urban rail transit station is a task that considers many factors and different professionals such as railway engineer, urban planner, economists and stakeholders mainly; users and governments that should come together to identify the factors and to determine their relative importance. Therefore, locating a station is not an easy task, if we consider locating station at optimum position to attract maximum ridership and integrate with other transportation modes.

Accessibility of rail transit is determined by station ability to draw commuters from catchment area of 400m-500m radius in high density down town and greater area in suburban areas.

According to the U.S. Department of Transportation Federal Railroad Administration Office of Railroad Policy and Development 2011: 4), the development of station area plan begins with developing a vision, setting goals and objectives; followed by the three primary work areas: station location, transportation connectivity, urban design and infill development.

2.3 Light Rail Transit System

Light rail transit system is a sum of different sub-systems, such as: tracks, rolling stocks (vehicles), stations, and electrification and signals that are accurately integrated. Perrott & Menzies (2009) broadly defined urban LRMT Light Rail Metro Transit systems as urban rail transportation solutions that use electrically powered coaches (known as rolling stock) to transport customers between fixed stations. According to them, Light Rail Metro Transit) has different classifications based on system right-of-way whether they are segregated or not and rolling stocks capacity.

Light rail transit is also defined by Robert R. Clark (1984), as mode of passenger transportation using a fixed guide way system and generally employs electricity from external source as a means of propulsion. He described LRT as a versatile mode which has difference in performance and capacity from system to system and from line to line within the same system that leads LRT as a viable solution to very large transportation problem.

Antero Alku (2011) stated Light rail system as a four form system and these are:

- It works in the tunnels as a metro;
- On own right of ways; it works like a train;
- On streets, it works like a traditional tramway or a bus; and
- On market squares and other pedestrian areas, it works like an old fashion slow streetcar or coaches.

Economically, light rail transit system is cost-intensive investment and most of the time; operation is dependent on government subsidies. In order to create subsidy-free light rail transit system, proper planning and operation are vital instruments. Lai (2012) stated that rail transit system has to be competitive with other transport modes and attract sufficient trips to generate revenue and reduce congestion, in order to justify the high costs associated with investment and operation. If it is planned properly, light rail transit investment is expected to encourage and concentrate economic and community growth around the rail stations and along rapid railway routes. Transit system station needs to be integrated with surrounding land use to encourage TOD (transit oriented development).

Vuchic (2005) described the advantages of LRT over buses as spacious articulated cars operating in 1-4 trains that may use short tunnels in city centers or operates in pedestrian streets which makes LRT largely free from traffic congestion, allow them higher operational speed, reliable service and strong and attractive image in the city. LRT is a transit mode that has performance and investment cost between buses and metro systems and it has diversity in physical and performance features that makes it applicable at locations.

The reason for LRT is that construction of large road network would not bring sustainable active urban transportation. Since increasing road space may reduce the quality of urban environment, prevent people from walking and cycling, and force those households who can afford to move into cleaner and less noisy exurban areas. The interaction between transport and land-use, and the dynamics of related developments must be considered.

Deutsche Gesellschaft for Tecnische Zusammenarbeit (GTZ) Gmbh (2004) explained that a car-oriented life style is out of reach of most people in developing countries and that the increment in private car and other motorized transport service leads to overload of existing roads, congestion and environmental degradation of urban space.

Now days, a solution for this problem and sustainable urban transport is mass transit (LRT and BRT) or transit oriented development (TOD) around or along transportation systems. Only public transport can assure mobility in large cities. Figure 3 illustrates traffic and land-use interaction (traffic spiral) as provided by Deutsche Gesellschaft for Tecnische Zusammenarbeit (GTZ) Gmbh, (2004).

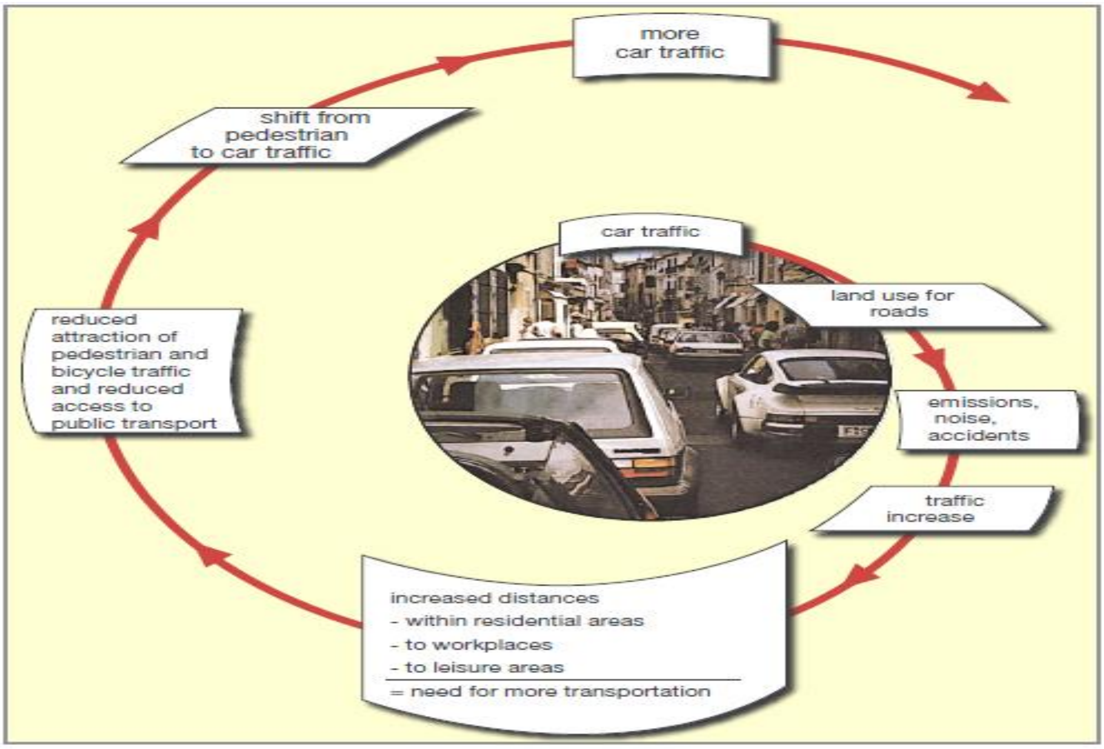

Figure 2.1: Traffic and land-use interaction (traffic spiral)

2.4 Light Rail Transit (LRT) Station

2.4.1 Definition

A station is a point along railway line where trains stop for passengers to alight and/or board and for freight to load and/or unload. Unlike bus stops that can be easily relocated, rail transit stations are permanent structures that involve major investment and often have strong impacts on their surroundings (Vuchic, 2005). Light rail transit station is only for passenger traffic. As explained in previous section, LRT station is one of the components of light rail transit system. Many scholars and books defined LRT station in the following ways:-

- A station is defined as a public transport facility of high quality, which acts as a central departure and/or destination point to accommodate high passenger volumes where passengers transferred from and to different modes of transport services. Stations are normally located at points of high travel demand and can be sited from outer sub-urban areas to inner-city areas and generally serve key catchment areas such as commercial and business districts, and may contain a moderate to a very high level of supporting structures such as park-and-ride, kiss-and-ride, public and bicycle amenities (Queensland Government, 2012). Stations are also considered as shopping malls; meeting places and urban landmarks. Development of railway station attracts economic activities such as shops, retail and offices at its surrounding. Amtrak (2013:7) defined station as a major hub in a multimodal network, connecting downtown and other important places in the region. Further definitions were provided as follows:

  - Transfer stations are joint stations for two or more lines at which passengers between lines, terminals are, strictly defined, end stations on a transit line, but sometimes the term is also used for major transfer stations (http://www.amazon.com/Urban-Transit-Operations-Planning).
  - A light rail station is a station or stop in a rapid transit system. It can be as simple as a bus stop or as extravagant as an underground or elevated multi-use transit hub (Topalovic et al., 2009).
  - Light rail station is point where passengers board and alight from trains, and ranges from simple platforms at ground level to complex structures above or below ground which may be accessed via stairways, escalators and elevators (This Is Light Rail Transit, 2000:12).

Station locations and park-and-ride considerations should be reflective of economic development objectives in that area because stations have many advantages in developing the surrounding areas. The following are some of the advantages:

- Stations are potential catalysts for new transit-supportive development;
- Limiting free surface parking at or near stations will make more land available near the station for higher-density development where zoning allows;
- Station can serve as a centerpiece of a mix of transit-supportive land uses;
- Park and ride locations must be within the commuter shed for modal changes; and

- Stations located partially or fully on or in private property should be considered (i.e., within developments or activity centers being served).

Stations are one of the components of light rail transit systems. Light rail connects neighborhoods, districts and downtowns while stations are access points. Locating stations at the right places with the right connections with other transportation modes is essential (David Evans And Associates, Inc. and Sera Architects, Inc, 2009).

Generally, stations are selected places on a railway line where trains stop for:

- Exchange of goods and passengers;
- Control of train movements;
- Enable trains to cross from opposite directions;
- Sorting bogies;
- Changing engines and staff; and
- Taking diesel and water for locomotives.

Adequate distance between stations should be provided to maximize average operating speed. Location of stations in close proximity to each other would be unreasonable for train operations except in instances where stations provide essential distribution for passengers in large urban areas. Closely located stations will reduce train operational speed. Hence, minimum station spacing should be determined (Northern New England Intercity Rail Initiatives, 2014). A review of standard practices in most North American cities indicate that stations are generally located 400 m apart in the central business district, when acting as a local service. In the outlying areas of the city, it is common for stations to be spaced at larger distances apart, between 800 to 1000 m.

2.4.2 Types of stations

Categorization of stations is an important tool for use in planning and programming the size and amenities of stations to meet local need, and in understanding the underlying factors that determine stations' roles in the transportation system. Knowing station types are important for planning station sites and for programming station sizes. There are three types of stations based on their location relative to track; Online, Inline and Offline stations.

Amtrak's Station Program and Planning Guidelines (2012) have categorized stations into four based on annual passenger flows, customer services and amenities consistent in station and whether the station is staffed or un-staffed. According to Amtrak (2012), there are five station categories according to the following bases:

Based on size

- Category 1 – Large;
- Category 2 – Medium;
- Category 3 – Caretaker; and
- Category 4 - Shelter.

Based on location

- Online station: Online stations are located within the vehicle runway and the transit way so that vehicles can access them without leaving the runway. Online stations are important elements of transit-way service speed, reliability, and accessibility.
- Inline station: Inline stations are located immediately adjacent to the vehicle runway, typically along freeway interchange ramps. Although they require the vehicle to exit the primary runway, they provide a fast access opportunity and immediately return to the runway.
- Offline station: Offline stations support transit way accessibility and ridership, but require transit way vehicles to exit the running way and require several turning movements and potential traffic delays that impact transit way service speed and reliability, especially during peak travel times. Figure 2.2 shows the layout of Online, Inline and Offline stations.

Figure 2.2: Stations Based on Their Location Relative to Tracks (Online, Inline and Offline)

2.4.3 **Station Location Planning/selection**

There are many researchers who did studies on station location selection. (Scott A. Burger and Bill Byme, 2015), explained factors they used to select rail transit stations and park-and-ride location planning process as (land availability, highway access, proximity to major land-uses, shared parking possibilities and transit-oriented development (TOD) that are potential to influence decisions of system users. By taking these factors into account and reviewing previous works, they proposed station location planning considerations.

Determining the location of transit stations is a critical part in designing a rail transit system (Lai, 2012). There are five steps considered in locating rail transit station selection and these are:

- Review the framework: understanding priority objectives and development strategy;
- Map target locations: determining potential station locations;
- Evaluate locations: refining target station locations through analysis;
- Consider the location type: determining location type and indentifying target sites ; and
- Evaluation flowchart: refining target sites by using a set of defined criteria.

The above is very clear and convenient process, since it selects station location from candidate station locations without knowing the alignment and decide alignment from consecutive station, it cannot yield the real track alignment that satisfies various geometric constraints (Lai, 2012)**.** Another method of selecting station locations is placing along selected alignment.

Station size and the complexity of its site design can vary significantly from location to location; the site design issues included here are consistent across many station categories and locations. The relationship of the station to the community, surrounding development and other transportation modes is critical to its success.

Maps of population density, community centers, commercial districts or malls, other public attracting places, amenities or institutions, park-and-ride locations and public parkades and existing charging stations are very important inputs for mapping target potential locations (LAB and TIPS, 2011).

Development of station area planning has three primary work areas: station location; connectivity with other transport modes; urban design and infill development. Optimal station location is a foundation for connectivity with other modes and for surrounding area development (Development, June 2011). In order to attract many ridership, higher density residential, higher density commercial, employment nodes and mixed use are potential land-use to locate stations.

Locating, rail transit station is a key element in railway design. Station area planning should be designed in which it can support people to easily access available transportation modes since, Station locations have direct impact on passenger attraction, ridership, vehicle operating speed and operational system such as travel time, riding comfort and cost of operation (Lai, 2012).

2.4.4 **Station location selection criteria**

Proper site selection plays a vital role for both social and economic activities. It is obvious that inappropriate site selection leads to heavy social and economic losses. Taking business operations as an example, site selection is the first key factor and directly related to customer groups, capital investment and recovery, and development strategy. Therefore, making good preparations and analysis on the parameters of the site selection is absolutely necessary.

According to Jha et al. (2013), Selection of rail transit routes and intermediate stations depend on many factors, such as demand, ridership, transfer stations, right-of-way, and construction costs.

The Metropolitan Council (2012) Transit way Guidelines identified four key transportation connected site location factors based on primary or secondary factors for each mode: (i) access to station for transit vehicles and customers; (ii) impacts on existing road network; (iii) land availability for Park and Ride Plan; and (iv) railroad track-way operational impacts. The others are land use- related factors which are:

- Land availability;
- Land types and costs (e.g., public right-of-way, joint-use, private, etc.);
- Mix of land uses and compatibility with transportation functions;
- Development plans, including comprehensive and station-area plans;
- Available infrastructure and the cost of providing additional infrastructures, including bicycle and pedestrian infrastructure (e.g., sidewalks, bicycle-pedestrian overpass/underpass, etc.);

- Proximity to affordable housing;
- Proximity to employment; and
- Size of and proximity to transit-dependent, low-income, and minority populations.

According to Metropolitan Council (2012), station site selection is based on:

- Acquisition of land;
- Proximity to town or village;
- Nature of land Area –gradient for station yards: 1 in 400;
- Approach roads to station site;
- Station site alignment;
- Site drainage –grade of 1 in 1,000;
- Station amenities;
- Type of station –Through type or Terminal type

Rail transit way stations should be sited to maximize convenience and minimize travel times for subject passengers and vehicles under existing and planned future conditions. According to David Evans and Associates Inc and SERA Architects Inc (2009), there are some ideal characteristics of light rail transit station area considered in station locations such as good connections, density, diversity and use. With increased interest in new transit systems for congestion relief, optimal stations location planning is a principal activity.

Hence, there are various studies done on station site optimization based on different factors. Optimization of station location is obtained by considering population map, employment and transportation systems while site selection is done for the station to be easily connected to other modes and to enhance surrounding area development (Development, June 2011). Samanta et al., (2005:2-8) used a algorithm to optimize station locations along a rail transit line so as to minimize the overall system cost (i.e., capital cost, operator cost, and user cost) by using GIS and anti logarithm.

On related problem, Olowosegun Adebola and Okoko Enosko (2012), studied on determination of best locations for bus stops. They used Slope Map, Shelter Map and Bus-Stop Spacing Map to determine the best bus stop location. According to them, bus stops have to be located in accordance to the following:

- Four hundred (400) meters interval on the major road;
- Available setback from the road ideal for shelter; and

- Slope Map.

Railway station location selection is also a multi-criteria or factor problem. The factors should be considered simultaneously as their effect is concurrent. Considering all criteria at once is a complicated task. To handle such problems in transportation planning, GIS combined with multi-criteria decision making software is best alternative.

2.4.5 Station accessibility evaluation

Station accessibility has two dimensions: (i) external accessibility (how easy it is to get to and from the station); and (ii) internal accessibility that is ease of movement within the station areas such as kiss-and-ride, park-and-ride, platform, concourse, etc. (MoTaC and ERC, 2009:9). The scope of this research is only external accessibility. This is because internal accessibility to all users has been done previously.

Intermodal exchange and way finding

To ensure as seamless as possible journey, the station design has to take into account that passengers do not start and end their journey in a station. Their travel experience is very much determined by their approach and departure from the station. Depending on location this can be any combination of the following forms of transport:

- Walking
- Cycling
- Car drop off or taxi
- Bus or tram
- Car parked in station car park
- Underground railway
- Airports

Interchange between all modes must be efficient and obvious to the traveler with clear signage, minimum changes of level and where possible protected from the elements (Network Rail, 2011).

Interchange - Station Design Check List	
1	Does the spatial organisation provide for efficient vehicle movement, while minimising conflicts between vehicles, pedestrians and other means of transport?
2	Does the design include conveniently located pick-up and drop-off areas for taxis, buses and private vehicles?
3	Is there an integrated local transport strategy and is the design coordinated with other means of transport?
4	Have appropriate bicycle facilities been provided?
5	Have appropriate cark parking facilities been provided?
6	Does way-finding comply with Network Rail's wayfinding standards?
7	Has an independent[6] way-finding consultant been appointed to determine location and specification of signage?
8	Does way-finding and information support onward movement beyond the station footprint?

Figure 2.3: Station design checklist

A station is said to be accessible if it is easily accessed by modes such as pedestrians, buses, private cars and bicycles. Pedestrians access station on foot walking a reasonable distance. Many researchers have identified reasonable walking distances. Maximum acceptable walk times at either origin or destination are quoted as standard maximum walk times five minutes for access to bus stops and ten minutes for access to rail or LRT based on a walk speed of 80 meters per minute (4.8kph/3mph). In rural areas these times may be doubled.

Station accessibility assessment is done based on ideal station characteristics and identification of missing elements for stations under consideration. Ideal characteristics, by definition, are not always achievable and must be balanced with constraints and other considerations. According to this report, ideal characteristics of stations are:

- **Good connections**
  - Sidewalks connect the neighborhood to the station;
  - Busy streets nearby have marked pedestrian crossings;
  - Pedestrian crossings are provided over or across physical barriers (such as the railroad or major busy streets) between the surrounding communities and the station;

- Buildings are pedestrian-friendly (the front door or entrance faces the street or sidewalk and there are ground floor windows);
- Streets and sidewalks are well lit;
- Bike lanes, multi-use paths, or low traffic streets provide bike access to the station;
- Bus stops are located near the station, with clear paths from the stop to the light rail station;
- Etc.

- **Density, Diversity, and Use**
  - Station area includes a variety of housing types and densities such as apartments, condominiums, townhouses/row houses, live-work units, and single-family homes;
  - Station area provides transit access to a variety of jobs and/or employment centers;
  - Retails, restaurants, and other commercial uses present an opportunity to be supported by transit;
  - Station areas include institutions such as schools, parks, and medical facilities that would benefit from transit service;
  - Etc.

- **Opportunities for new uses**
  - There is vacant or underutilized land near stations;
  - A light rail station could support or encourage new development consistent with the city and neighborhood plans and policies;
  - Etc.

- **Get the land uses right**
  - Make retail strategy market-driven, not transit-driven;
  - Develop mixed-income housing and encourage every price point to live around transit;
  - Segregate uses and vary density where appropriate. Mixed uses don't have to be in the same building;
  - Allow employment areas near the station to promote reverse commuting and optimize transit capacity.

- **Build a place, not a project; ensure good urban design**
  - Design the station as a positive edge, center of, gateway to, or main amenity for the station community;
  - Use high quality urban form to support mixed incomes and uses;
  - Balance higher densities with additional amenities (e.g., attractive design, neighborhood-serving retail and services, functional open spaces);
  - Create landmarks and beacons;
  - Preserve and invest in existing neighborhoods;
  - Extend the interconnected street grid and establish a finer-grained lot and block structure in new or redeveloping neighborhoods;
  - Transitions into the surrounding single-family residential areas of a neighborhood;

- **Get the parking right**
  - For station locations that must accommodate park-and-ride facilities, locate them within a five-minute walk of the platform but not directly in front of the station; locate utility structures so as not to preclude redevelopment of prime, station proximate sites.
  - Discourage station spillover parking into the neighborhood: Unless a park-and-ride facility is provided, stations are meant and designed to serve the surrounding neighborhoods and land uses and be accessed by foot, bike, or bus rather than by automobile. On-street parking should be managed to avoid spillover from the station through programs such as parking permits and metered parking.

By using these checklists, any station assessments can be done. In the case of this research, only external accessibility evaluation of station location has been done.

In the process of creating active urban transportation, railway transit system as a means of mass transport, should be accessible to all modes and pedestrians and stations should be easily and naturally accessible, with a clear layout for street-to-train, bus-to-train, and station-to-area destinations.

A primary factor in locating a single station for all transit-way modes is creating access to the station for transit vehicles and customers. It is critical to ensure that customers and transit vehicles, including those specific to the mode and those connecting for transfers, have safe and convenient access to the station. Similarly, convenient access intern will ensure efficient transit operations for all modes, and is critical in providing fast and reliable service on the transit way.

If a station is located at a place where other modes of transport are accessed or linked to, the station is defined as intermodal connected station (Northern New England Intercity Rail Initiatives, 2014).

An intermodal connected station attracts many riderships, since families could choose to own one automobile instead of two because they will be confident that other transportation modes will enable them to move conveniently throughout the city. Shifts in transportation modes will yield a significant benefit to personal and urban health and to environmental sustainability

The proximity of stations to rapid transit, intercity and commuter rail, local and intercity bus, major roadways, or airports will improve intermodal connection between travel modes and attract maximum rider's mobility (Northern New England Intercity Rail Initiatives, 2014). Passenger access to railway station can be through private automobile, taxi, transit, bicycle and walking. Therefore, proper station location planning shall guarantee that each mode is accommodated and transfers are provided.

The Guideline described types of station access that should be considered when locating a station and selecting the station type as transit way, connecting roadways that support transit transfers or customer access, sidewalks, and trails.

Railway transit system accessibility is analyzed based on station accessibility analysis; and station accessibility will be analyzed based on the following station access criteria:

- Private automobiles and taxi pick-up facilities areas for private automobile, group ride, and taxi stands should be provided to facilitate easy passenger drop off and exit from stations. Easily identifiable taxi stands should be built in close proximity to the main station entrance;
- Parking availability for park-and-ride and kiss-and-ride;
- Private car rentals and car sharing;
- Transit connection: Bus stops should be located near LRT stations so that passengers getting off the bus and walk the shortest possible distance to access the station;
- Pedestrian network/ walkways; and

- Bike and bike sharing.

The average straight line distance of each access mode may differ from each other. Comparing the walk and private car mode, a large number of people who walk to the station have their point of origin within a 500-meter radius of the light rail transit station. While for the private car mode, most of the origins are farther from the center. The mean of the straight line distance for walk mode is 500m, and for the private car mode is 1500m.

Light rail transit (LRT) line may be constructed having its own right-of-way or in the medians of road /elevate or at grade. For many advantages, LRTs are constructed in road medians worldwide. Some of advantages of such stations include avoiding high right-of-way acquisition costs, increasing train speeds, and limiting modal conflicts.

In Los Angeles LRT networks, they used seven criteria and reviewed pertinent literature to analyze accessibility of elevated stations. These criteria were: 1) cumulative opportunities; 2) cumulative dis-amenities; 3) infrastructural barriers; 4) connectivity; 5) station visibility and legibility; 6) platform accessibility; and 7) environmental conditions.

2.5 LRT Station location planning using AHP and GIS

2.5.1 Analytical Hierarchy Process (AHP)

AHP is a multi-criteria decision making tool, which was proposed by Saaty (1980) and is a structured technique for decision making based on a hierarchical framework constructed through mathematical pair-wise comparisons.

The weights for the decision making criteria are derived based on the pair-wise comparisons of the relative importance determined by experts between each two criteria (the sum of the weights equals to 1). As suggested by Saaty (1994), a judgment or comparison is the numerical representation of a relationship between two elements that share a common parent.

AHP is the most creative multi-criteria decision making technique. It structures evaluation factors descending from an overall goal to criteria, sub-criteria and alternatives in successive levels (Saaty, 1990).

AHP was framed as a multi-criteria procedure and integrated with Geographic Information System (GIS) to develop an optimal transit station site assessment system and accessibility analysis with the flexibility to account for the population in the study area, land use as well as proximity to parking buildings and bus stations/stops and distance from road network and LRT lines.

And GIS is a powerful tool to develop better public transportation analysis technique due to its ability to manage, recall and evaluate information effectively. GIS has many applications in transport planning, railway operation management, resource allocation, optimization of railway alignment and station locations and in handling and analysis of different spatial data related to railway within a single geodataset.

Once all spatial data within study area have been collected into a geolocated dataset, the information can be used to inform the engineering works are required and so on. For example, any locations where railway alignment deviates or failed from existing track alignment can be quickly identified and resource needed for track repairing can be allocated to the place. The list below identifies the major functions or disciplines in which GIS has been successfully deployed in railway organizations:

- Real estate management;
- Facility management;
  - Track,
  - Power, and
  - Communications and signaling.
- Asset tracking;
- Commodity flow analysis;
- Emergency response management;
- Environmental and construction management;
- Intermodal management;
- Passenger information;
- Capacity planning;
- Marketing;
- Supply chain management;
- Site selection; and
- Risk management.

Since AHP is a comprehensive approach due to its ability to consider various simultaneous criteria in the decision-making process, this paper will highlight on the application of multi-criteria techniques incorporated with GIS in identifying possible LRT station that take into consideration important and critical spatial criteria. Only through the use of GIS is it possible to visualize all of this information simultaneously and quickly, and thus easily understand all the relative impacts that can result from the station under consideration.

Applying AHP to a decision-making problem involves the following four fundamental steps (Piamviriyawong, 2006).

- **Model specification**: First, feasible investment alternatives are specified followed by the determination of criteria for the evaluation of alternatives. These criteria are further grouped into logical categories.

- **Pair-wise comparison of categories and criteria**: The relative importance of criteria within each category and of each category within the group of categories is established through pair-wise comparisons using a square matrix structure. The values of importance are taken from Saaty's 1-9 scale mentioned above.
- **Weighting of investment alternatives**: Every investment alternative is rated with respect to every investment criterion in the evaluation model. Pair-wise comparison is applied to obtain weighting for qualitative data. If quantitative data are available, then the weighting is done by using the existing or estimated performance data.
- **Investment rankings**: Finally, weighting of the alternative is combined with the weighting of the criteria to form an overall rating for each investment alternative. The alternative with the highest weight is ranked as the best choice, taking into account the relative importance of each criterion and the relative desirability of the alternatives with respect to each criterion.

(Saaty, 2008) also clearly confirmed the following AHP processes that should be undertaken:

- Identifying the problem by identifying the goal;
- Identifying the criteria that affect and influence the problem;
- Identifying the suggested alternatives or solutions that will be compared and differentiated;
- Constructing the hierarchical model, including the higher level that represents the desired goal; the middle level that represents criteria; sub-criteria that influence the problem; and the lower level that represents the suggested alternatives and solutions that will be compared and differentiated in order to solve the problem;
- Collecting data, noting that it is required here to identify the personal judgments of the decision makers, the experienced people and researchers who are familiar with the problem in order to provide solutions for it. This is accomplished by conducting personal interviews or through special questionnaires related to the analytical hierarchy;
- Designing pair-wise comparisons matrix, where elements are compared by two-way method for each trait; and
- The pair-wise comparison starts from the top of the hierarchical model, which represent the goal, as mentioned before, the highest level in the model (the goal). The beginning is done by comparing the criteria relative to the goal where this comparison

follows the pair-wise method by comparing between two criteria for the same goal followed by making a shift toward another two criteria to select the goal.

These are steps used in four levels AHP model. While three level AHP model is similar to four levels but there is no fourth level in three levels AHP model. In this research three level AHP model was used.

2.5.2 **Geographic information system (GIS)**

Geographic Information System (GIS) is a system designed to capture, store, manipulate, analyze, manage and present all types of geographical data that is spatially geo-referenced at all scales. In the simplest terms, GIS is the merging of cartography, statistical analysis and database technology. The GIS applications are tools that allow users to create interactive queries, analyze spatial information, edit maps and present the results of all these operations (Clarke, 1986).

2.5.3 **Application of GIS in Railway Engineering**

GIS applications cover much of the broad scope of transportation. Transportation analysts and decision makers use GIS tools in infrastructure planning, design and management, public transit planning and operations, traffic analysis and control, transportation safety analysis, environmental impacts assessment, hazards mitigation, configuring and managing complex logistics systems, just to name a few application domains. Similarly, GIS is a useful tool that can be applied in many decision making problems. It helps in decision making process by handling and considering simultaneous factors/ criteria that affect decision making.
Rail way engineering needs GIS in different decision making problems such as:

- Data handling in a single geo-dataset; many railways related data with different attributes that can be stored, edited and analyzed for planning and design purposes;
- Resource allocation;
- Railway system planning;
- Identification of areas that have drainage problems and flood area delineation;
- Optimal railway alignment and station site selection;
- Station access evaluation;
- Earth work estimation (cut and fill);
- Railway system operation management;
- Railway maintenance management; etc.

Most GIS have very limited capabilities for integrating geographical information and the decision maker’s preferences. Therefore, it is suggested there should be integration between GIS and AHP.

This research is envisaged to identify optimal location of urban railway transit stations which helps to create more convenient transportation options by reducing congestion, primarily based on population density map, distance from collector road network, proximity to parking building and bus/taxi stops/stations map and land use and site slope condition maps taking the Addis Ababa LRT. In addition, accessibility of phase one LRT stations has been studied in this research.

CHAPTER 3

3 METHODOLOGY

3.1 Introduction

This study adopted an analytical, descriptive method by using the analytic hierarchy process (AHP) integration with geographic information system (GIS). This was done first, through station accessibility evaluation and site suitability for new stations along with LRT lines; and second, by developing or through identification of criteria were the major factors considered in the methodology. In the case of new station site suitability analysis, development of LRT station site selection decision determinant criteria was performed followed by weight determining process criteria using AHP Super Decision software.

The first step to achieve this goal was the development of questionnaires where 8 experts were asked to determine the relative importance of each factor. The method evaluates the relative significance of all the parameters by assigning weight for each of them in the hierarchical order; and, at the last level of the hierarchy, the suitability weight for each class of the factors was given. Typically, the priority of each factor involved in the AHP in order to produce the land suitability map, the actual factors and class weights (ratings) of the parameters involved in the study are needed. These are determined systematically based on the AHP analysis.

The relative importance of the criteria was judged by experts who could evaluate the relative significance of the criteria that determine station location decision. Each respondent was asked to compare all of those factors and to rank them based on her/his preference. To help the respondent in evaluating those factors, the Analytic Hierarchy Process (AHP) program was used. AHP allows respondents to judge those key factors using a pair wise comparison method. With this approach, the respondent compared two factors at a time, decided which one is the more important factor in determining locations of transit alignments, and set the preference level of the selected factor. The comparisons were done using actual measurements or based on the relative subjective evaluations of the respondents.

By using relative importance matrix judged by experts, weight criteria were determined using AHP excel template. Then, the weights were used as an input in GIS multi-criteria spatial analysis for suitable station location identification.

Station site selection criteria were determined by reviewing related literatures. Criteria weights were determined by means of AHP which were then used as inputs in weighted overlay of these criteria in ArcGIS for identifying suitable station sites.

3.2 Methods Used in New Station Accessibility Analysis

The following figure 3.1 shows methods flow chart used in station accessibility evaluation.

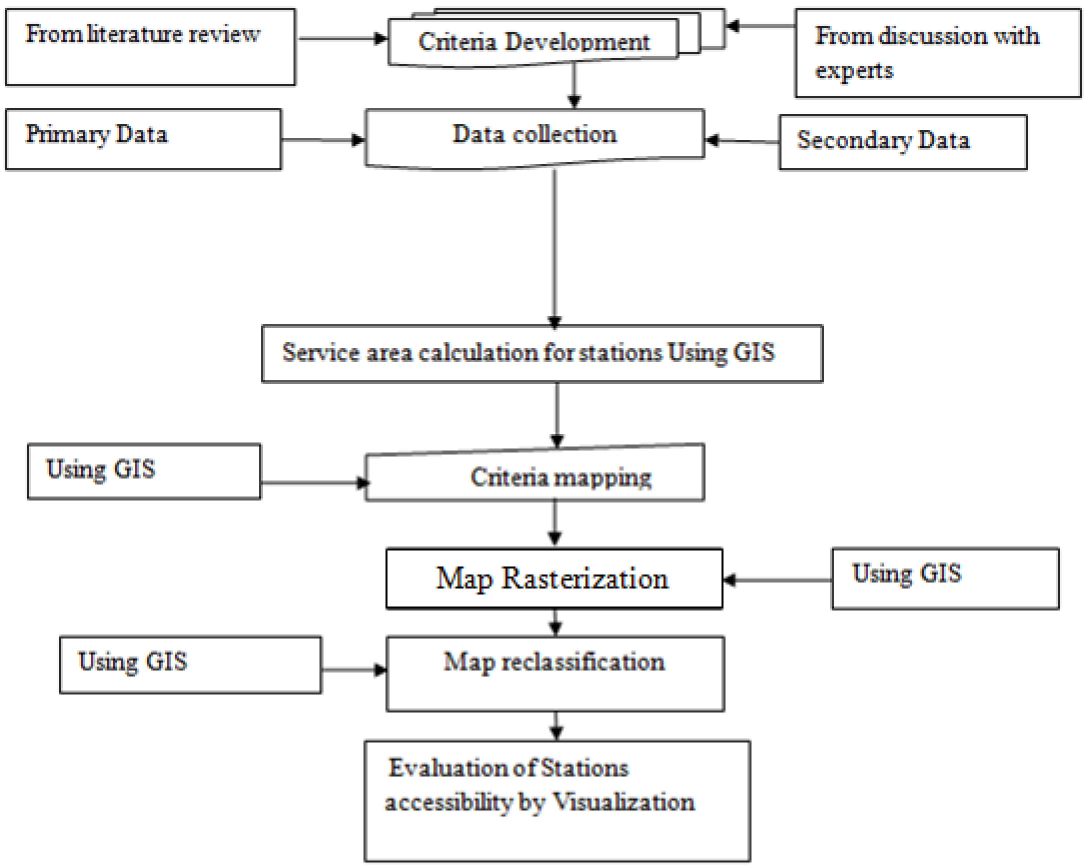

Figure 3.1: Methods Flow Chart Used in Station Access Evaluation

3.3 Methods Used in Station Suitable site Selection

As explained above, criteria development, relative importance of criterion judgment by experts, criteria weight determination using AHP/ANP and GIS Spatial Analyst tools were applied in potential station site analysis. Figure 3.2 shows methods flow chart in suitable station site analysis.

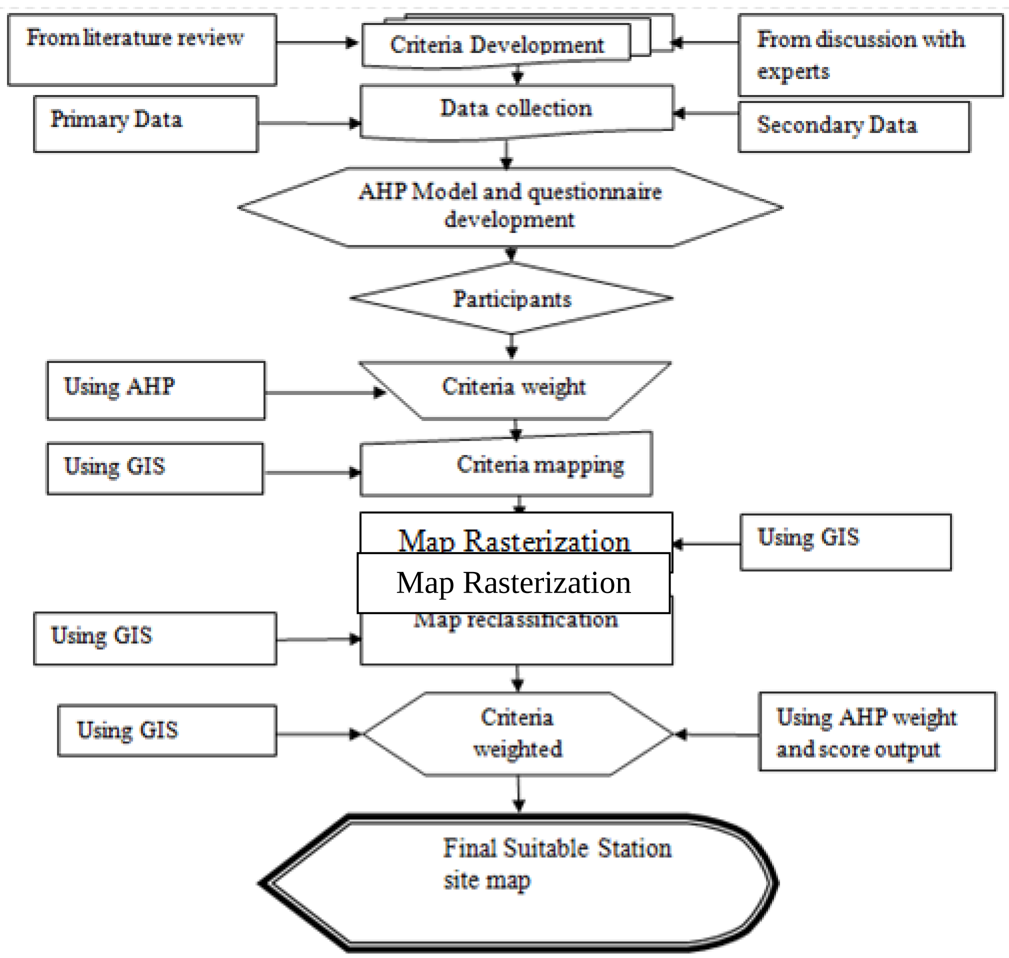

Figure 3.2: Methods Flow Chart in Suitable Station Site Analysis

Lists of activities in this topic are:

3.3.1 **Euclidean Distance Calculation**

The Euclidean distance operation describes each cells relationship to a set of sources. The function gives the distance from each cell center to the closest set in the raster format data set. This function was used to calculate distances that are distance from bus station and parking building to the stations. The Euclidean distance output is a raster file format that has different layers or concentric rings from the point of reference. The distance is given in linear units meters, kilometers, miles etc. In this study case, Euclidean distance calculation was done for distance from road and from LRT lines.

3.3.2 **Buffering**

A buffer is an area formed from a locus of constant radius from a given point or along a linear feature. This analysis can be done on either points or lines and the result is always a new polygon layer. These buffer polygons define the inside and outside of a region which are typically distinguished by different codes in the attribute table. In this project, buffering was done on all the bus stops/stations and also on all Multi-storey parking buildings aimed at identifying proximate bus stops and parking building to LRT stations.

3.3.3 Rasterisation

Rasterisation (or vectorization) is the task of taking an image described in vector graphics format (shapes) and converting it into a raster image (pixels or dots) for output on a video display or printer, or for storage in a bitmap file format. And Rasterisation refers to conversion from vector to raster data.

3.3.4 Reclassification

This is the process of assigning weights to different classes of a raster data set. This process is aimed at showing how the different concentric layers are placed and how suitable are they. In this project the datasets reclassified were slope, Euclidean distance of railway road, Euclidean of LRT line, land use in raster, and population in raster format too. Values were assigned to each layer on a uniform scale of 1-5. This scale is thus referred to as the suitability scale. Since all the data was harmonized by this process, the suitability process was possible to be carried out.

CHAPTER 4

4 DATA COLLECTION

4.1 Study Area

Addis Ababa is the capital city of Ethiopia and the place for the Head Quarter of the African Union and it is sometimes referred to as “the capital city of Africa”, due to the presence of different international organizations. Addis Ababa is attracting conference attending tourists as a result of its political location and booming economy.

According to the 2007 census data, the population of Addis Ababa was 3 million (Central Statistical Authority 2007 Report). The area of the City is about 529 km^2; organized into 10 sub-cities and 99 woredas. Due to its location at the center of Ethiopia, Addis Ababa is a transport hub connected to different parts of the country.

As a result of fast economic growth in the country, Addis Ababa is transforming from a predominantly administrative and service center into an industrial and financial center which intern leads to high passenger and goods mobility.

Currently, Addis Ababa’s transportation system has various problems: aged fleet, chaotic movement of mini-bus taxis, unacceptable carbon emissions which is hazardous to life and property and unsafe and unreliable (Yehualaeshet Jemere, 2012). More than seventy per cent of the vehicles in the Country are operating in Addis Ababa with three million populations whereas, thirty percent of the vehicles are operating where more than ninety-five of the population are settled which is not reasonable.

Bus and taxi comprise Addis Ababa’s public transport. However, walking is the predominant transport mode. So far, Addis Ababa has solely relied on traditional buses for passenger mass transit. However, currently though, the construction of light rail transit (LRT) is well underway. Since, the center of city is highly populated and has high traffic congestion, transit services beyond traditional buses is urgently needed and was the reason for the construction of LRT. In this regard, there are two lines under Phase I of AALRT; East-West (E-W) and North-South (N-S) lines. The E-W line has a total length of 17.4 km and the N-S line has total length of 16.97km. The numbers of stations along both lines are 39 of which five are common to both lines.

According to information in conceptual design document, there are twenty-two LRT stations placed under Phase I of E-W route project, five of which are shared with N-S route. The average interval between the two adjacent stations is 815 meters. The longest interval is 1,210 meters and the shortest interval is 525 meters. Similarly, twenty-two LRT stations are placed along N-S route, five of which are shared with E-W route. The average interval between the two adjacent stations is 793 meters. The longest interval is 1,370 meters and the shortest interval is 510 meters.

The study area for the stations' accessibility analysis of this research is the whole Phase I AALRT networks. While, the whole phase two or phase one line extensions are for suitable or optimal station location selection.

Figure 4.1 below shows the AALRT Phase I network and its future extension. Similarly, figure 4.2 shows the AALRT network and its future extensions. Both were provided in Bankable Feasibility Study for Addis Ababa Light Rail Transit, 1st Draft, and Volume I, 2009.

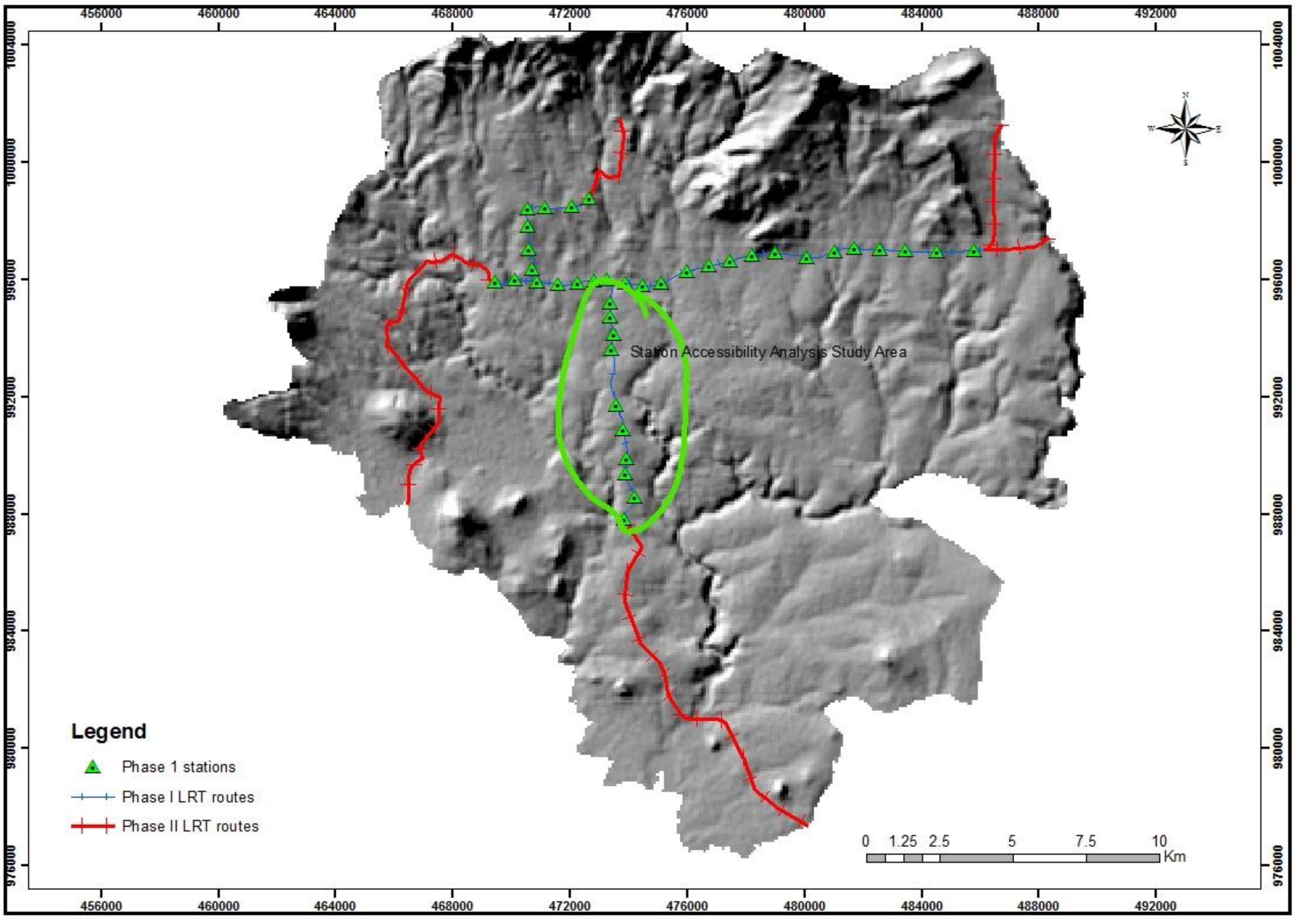

Figure 4.1: Addis Ababa existing and future extension LRT network

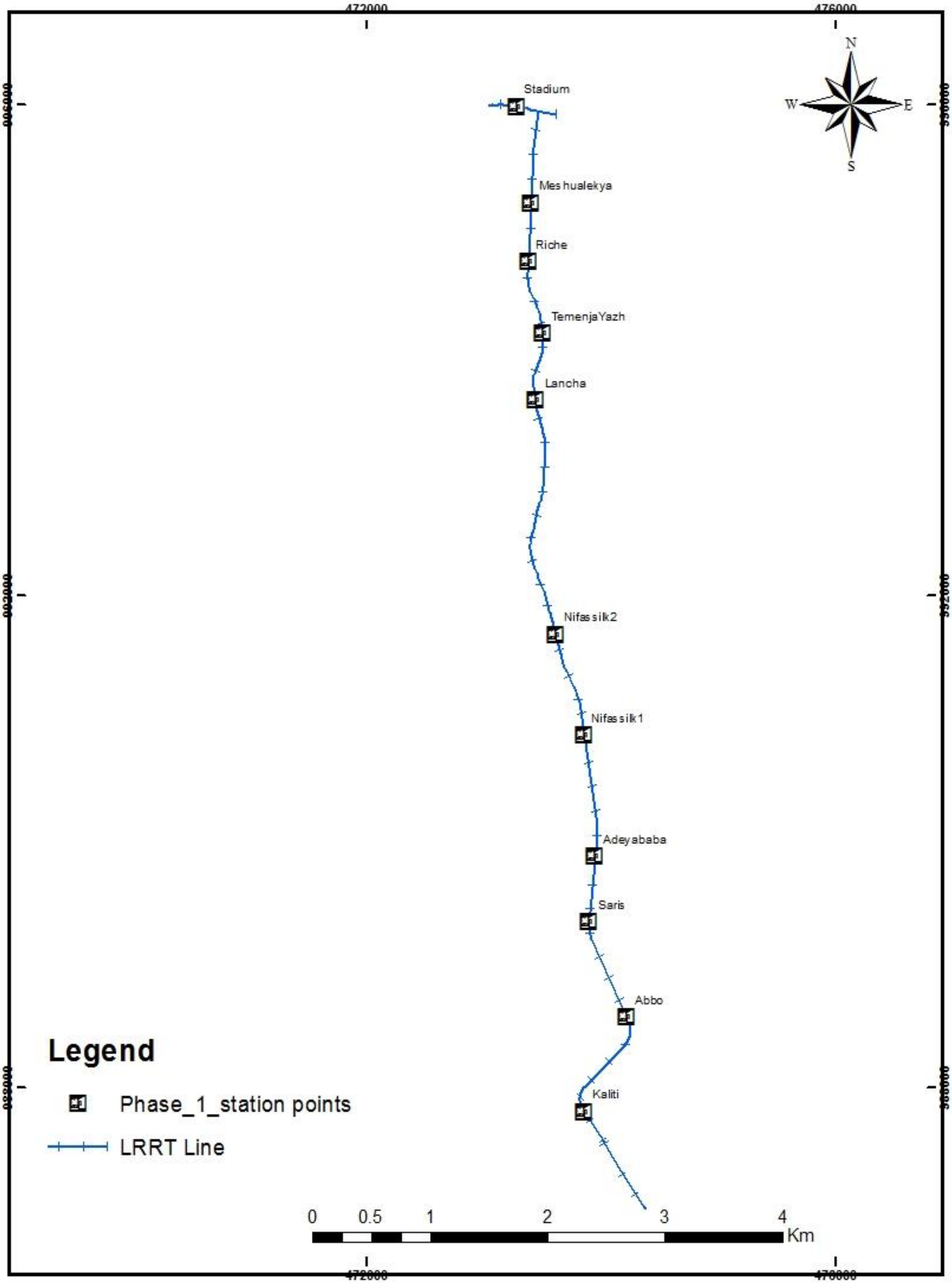

Figure 4.2: Study Area for existing stations accessibility analysis

4.2 Primary Data

4.2.1 General

The primary data were collected from experts through questionnaires. The experts were selected based on their knowledge on transportation planning. Depending on AHP model; a questionnaire was developed which was presented to a group of specialists whose members were anonymous to one another. The process elicits qualitative judgments that indicate the strength of a group of decision makers' preference in a specific comparison, according to Saaty's 9 point scale (Shahroodi et al, 2012). If the members of the group know one another, the decision of one could be influenced by the decision of the other leading to poor judgments. In view of the above, data were collected. In the case of discrepancies arose between judgments of the experts, the researcher would provide more explanations to those concerned for more thoughts in reaching consensus.

4.2.2 Participants

The study was applied to a group of 8 experts that encompassed different specialists and students working in transport planning related. They are selected based on their expertise and experience. The data collection was administered on those specialists in order to develop the weights.

AHP is a subjective method that is not necessary to involve a large sample, and it is useful for research focusing on a specific issue where a large sample is not mandatory (Cheng, 2002). Cheng and Li (2002) pointed out that AHP method may be impractical for a survey with a large sample size as 'cold-called' respondents may have a great tendency to provide arbitrary answers, resulting in a very high degree of inconsistency. AHP survey with a small sample size has been conducted in previous research. For example, Cheng and Li (2002) invited 9 construction experts to undertake a survey to test comparability of critical success factors for construction partnering.

4.3 Secondary Data

Secondary data is normally collected through examination of existing documents in pertinent organizations. In this regard, secondary data were collected by gathering raw data (shape files, AutoCAD files, population and travel demand). Table 4.1 shows the list of required data. Collected data were converted to format that is used in GIS dataset. Table 4.1 shows the required data and table 4.1 shows the Addis Ababa road network and population density as provided by AACRA.

Table 4.1: Required Data

Data List	**Source Organization**	**Data Format Required**	**Data Format**
Road network(GIS shape file)	AACRA	Shape file	AutoCAD
Land-use	AASOIDPO	Shape file	Shape file
Ortho-photo	AASOIDPO	Raster	Raster
GIS shape files(phase I & II stations)	AA LRT office	Shape file	
Population (point Data) and socio-economic data (population density)	Federal central statistics agency	Population density in raster map	Raw data
AA DEM(Digital Elevation Model	AASOIDPO		
GIS software (ArcGIS 10.2)			
AHP(Super Decision) software			

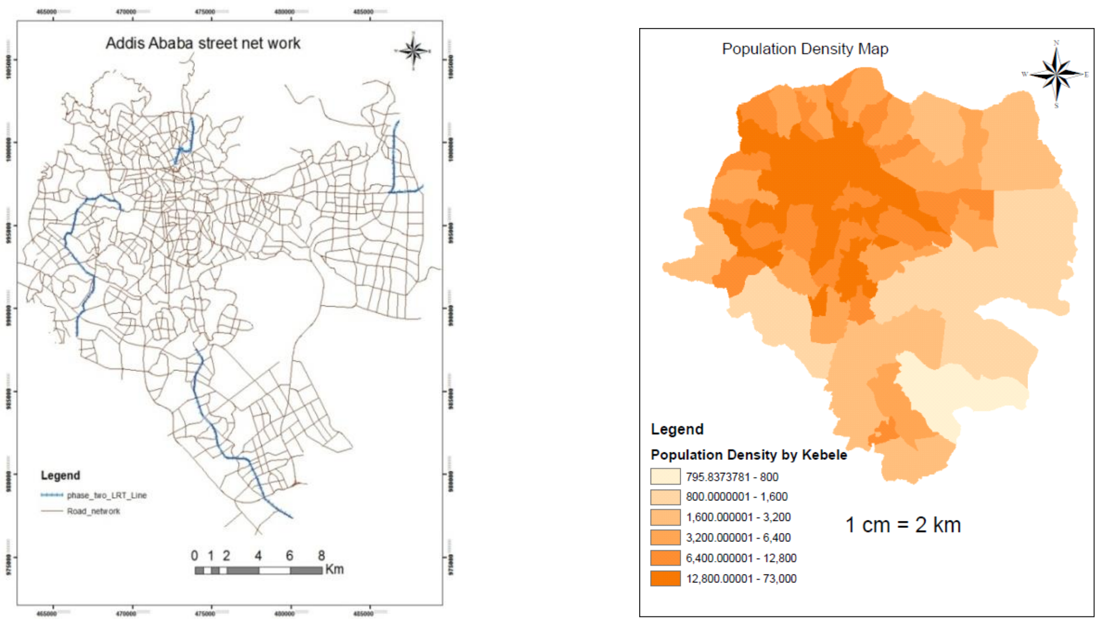

Figure 4.3: Addis Ababa Street Network Converted to GIS shape file and Population Density

CHAPTER 5

5 PHASE ONE STATION ACCESSIBILITY ANALYSIS

5.1 Station Access Guidelines and Standards

This chapter proposes a practical rail transit station external accessibility assessment methodology based on guidelines and standards acquired from literature review. Since passengers do not start and end their journeys at stations, the station design has to take into account that their travel experiences are very much determined by their arrivals and departures from stations.

Depending on location, this can be any combination of the following forms of mobility:

- Walking;
- Cycling;
- Car drop off or taxi;
- Bus or tram;
- Car park in station;
- Underground railway; and
- Airports.

Hence, station accessibility both external and internal should be considered during station design. The scope of this study is only external accessibility which considers station intermodal connection because; internal accessibility assessment has studied previously. Furthermore, station accessibility should be evaluated based on guidelines and standards. The guidelines and standards that followed by access mode are intended to support implementation of the access hierarchy with the goal of achieving an optimal balance of access to the transit system.

- **External Connectivity**

Connectivity implies to connection the station has with other available transportation modes. An intermodal transit station (ITS) can provide the foundation for greater integration of future transportation services, increased connectivity to other regional transportation providers, reduced rates of vehicle-miles traveled (VMT), and reduced congestion. In addition, development of an ITS can leverage investment that supports economic development, environmental benefits through reduced energy consumption and air pollution emissions, and enhanced quality of life .

Accessibility of station can be enhanced through the design of compact urban environments and interconnect networks of streets at neighborhood and urban scale. And this will be obtained by integrating transport plan and the city's land use plan (Tesfaye, 2012).

According to David Evans Associate Inc. and Sera Architects (2009), the following checklists are characteristics of Ideal station location that can be used as a reference to check missed elements of stations. These ideal characteristics may not be fulfilled but, help to assess accessibility of stations relative to absolute station.

5.1.1 Pedestrian Access Guidelines and Standards

According to Regional Transportation District (2009), the following walk speeds shall be used at station facilities for transit access:

- Level walk speed: 200 feet per minute
- Horizontal component of stair walk speed: 130 feet per minute
- Appropriate adjustments for barriers, such as an elevator or street crossing, shall be added to the walk time.

At stations where elderly or disabled persons comprise an estimated 20% or more of transfers, a horizontal walk speed of 150 feet/minute and the elevator time shall be used instead of stair walk speed.

For distance calculation purposes, the centroid of the platform shall be taken from the distance between the front of the trains (highblock) in each direction and the extreme edges of all the platforms. The bus connection points are the designated gates.

5.1.2 Bus Transfer Access Guidelines and Standards

For rail-bus connections, knowledgeable commuters generally have above average walk speeds, but less frequent and new riders require more time to find their way. Crowding at stations during peak periods also impedes free-flow, and elderly and disabled passengers need more time to make their connections. Sight distances also affect perceived convenience.

The proximity of the bus gates to the train platforms is governed by establishing the distances (and travel times) that provide for desirable, average and maximum transfer connections. The probability of making a connection is also of concern. A missed connection means the passenger will wait a time equivalent to the headway (time between buses) on the connecting route. Table 5.1 shows rail-bus transfer distance standards as provided in Transit Access Guidelines, Version 2.4 (2009).

Table 5.1: shows Rail-Bus Transfer Distance Standards

Transfer Time ↓	Maximum Walk Path Distance	Maximum Arc Distance	Weekday Bus Trips
Desirable < 2 minutes	125m	75m	>75%
Average = 3 ½ minutes	210m	130m	>85%
Maximum < 5 minutes	300m	180m	100%

5.1.3 **Bicycle Access Guidelines and Standards**

All stations, regardless of whether they have park-n-ride facilities, shall also have bike parking. Parking shall be provided in the form of bike racks, bike lockers, bike station, or a combination thereof.

5.1.4 **Auto Access**

These guidelines and standards cover both kiss-n-ride drop-off/pick-up areas as well as park-n-Ride facilities. It is important to recognize that in certain instances, competing demand for space or physical site constraints may make the guidelines impractical. The kiss-n-ride facilities at stations typically include areas used for dropping-off and picking-up transit passengers, as well as taxi stands, provisions for paratransit vehicles and private shuttle buses. It may be possible to combine kiss-n-Ride and transit areas provided that automobiles not delay transit vehicles (Regional Transportation District, 2009).

5.1.5 **Kiss-and-Ride**

Guidelines

These facilities should be convenient for both pedestrians and motorists to use, or else they will find other locations to engage in pick-up/drop-off activity that may cause desirable conflicts. The kiss-and-ride should be designed to maximize vehicle turnover, facilitate traffic flow, and avoid conflicts between pedestrians and other access modes and vehicles. One-way traffic flow is recommended and the site should allow for re-circulation.

Standards

All stations, regardless of whether they have park-n-Ride facilities, shall also have kiss-n-Rides when practicable, that are sized to meet forecast or demonstrated demand. Stations located in TOD areas may be accommodated by on-street kiss-n-Ride facilities, subject to the review of local jurisdictions. Except where prevented by physical site constrains, the kiss-n-Ride shall not exceed a walk distance of 400 feet from the platform center, and a maximum arc distance of 240 feet. The kiss-n-Ride shall have a direct line of sight to the station entrance. Pedestrian crossings from the drop-off/pick-up lane shall include a stop sign and marked crosswalk. Signage shall direct both vehicles and passengers existing stations to drop-off/pick-up areas. Figure 5.1 below shows all facilities or elements needed at LRT stations as provided in Accessing Transit: Design Handbook for Florida Bus Passenger Facilities, Vol. III, 2013

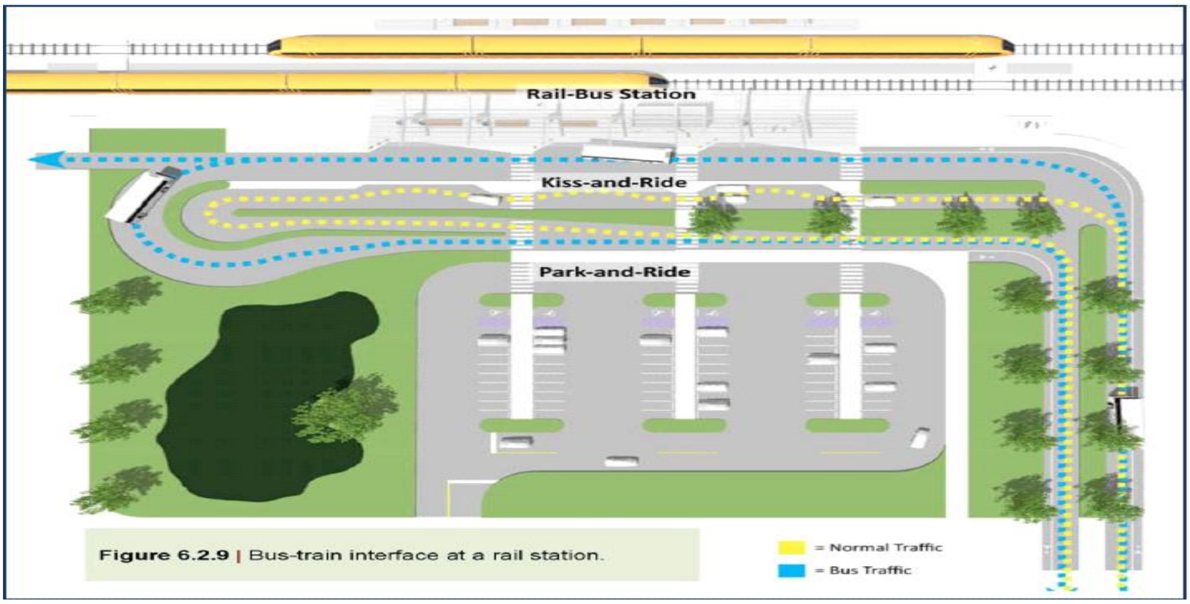

Figure 5.1: Typical Intermodal Railway Station Interface with Bus

5.2 Results and Discussions

5.2.1 Criteria Mapping and Analysis

This chapter evaluated the accessibility of constructed phase one station sites for pedestrians, bicycles, intermodal transit, and (At the moment, kiss-and-ride is not common in Ethiopia) passenger-drop-off vehicles. Based on these criteria, access of the stations evaluated and some recommendations have been done. Passenger flows within light rail transit system redistributed only at stops and boarding / alighting to the street network (China Railway Group. Lt., 2009). For LRT station to meet this target, station site should be integrated with other transportation mode such as integration / connection with collector road, pedestrian and bicycle walkways.

5.2.1.1 Current Addis Ababa LRT system characteristics

As mentioned above, there are twenty-two LRT stations under Phase I of East-West route project; five of which are shared with North-South route. Average interval between two adjacent stations is 815 meters. The longest interval is 1,210 meters and the shortest 525 meters. In view of the above, accessibility of AALRT stations were analyzed based on the following station design criteria identified after intensive literature review. The following factors were considered in evaluating accessibility of Phase I Addis Ababa LRT stations.

- Inter Connectivity
  - Road network;
  - Accessibility to Pedestrian;
  - Accessibility to Bicycle users to station;
  - Park-n- Ride availability; and
  - Bus and taxi transfer station.
- Ridership
  - Population density

5.2.1.2 Connectivity

(i.) Road Network

The line for LRT should be coordinated with the existing roads and planned roads in the future. One of the most significant hard factors in influencing walk trips is the presence of a cohesive and efficient street network. The key to providing pedestrian access is to reinforce the principle that streets should be designed for all travel modes, not just cars. In the figure 5.2 below, road network of the study area is used for connectivity analysis within 800m radius surrounding LRT stations.

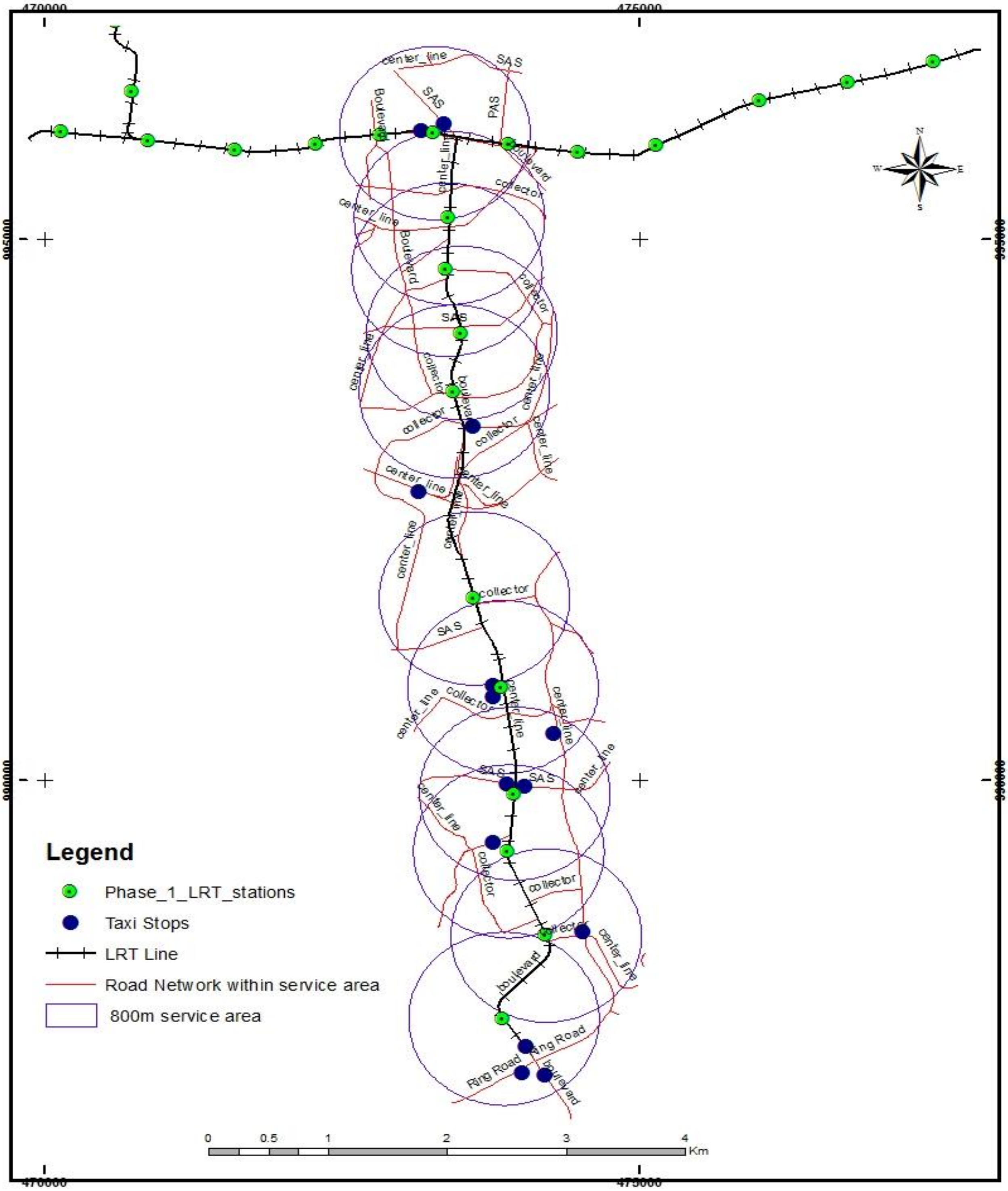

Figure 5.2: Study area LRT station connectivity with other modes

(ii.) **Park-and-Ride**

Park-and-ride is the act of parking at a customary built surface car parking area, on the city outlets and transferring to public transport to travel onward to one's destination. The main objective of building light rail transit in Addis Ababa is to meet the current large transport demand and traffic congestion. Since the AALRT system has large capacity to move mass passenger at a time, it can meet the demand. At the same time, it has to solve congestion problem. It should be noted that the LRT infrastructure will also induce problems because it replaced road lanes in some areas and be obstacle in places of at-grade crossings by increasing car turning time.

In view of the above, for AALRT to reduce traffic congestion in addition to transporting mass, system stations has to provide parking or shall be close to public parking buildings. Stations at suburbs should have parking areas because, in sub-urban locations, there are few origins and destinations within close walking distance and auto travel is predominant mode, and there is more space for large parking lots. But intermediate stations can optionally combine parking. Similarly, parking facilities should be provided at suburban area of the LRT stations. So, parking should be provided at some stations, depending on modes of access used by the riders to be served in the area. This suggests community in service area of stations of 400m-800m radius away from geographic center of stations may access LRT stations by various modes such as walk, cars, bicycle and bus.

Densely populated urban areas or sub-urban centers have a significant fraction of transit riders that access transit services on foot in order to avoid the costs associated with owning/driving/parking a vehicle, while suburban areas typically have many transit riders relying on access by auto. Denser projected land-use assumptions near transit lines, which resulted in significantly higher ridership projection (Byrne, 2008)

Walking-based stations should be easily accessible to pedestrian while, park-and-ride should have easy access to the existing road network and preferably be near the roadways carrying significant traffic volumes. Personal vehicles need to be accommodated at stations to encourage transit-way ridership, which is usually done through a park-and-ride lot where the customer parks his/her personal vehicle and rides transit to their destination.

Consequently, light rail transit stations should be sited to maximize convenience and minimize travel times for transit-way passengers and vehicles under existing and planned future conditions, with primary emphasis on existing conditions. This study proposed that downtown stations can take advantage of existing surface parking and proposed multi-storey parking buildings while suburb stations can use park-and-ride under the proposed City Master Plan. Additional park-and-rides may not be needed at the suburb stations since the transport planning team at AASOID have considered current and 10 to 25 years projected park-and-ride demand of the areas. Figure 5.3 depicts the proposed city center parking building multiple-ring buffering in Addis Ababa.

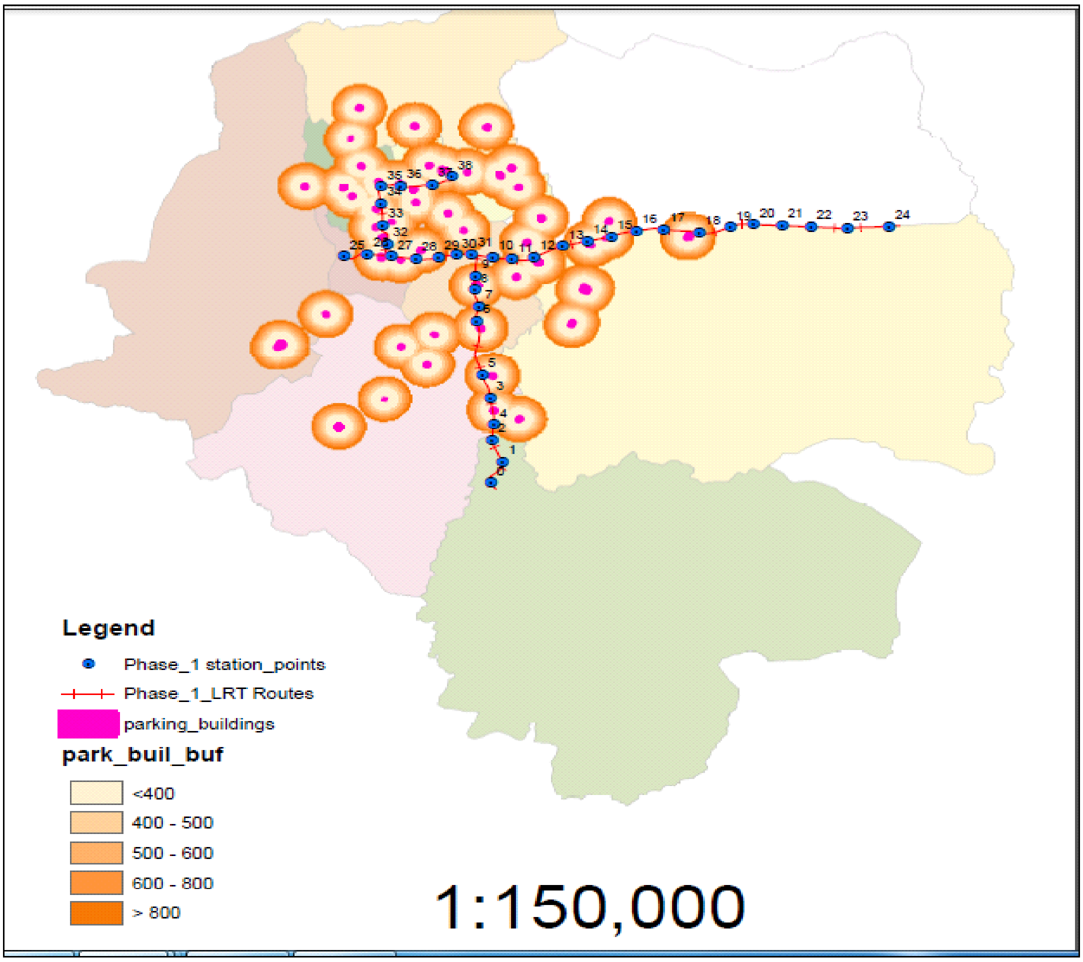

Figure5.3: Proposed City Center Parking Building Multiple-Ring Buffering

Figure 5.3 shows multiple ring buffers with different radius of parking building proposed to be constructed in Addis Ababa is overlayed by Phase I LRT stations. If parking buildings are available in walking distances to LRT stations, passengers can park their private cars and take mass transit to their destinations contributing to decrease in current traffic jam.

Observing Figure 5.3 most of the stations are within walking distances (400m) of and some of them are within 800m from one or more parking buildings. Even if provision of parking buildings at intermediate stations is optional, the above stations which are within walking distances from parking buildings are almost intermediate stations.

Suburb stations should provide parking for park –and-ride users that access stations by driving. Park and ride stations are more common on the outskirts of the downtown core so that commuters can park near the station and access the downtown via LRT (CMR, 2009).

Figure 5.4 shows the rough map of park-and-ride site proposed in the Addis Ababa City Master Plan as provided in the AASOID Transport and Road Network Planning Report, May, 2015

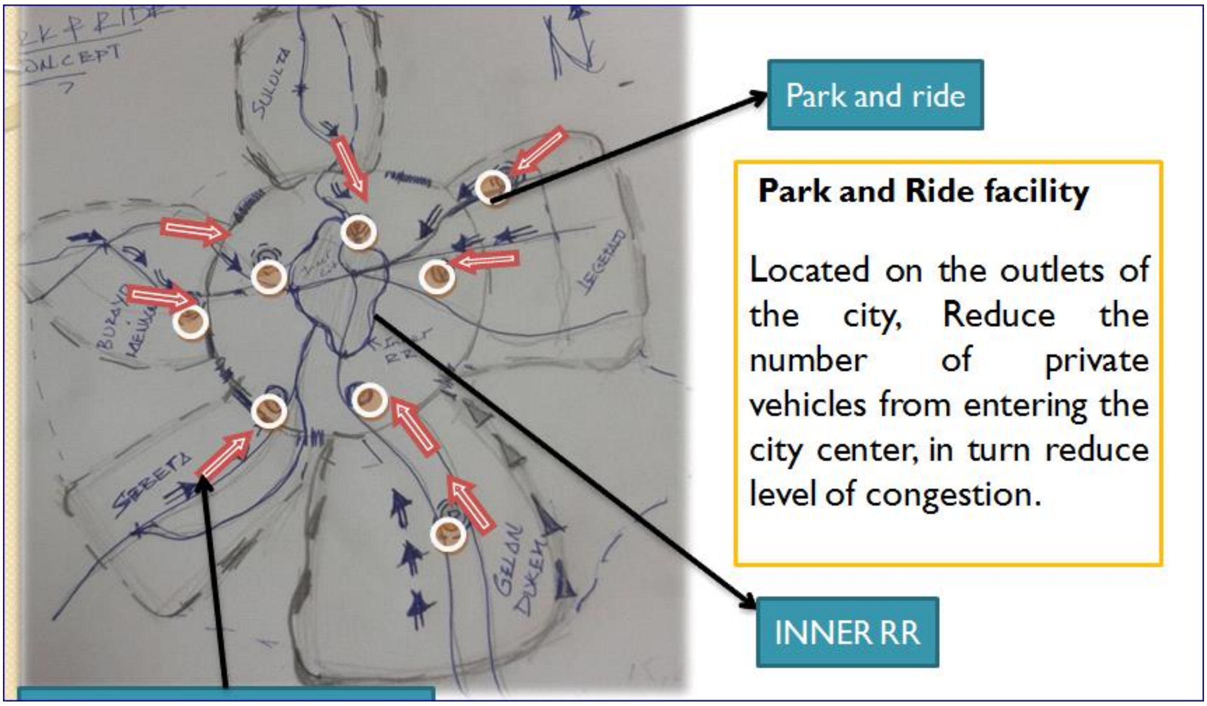

Figure 5.4: Park and Ride Locations in Addis Ababa

Park-and-ride will attract riders who would not take transit with either BRT or LRT transfer. Locations of the facilities are: Lebu, Ayat, Gelan, Akaki, Addisu Gebeya, Asko and Tatek**.** These park-and-rides are located at strategic points throughout the city transportation network to attract and encourage people to integrate public transit into their trip decisions.

(iii.) **Pedestrian and Bicycle Access**

Pedestrian and bicycle traffics are major sources of transit ridership. In reality, whatever their original access mode, all transit patrons are converted to pedestrians before boarding and immediately after alighting. Pedestrian access, therefore, is the highest priority access mode, and transit facilities should reflect this in their design and layout.

All transit trips begin and end with a pedestrian trip regardless of the travel mode between origin or destination and the transit system. For that reason, the conditions that support transit access have the additional benefit of supporting pedestrian and bicycle trips for shorter distances by creating more choices for travel, high quality transit access maximizes the benefits of the infrastructure investment in transit both capital and operating.

Pedestrian routes or sidewalks are how all transit riders eventually get to and from the station that provide pedestrian access to the neighborhoods and services surrounding the station. A well-developed sidewalk network, with high quality pedestrian treatments, that connects the station to the neighborhood and nearby services is vital to providing effective and efficient station access from as many routes as possible. Like vehicle facilities, sidewalk corridors should mirror the urban context for example, should be wider along main streets, or have sidewalks and tree lawns within single-family neighborhoods and be wide enough for expected foot traffic, particularly around train stations.

Similarly, pedestrian routes that arrive at the station should continue past the station property edge to the platform entrance. To serve all riders, sidewalks need to be designed based on the physical needs of wheelchair users and visually impaired in order to have consistent, equitable, and reliable access. This access would include minimum 1.5-m-wide sidewalks with seamless transitions between streets and other surfaces. Research shows that people are willing to walk about a 400-meter, or 10 minutes, to light rail stations. The sidewalk improvements and network should reflect this distance along the actual street network to station entrances.

A one km pedestrian access distance is normal in suburban conditions and within 500m in urban conditions are favorable thresholds for a higher capacity rail transit system. The draft stated that in the more densely populated areas this radius should be constant, as operations may be affected if the stations are too close together. In general this distance provides an optimum rapid transit system performance whilst maintaining a reasonable walking distance to any station along the transit corridor.

In 2006, the Addis Ababa modal share was pedestrian 45% and bus transport was about 46%. Private car modal share is only 9%. This implies that pedestrian and public transportation are taking the lion's share of Addis Ababa transport systems. So, this needs good intermodal transit planning. Figure 6.5 shows the Addis Ababa modal share by 2010 as provided by AASOID Transport and Road Network Planning report May, 2015.

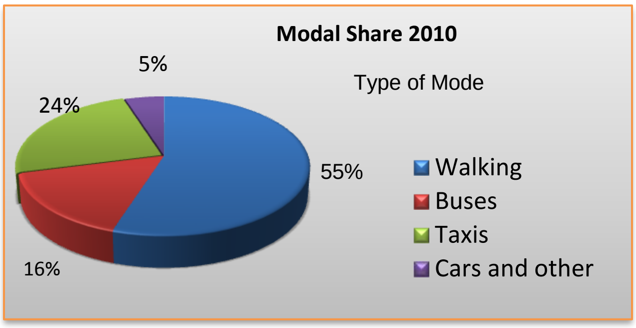

Figure 5.5: 2010 Addis Ababa modal shares

For AALRT system to meet the intended aim stations should be accessible to pedestrian, bus and bicycle traffics since most passengers are pedestrians. New investment in urban transit tends to be oriented to one of two accessibility options; either convenient walk-up accessibility or the provision of significant park--and--ride. The type of access depends on how and where transit planners locate transit stations in the urban environment.

According to new Addis Ababa master plan road network, there are some non-motorized lanes dedicated to pedestrians and bicycles and there are pedestrian sidewalks along many collector roads. With existing pedestrian-walk--way network, it enables pedestrians to access motorized public transportation mode LRT and BRT after walking reasonable walking distances which in turn encourages healthy community. Figure 5.6 shows circular station the service area or catchments of 500m radius.

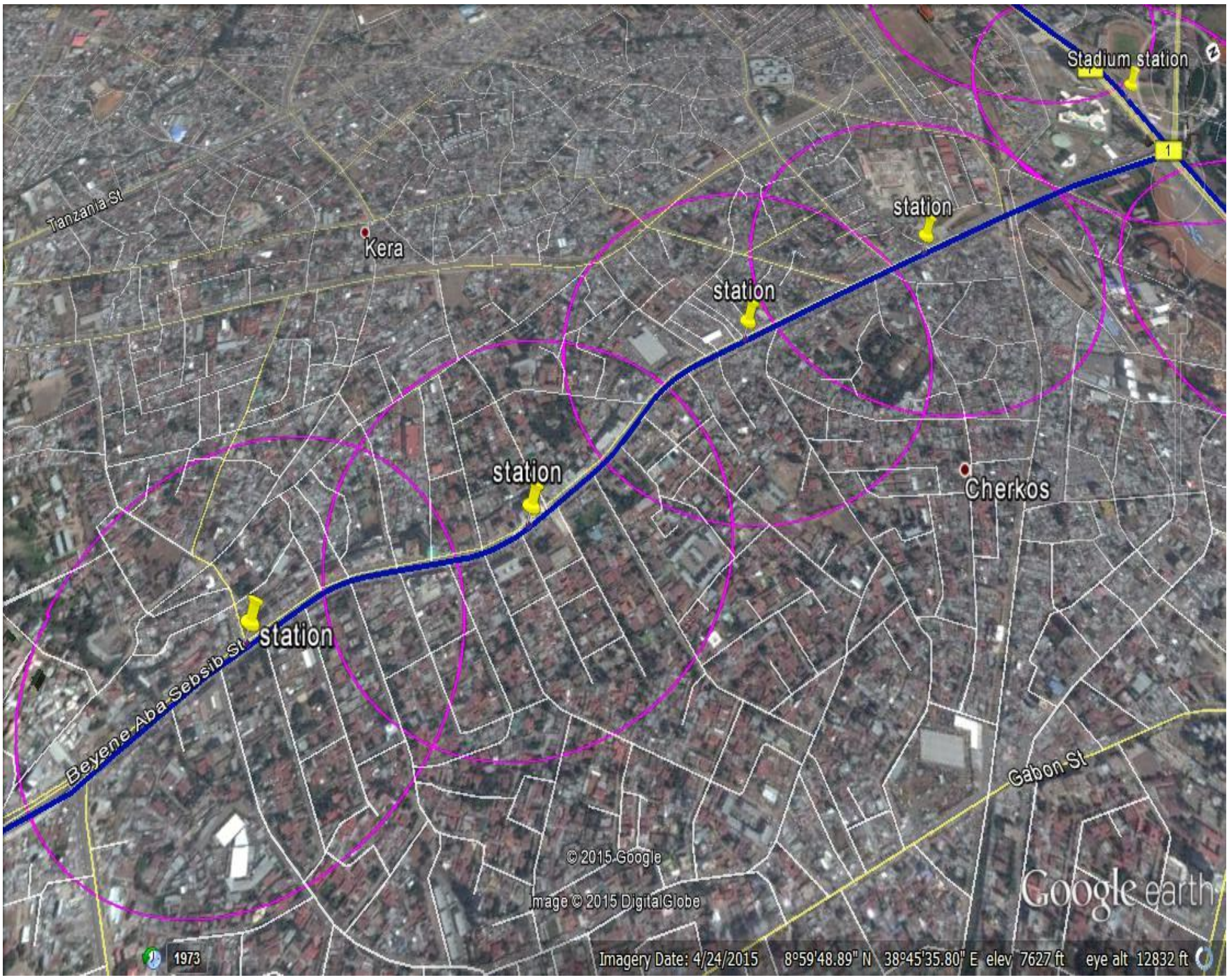

Figure 5.6: Circular station service area within catchments of 500m radius

The figure above shows that station catchments overlap, meaning people within area of overlapping can use one of near stations.

(vii.) **Bus/Taxi transfer stops**

To substantiate the high cost related with the built and operation of rail transit system, sufficient trips need to be attracted from alternative modes so as to generate revenue and reduce congestion. Hence, bus access should be provided at each station for various local, cross-town, express, and circulator/shuttle routes, depending on the station. Bus/taxi stops should be added for all stations and would typically be adjacent to the rail platform to provide convenient transfers for passengers of long distance because LRT does not provide door to door services.

Bus stops are located near the station, with clear paths from the stop to the light rail station. According to these draft ensuring, efficient transit connections to and from rail stations is crucial in the development of a seamless, well-integrated transit network. Transit stops and/or transfer way finding signage should be immediately visible upon exiting the platform. Well-located bus stops will minimize walking distances to and from the platform entrance and avoid the need to cross roadways, particularly busy arterials. Minimizing distances between bus stops facilitates bus-bus transfers and simplifies bus-light rail transfers. In some station areas that have pedestrian-friendly walking environments and where crossing busy streets is not necessary, short walks between the station platform and alternative modes of transportation may help support street-level retail and an active station area.

Bus stops should be located on-street in travel lanes with curb extensions (unless off-street facilities are necessary to accommodate layovers or transfers) to prioritize bus movements. Bus stops should not be located where they will block crosswalks, obstruct traffic signals, or be obscured from motorists, bicyclists, and pedestrians.

The study area stations case, there are bus stops within 500m catchment. This implies bus and taxi riders from outside of the catchment area can access LRT stations. Figure 5.8 below shows access modes.

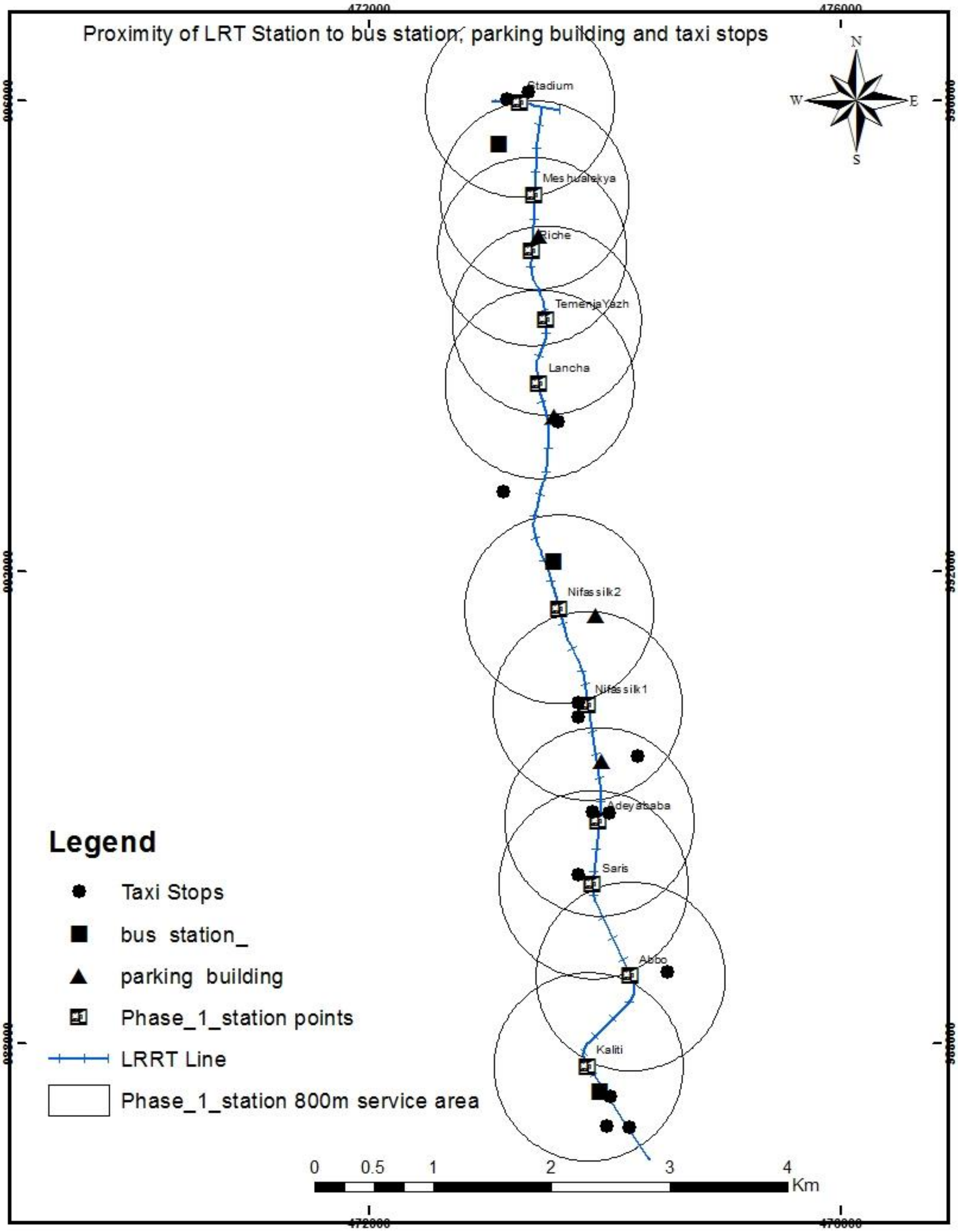

Figure 5.7: Connectivity to Bus top, park-n-ride and taxi stops

As explained above, parking should be provided at Saris, Abbo and Kaliti stations and optionally at downtown or city densely populated area as people prefer walking to driving to stations because of its minimum distance from homes. Provision of parking can reduce congestion on this direction at some points because car riders may use LRT during peak hour. Regarding bus transit transfer access, almost all stations are within short distance from bus stops/stations. As a recommendation in this case, multi-storey parking or surface parking should be provided at suburbs stations of Addis Ababa in order to attract park-and-ride users for LRT transit system be a profitable system. The general study area LRT stations accessibility is summarized in the following table5.2.

Table 5.2: Summary of study area stations accessibility

	Station name	Boulevard	Collector	Ring Road	PAS	SAS	Park-n-ride	Kiss-n-ride	Bus Stop
1	Lagahar	4					√	√	√
2	Stadium	2				1	√	√	√
3	meshualekiya						√	√	√
4	Riche	2	2				√	√	
5	TemenjaYazh	2				2	√	√	
6	Lancha	2	2				√	√	√
7	Nifassilk 2	2	1				√	√	
8	Nifassilk 1	2							
9	Adey Abeba	2				2	√	√	√
10	Saris	2	2						
11	Kaliti	2		2				√	√

(viii.) **Population density**

As observed in Figure 5.9, most of the Phase I stations are adjacent to zones with high population density; High population density is one of the factors that affect ridership. High population density implies that there is high ridership. Figure 5.9 shows population densities in the Kebeles of Addis Ababa as provided by the Ethiopian Central Statistical Agency in 2007.

Population density was calculated for projected population and 3.2% Addis Ababa population growth rate was used for the projection. And then, population density is the ratio of projected population over kebele area in square Km.

Finally, population density information with other kebele attributes were tabulated and mapped by using GIS for analysis purpose. The following figure 5.10 shows the calculated and mapped study area population density within 3000m catchment of buffer area from existing LRT stations. This density is grouped into five classes for analysis purpose. Maximum population density is 73,000/sq.km. Thus, most of the stations in this study area are accessible to walk-in traffic.

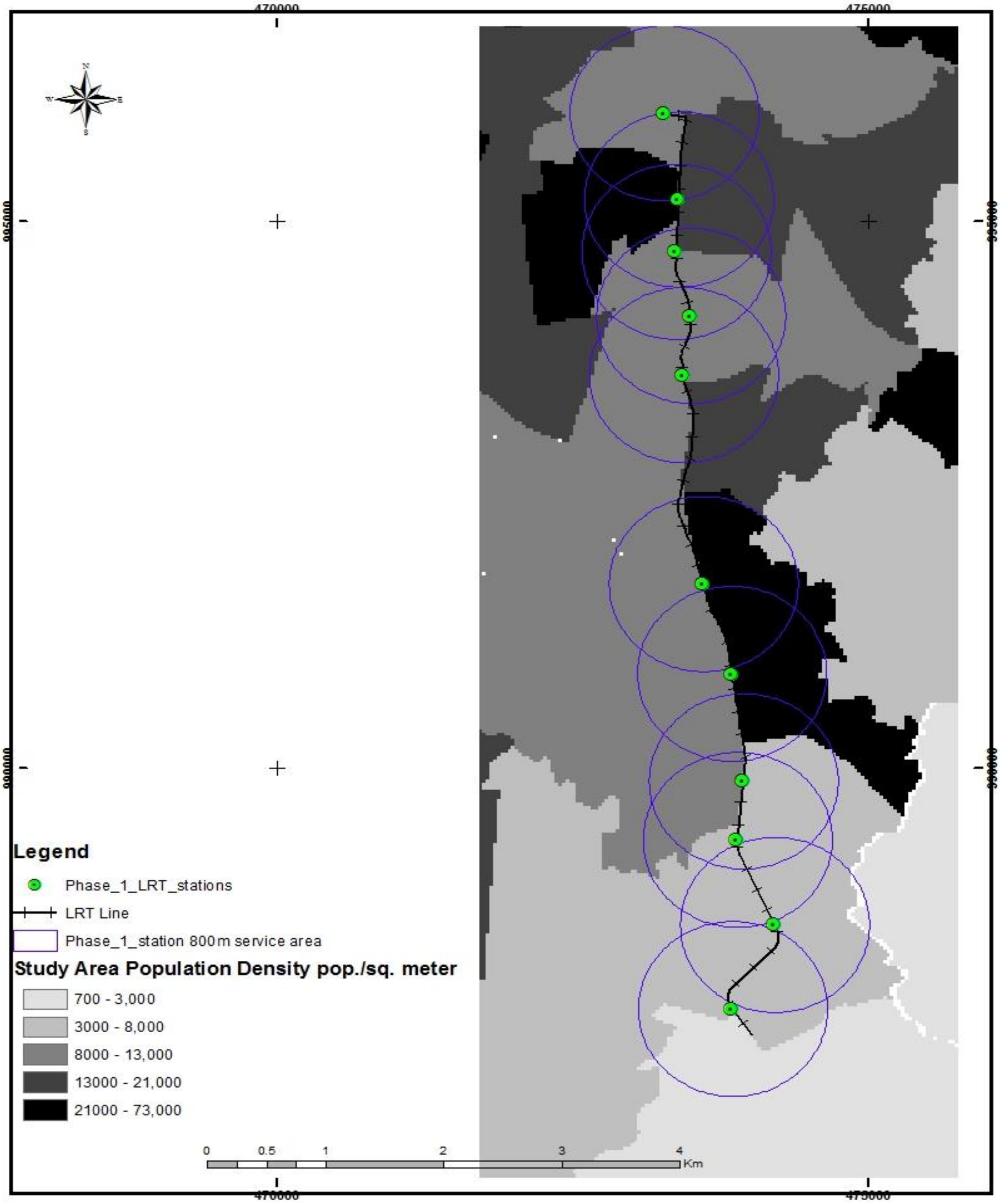

Figure 5.8: Study area Population density by kebeles

(ix.) **Land use**

Addis Ababa land use was categorized into ten groups to evaluate phase I LRT stations integration with land use. As shown in Figure 5.11 below, most of the stations, especially downtown, are located at the existing high density mixed residential and commercial areas. This will help the stations attract large pedestrian riders. Areas of medium and low population density will be converted to high density mixed use resident area, according to city master plan. Hence, the AALRT stations will be more accessible to pedestrian users.

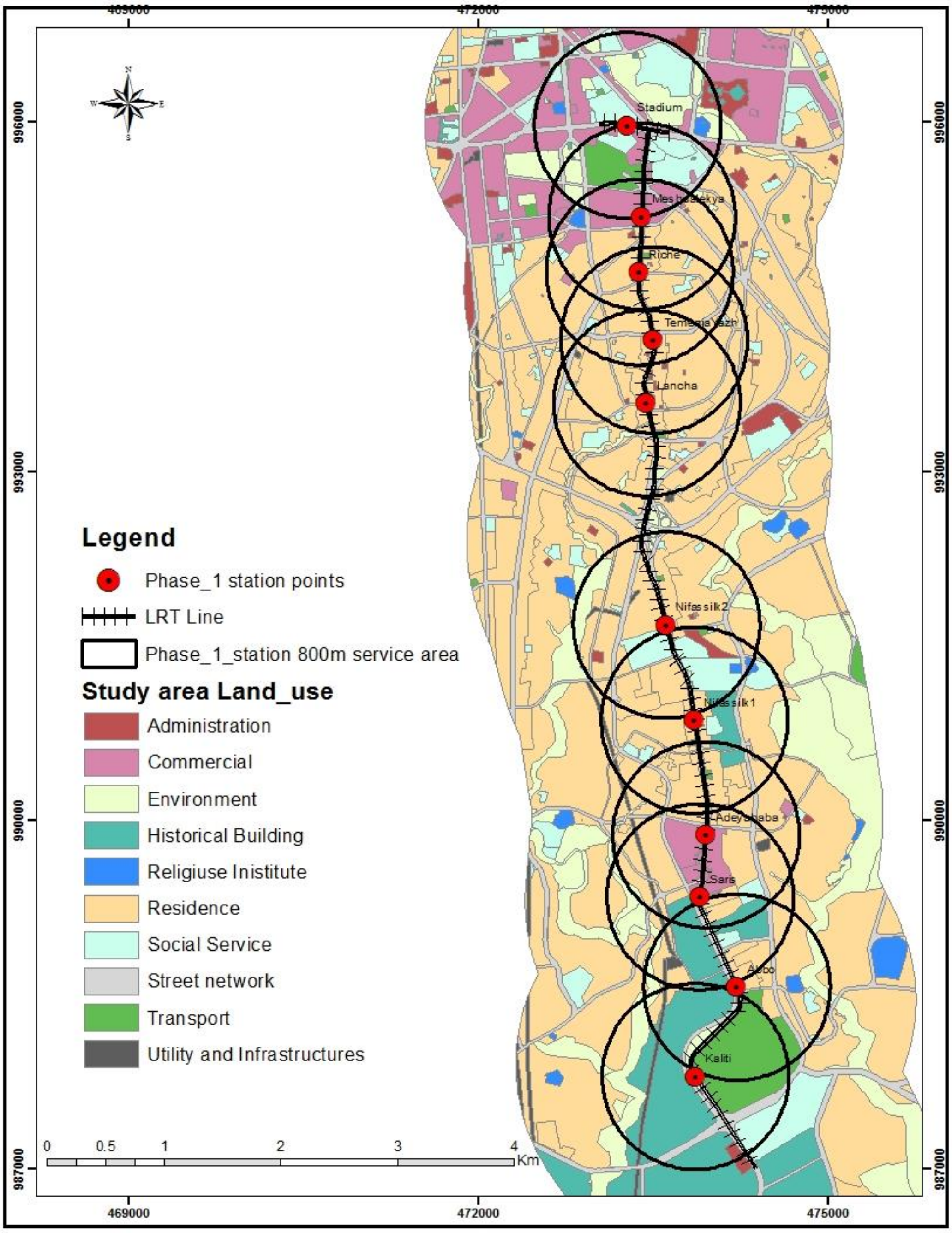

Figure 5.9: Study area Land use and LRT stations

CHAPTER 6

6 PHASE II STATION LOCATION SUITABILITY ANALYSIS

6.1 Development of Station Location Selection Criteria

This section discusses the determination of criteria and classification of factors for the identification of LRT potential areas which were divided into four main criteria and eleven sub-criteria: six sub-criteria under criteria one; three sub-criteria under criteria two and one each sub-criteria under criteria three and criteria four. Table 6.1 shows the details. These four criteria are: land-use compatibility; transportation connectivity/intermodal connection; community characteristics and topography. The eleven sub-criteria are: industrial, residential, commercial, educational, institutional and public gatherings all under the criteria of Land-Use Compatibility; then, bus connectivity/proximity to bus station, proximity to parking buildings and connectivity to road were under Transportation Connectivity or intermodal connection criteria; population density was under Community Characteristics criteria; and finally slope was under Topography criteria

There were four criteria and eleven sub-criteria in the form of eleven GIS-based layers incorporated for site suitability evaluation for LRT station. These criteria and factors for identifying the potential station sites were acquired from literature assessment, previous works and from planning, development and design professionals.

Based on the literature review and best practices, a series of guiding principles were used to determine suitable sites and these were:

- The site should be at least quarter mile away (spacing distance) from the nearest station in either direction;
- The site should be within 30m of commuter rail tracks;

For station locations that must accommodate park and ride facilities, locate them within a five-minute walk of the platform (200m) distance but not directly in front of the station; locate utility structures so as not to preclude redevelopment of prime station proximate sites.

A criterion is a basis for a decision that can be measured and evaluated. It is the evidence upon which a decision is based. Selecting or formulating criteria that need to be fulfilled in order to make the right decision is one of the difficulties in multi-criteria evaluation. The related factors were grouped based on the four criteria. In this process, the data of all the selected factors were kept, displayed and managed. Table 6.1 depicts Criteria developed for station location.

Table 6.1: Criteria Developed for Station Location

Major Criteria	Sub-Criteria
Land-Use Compatibility	• Industrial • Residential • Commercial • Education • Institutional • Public gatherings
Transportation connectivity or Intermodal Connection	• Bus connectivity/ Proximity to bus station • Proximity to parking buildings • Connectivity to road
Community characteristics	• Population Density
Topography	• Slope

6.1.1 Classification of criteria maps and data analysis

With regards to the acquired information, there were eleven important factors in the form of six GIS-based layers incorporated for suitability analysis for LRT station sites. These factor maps were overlaid together for final suitability evaluation of station sites. During the process however, the data of all the selected factors shown in Table 6.1 were retained, displayed, and managed individually. Because the factors have different scales of measurement, they cannot be compared with the raw scores determined by experts.

Therefore, in order to allow comparability, the factor maps were standardized. Standardization allows comparison of criterion scores within one alternative. In order to standardize, the raster features of all the factors were reclassified into a common scale range.

6.1.1.1 Land-Use Compatibility

Integrate transportation and land use to optimize transportation investment and create an accessible, efficient, and urban form. This criterion qualitatively evaluates the appropriateness of the station in relation to its surroundings for compatibility with area land use plans and general public acceptance.

It accounts for noteworthy construction, noise and light pollution impacts. It also considers the potential for future transit-oriented development near the station and the impact a station might have on area parcels.

The Addis Ababa Land Use Map of 2015 was classified into different classes of land cover. For pair-wise comparison purpose, it is grouped into six classes: Residential, Educational, Institutional, Commercial, Industrial and Public Gathering places. Figure 6.1 shows detailed land use classification. Among the land use groups, residential is highly suitable for station site because of attracting many public passengers. In this respect, high density mixed use residential areas are highly suitable for LRT station sites. Figure 6.1 shows the Addis Ababa Land use Cover as provided by the AASOID, 2015.

Figure 6.1: Addis Ababa Land Cover

6.1.1.2 **Distance from roads**

This criterion was classified based on Euclidean distance from collector road types. Areas in the inner road buffer are best suitable for collector roads while ring roads (BRT lines) should not be close to LRT line as it may create redundancy. Therefore, the outer areas outside of buffers around collector roads are ranked as none potential. The result of the reclassified Euclidean distance from the roads map is shown in figure 6.2.

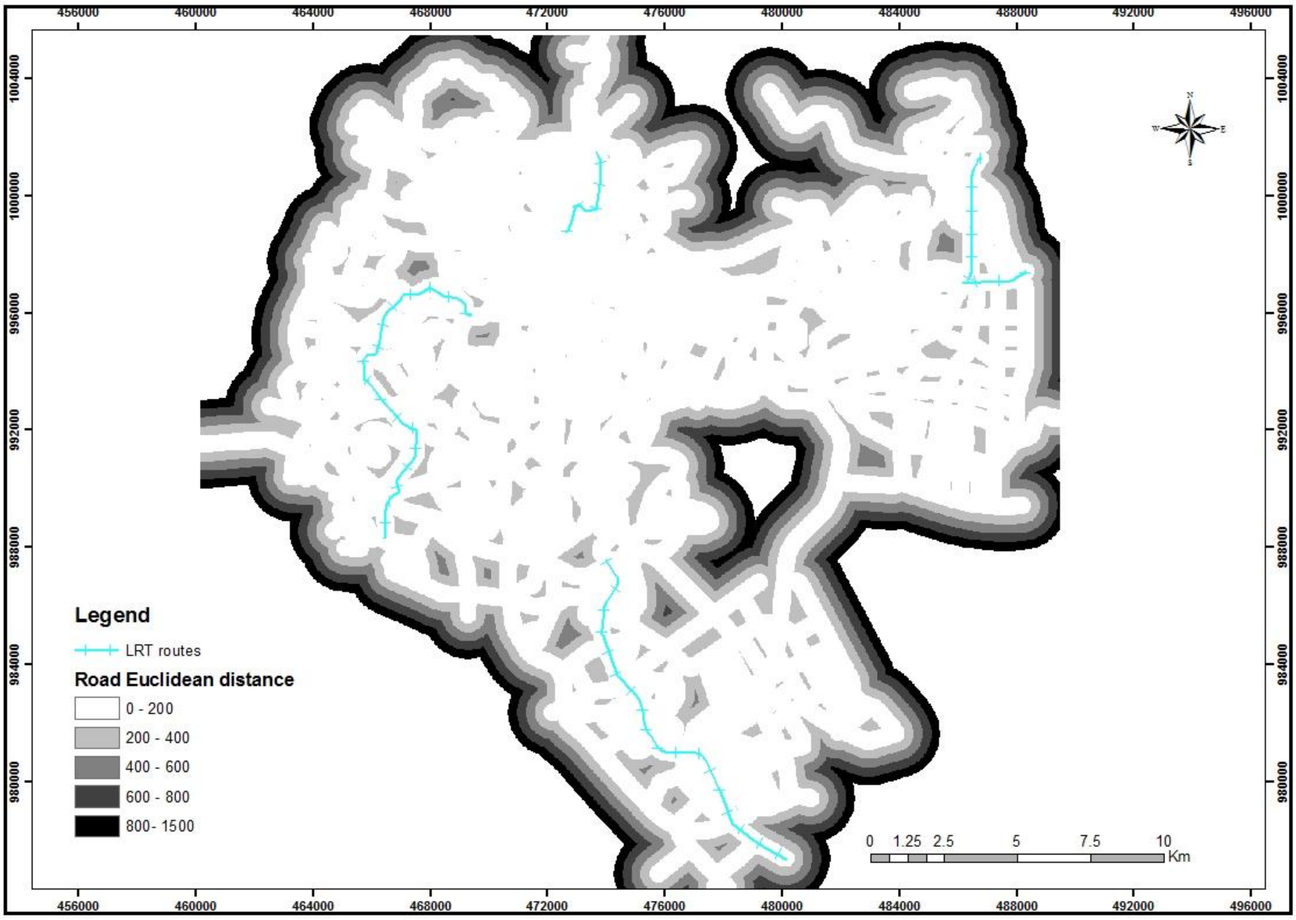

Figure 6.2: Road Euclidean distance

6.1.1.3 **Population density**

Select rapid transit stations which have potential for densities sufficient to support rapid transit service. Population data for the year 2007 were collected from the Central Statistical Agency of Ethiopia. Population density for forecasted population for year 2025 was calculated by using 3.2% growth rate and mapped. Areas with high population density are highly suitable for locating stations. Figure 6.3 shows population density by kebeles of Addis Ababa.

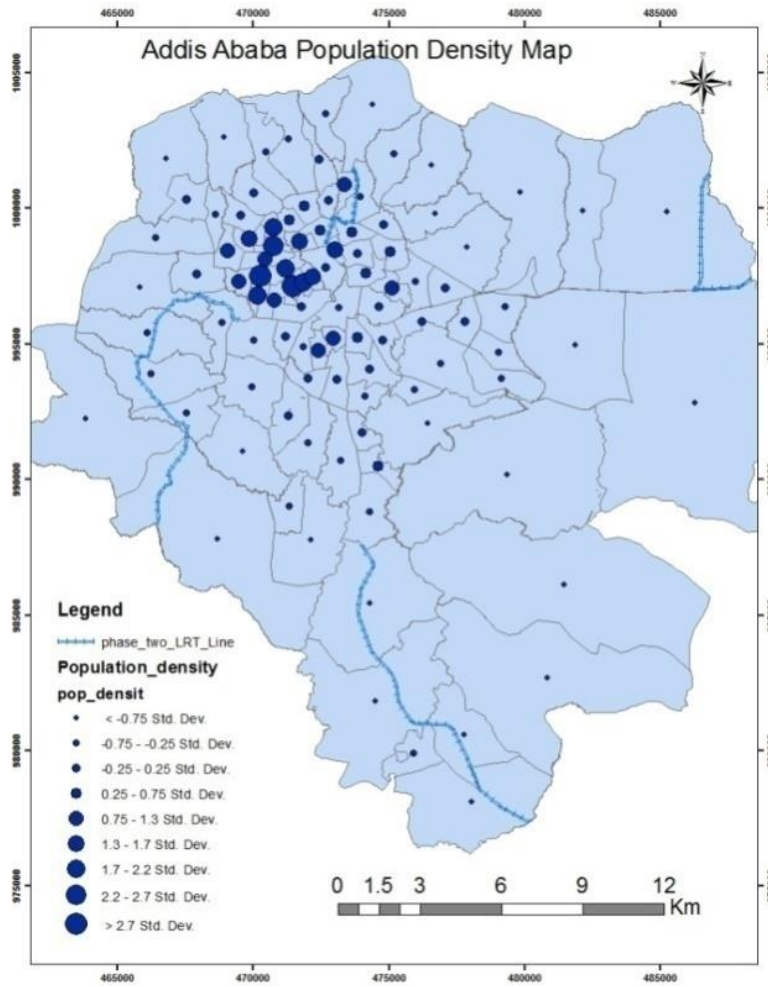

Figure 6.3: Study area population density

6.1.1.4 **Topography**

Topography describes the surface shape and relief of the land. It refers to various landforms (physical features) which represent the external shape of the earth (Tewodros, 2010). Furthermore, elevation and slope should be considered when selecting site for stations. But in this study, light rail lines run within the roads medians. Therefore, elevation factor was not considered. Under these criteria, slope is one of critical factors/sub-criteria that can affect station locations. The Addis Ababa slope map was classified into five classes in respect of percentages where slopes 0 - 3% are highly suitable for stations. In the case of slope calculation, the slope map of Addis Ababa area was developed by calculating the slope map from the DEM (Digital Elevation Map) of the city. The slope calculator function is located in the Arc toolbox of the ArcGIS software. The slope map was very essential in that it was used to highlight suitable sites for the railway station. Figure 6.4 shows the slope map of Addis Ababa.

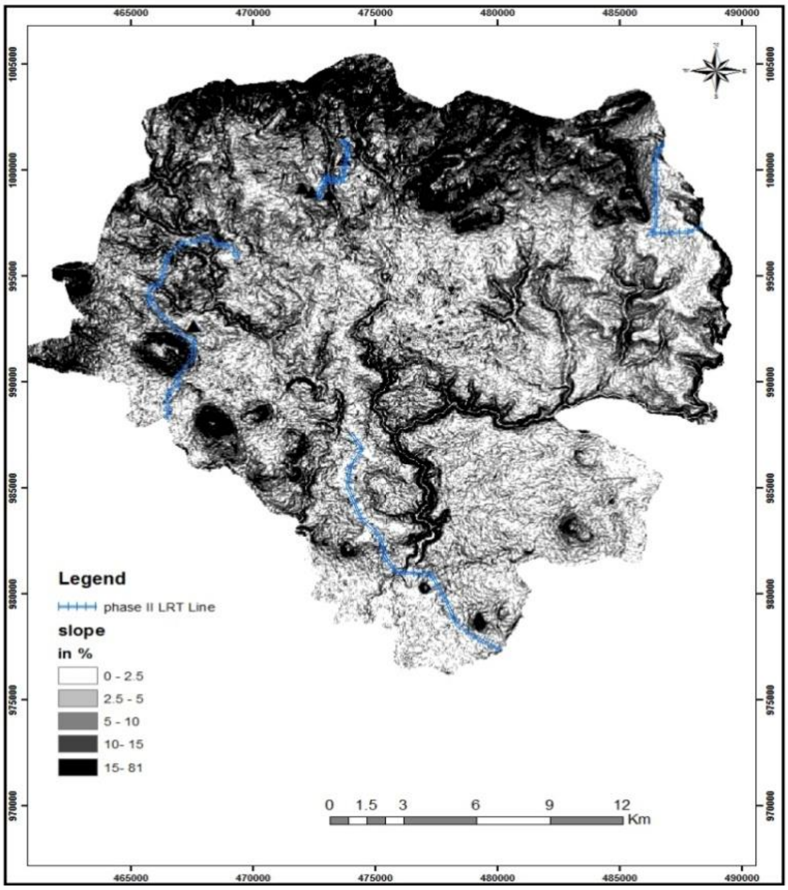

Figure 6.4: Slope Map of Addis Ababa

In this case, the reclassified slope map was acquired from the degree measurement unit for station requirement. Flat landform is the most suitable for station. In view of the foregoing, the 0-3 % slopes are ranked as highly potential; followed by 3-5% slopes as moderately potential; 5-10% slopes as marginally potential; and above >10% with no potential. Desirable maximum station-area grade or slope should be 0.5% and absolute maximum slope should be 2.5%. However, some existing conditions may require slopes exceeding the maximum 2.5% in the case of on-street stations. The result of the reclassified slope map is shown in figure 6.4 above.

6.1.1.5 **Proximity to other modes (access mode)**

(i.) **Proximity to Parking Building**

Parking building is multi-storey car parking planned in the new Addis Ababa City Master Plan and multi storey car parking is a building which is designed specifically to be for automobile parking and where there are a number of floors or levels on which parking takes place. Figure 6.5 shows proximity to parking building. For this study purpose, only parking buildings that are found on 800m distance LRT lines are used. This is by considering maximum distance that one can walk from parking building to nearest LRT station. The LRT route from Summit to Laga-Tafo has no advantage of parking building since there is no parking building within 800m catchment.

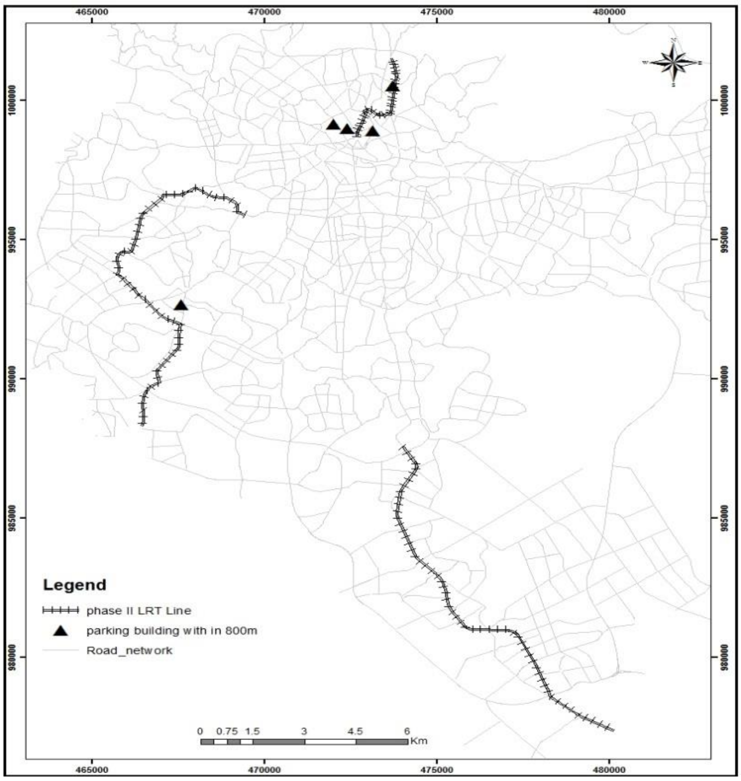

Figure 6.5: Proximity to Parking Building

(ii.) **Proximity to Bus Stations/Stops**

As seen in station accessibility analysis, the availability of other modes of transportation around transit station is important for mobility around station area. The other modes of transportation (Feeder Bus services etc.) facilitate easy movement of transit riders. Bus service includes proximity of bus stations and stops to LRT station. Bus station in this case includes intra-city bus station and intercity bus station. From figure 6.6, we can see that bus stations are accessible to only some stations.

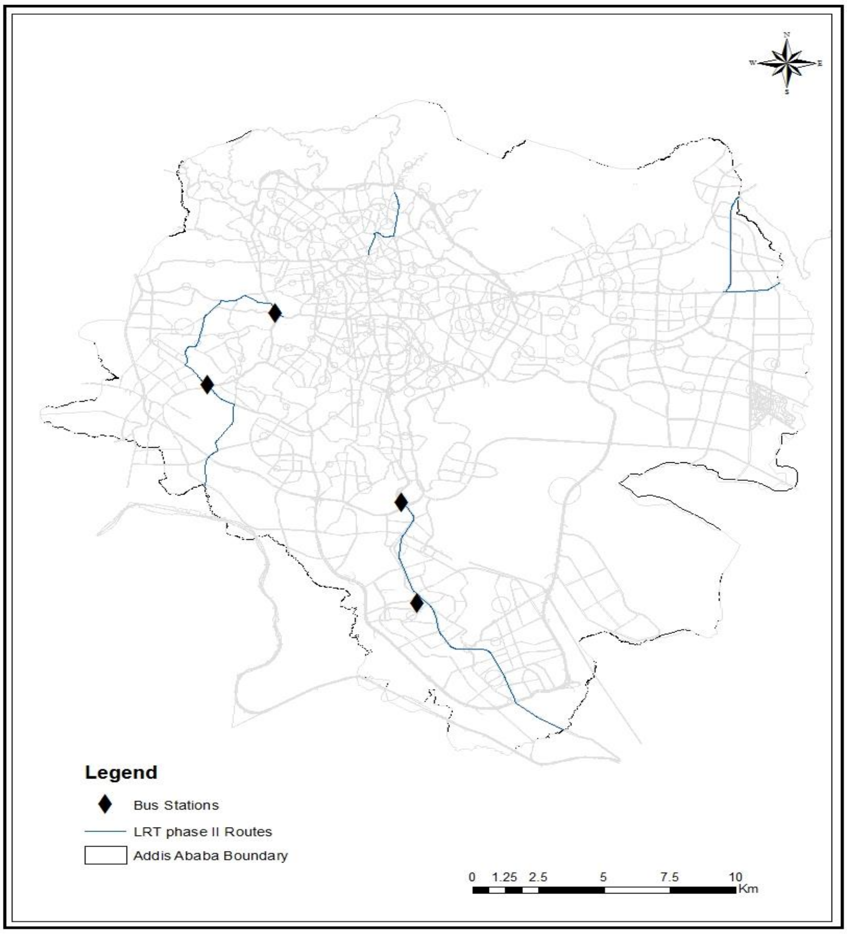

Figure 6.6: Proximity of LRT stations to Stations

6.1.2 **AHP Model Development**

As stated by Cheung et al., (2002), AHP goes through the following three stages and figure 6.6 shows the four levels AHP model as developed in this research.

(i) Constructing the hierarchy for criteria and sub-criteria;

(ii) Comparing the weight of criteria and sub-criteria; and

(iii) Evaluating the alternatives by computation of the relative weight of criteria and sub-criteria.

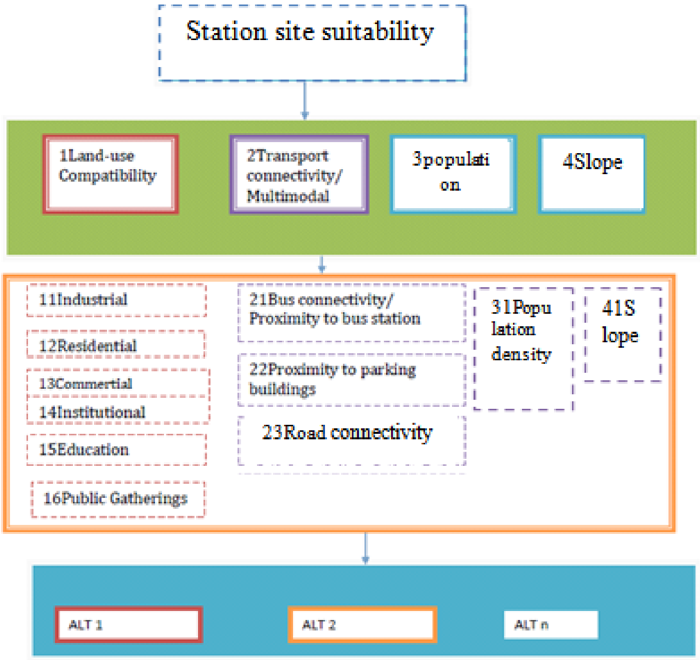

Figure 6.7: Four level AHP Model

In this research, the fourth level is not included since, GIS is used in selecting suitable station sites. If there were candidate stations used, AHP would have prioritized these station alternatives.

6.1.3 **Criteria Weights and Class Weights**

This is determined based principally on the expert's opinions.

When the AHP method is applied to solve spatial decision problems in a GIS environment, it is called spatial AHP method (Siddiqui et al., 1996). In the GIS database, the attribute factors are represented by map layers and contain attribute values for each pixel in a raster data format (Kiker et al., 2005).

AHP provides a structural basis for quantifying the comparison of decision elements and criteria in a pair wise technique (Laskar, 2003). Once the pair wise matrix is made, relative weights are calculated using pair-wise comparisons.

6.1.4 **Pair-wise Comparisons**

Pair-wise comparison of the criteria based on nine points Saaty AHP scale which is shown in table 6.3 below was done by the experts and it was entered into 6 X 6 matrix as shown in table 6.2. Their judgments on sub-criteria are shown in the tables 6.3 – table 6.9.

Table 6.2: Relative Importance of each criterion

Criterion	Land Use	Road Proximity	Bus Stops Proximit	Parking Building Proximit	Slope	Population Density
Land Use	1	0.33	1	3	0.33	1
Road Proximity	3	1	3	5	1	3
Bus Stations Proximity	0.33	0.33	1	5	0.33	0.33
Parking Building Proximity	0.3	0.2	0.2	1	0.2	0.2
Slope	3	1	3	5	1	3
Population Density	1	0.3	3	5	0.33	1
total	**8.63**	**3.16**	**11.2**	**24**	**3.19**	**8.53**

Table 6.3: Saaty nine point scale

Scale	Degree of preference
1	Equal importance
3	Moderate importance of one factor over another
5	Strong or essential importance
7	Very strong importance
9	Extreme importance
2,4,6,8	Values for inverse comparison

6.1.5 **Factors pair-wise comparison**

Both criteria that are relative importance comparison and factor rating were done by experts. For example, criteria that are extremely suitable for locating light rail transit station relative to other criteria, will be assigned a value of 5; criteria that are partially suitable will be assigned a value of 3; and criteria that are the less suitable for station sites relative to the other criteria, will be assigned a value of 1. Tables 6.4 – 6.10 shows details of pair-wise comparison.

Table 6.4: Five-point scale for pair wise comparison of sub-criteria scoring:

Score	Class
1	Less suitable
2	Suitable
3	Moderately suitable
4	Highly suitable
5	Extremely Suitable

Table 6.5: Category, land use, score and class

Category	**Land use**	**Score**	**Class**
1	Residential	3	
2	Industrial	3	
3	Commercial	5	
4	Education	4	
5	Institutional	3	
6	Public gatherings	5	

Table 6.6: Category, slope, score and class

Category, range, score and class Category	Range	Score	Class
1	0 - 4.0	5	
2	4.0 - 6.0	2	
3	6.0 - 8.0	1	
4	8.0 - 87.0	1	

Table 6.7: Pair-wise Comparison of Distance from road factor

Category	Range	Score	Class
1	0 - 100m	5	
2	100 - 200m	5	
3	200 - 400m	3	
4	400 - 600m	2	
5	600 - 800m	1	

Table 6.8: Pair-wise Comparison of Distance from LRT Line factor

Category	Range	Score	Class
1	0 - 30m	5	
2	30 - 50m	2	
3	50 - 100m	1	
4	100 - 200m	1	

Table 6.9: Pair-wise comparison of proximity to Parking Building Factor

Category	Range	Score	Class
1	0 - 100m	5	
2	100 - 200m	4	
3	200 - 400m	3	
4	400 - 600m	1	
5	600 - 800m	1	

Table 6.10: Pair-wise comparison of proximity to Bus Station Factor

Category	Range	Score	Class
1	0 - 100m	5	
2	100 - 200m	5	
3	200 - 400m	3	
4	400 - 600m	2	
5	600 - 800m	1	

6.1.6 **Weighting Criteria**

By using experts' judgment of criteria relative importance, the criteria weights were calculated as shown in table 6.11 below and these criteria were used in GIS multi-criteria spatial analysis process. The calculation was done by using excel AHP template.

Table 6.11: Calculate criteria weights

	A	B	C	D	E	F	G
4	Criterion	Land Use	Road Proximity	Bus Stops Proximit	Parking Building Proximit	Slope	Population Density
5	Land Use	1	0.33	1	3	0.33	1
6	Road Proximity	3	1	3	5	1	3
7	Bus Stations Proximity	0.33	0.33	1	5	0.33	0.33
8	Parking Building Proximity	0.3	0.2	0.2	1	0.2	0.2
9	Slope	3	1	3	5	1	3
10	Population Density	1	0.3	3	5	0.33	1
11	**total**	**8.63**	**3.16**	**11.2**	**24**	**3.19**	**8.53**

Matrix normalization

	A	B	C	D	E	F	G	H	I	J
15	**Criterion**	Land Use	Road Proximity	Bus Stops Proximit	Parking Building Proximit	Slope	Population Density	Total = 1.61=SUM(B16:G16)	Average= H16/6 = 0.27	Consistency Measure
16	Land Use	0.12	0.10	0.09	0.13	0.10	0.12	0.66	0.11	6.21
17	Road Proximity	0.35	0.32	0.27	0.21	0.31	0.35	1.81	0.30	6.24
18	Bus Stops Proximity	0.04	0.10	0.09	0.21	0.10	0.04	0.58	0.10	6.02
19	Parking Building Proximity	0.03	0.06	0.02	0.04	0.06	0.02	0.24	0.04	5.99
20	Slope	0.35	0.32	0.27	0.21	0.31	0.35	1.81	0.30	6.24
21	Population Density	0.12	0.09	0.27	0.21	0.10	0.12	0.91	0.15	6.24
22				=MMULT(B5:G5,I16:I21)/I16					CI	0.032
23									RI	1.24
24				CI=(AVERAGE(J16:J21)-6)/5					CR	0.025

n = 6

RI = 1.24

CI = 0.032

CR = CI/RI = 0.025 which is less than 0.1 and the above result is acceptable.

6.1.7 **Consistency Check**

AHP allows some small inconsistency in judgment because of human imperfection. It is necessary to verify consistency after the gaining of weight values (Chen et al., 2010). The inconsistency measure is useful for identifying possible errors in judgments as well as actual inconsistencies in the judgments themselves. As Rozann W. Saaty (2003) stated, inconsistency measures the logical inconsistency of one's judgments. For example, if one were to say that **A** is more important than **B** and **B** is more important than **C** and then say that **C** is more important than **A,** then he/she is not consistent. It is accepted that the inconsistency ratio should be less than 0.1. If inconsistency ratio is greater than 0.1, the judgment should be revised. The ratio scales are derived from the principal Eigen vectors and the consistency index is derived from the principal Eigen value. As provided by (Chen et al., 2010), the consistency index (CI) and consistency ratio (CR) are depicted as equation (1) and equation (2) below:

$$\mathbf{CI = (\lambda max-n)/ (n-1)} \text{ .... Equation 1}$$

Where,

n = Number of the Criterion,

CI = Consistency Index

λmax = The biggest Eigen-value of the Comparison Matrix.

$$\mathbf{CR = CI/RI} \text{ .... Equation 2}$$

Where,

RI = a constant corresponding to the mean random consistency index value based on n given in Table 6.11.

CR = Consistency Ratio

According to Saaty (1980), if the value of the consistency ratio (CR) is less than or equal to 0.1, the questionnaire is considered acceptable. If the CR is greater than 0.1, the questionnaire is not acceptable. In this regard, the results of the analysis in this research showed CR = 0.025<0.1 which is acceptable so, the calculated criteria weights are used as GIS input data to identify suitable station locations. Table 6.12 shows the consistency index value.

Table 6.12: Consistency Index value

n	1	2	3	4	5	6	7	8	9	10
RI	0.00	0.00	0.58	0.90	1.12	1.24	1.32	1.41	1.45	1.49

Remark: n is the number of factors

6.2 Results and Discussions

6.2.1 Multi-criteria preparation for GIS

The analysis that carried out in this project included proximity by buffering, overlay analysis. The following results were obtained:

- A digital reclassified map showing spatial distribution of Phase II LRT Line;
- A Geodatabase containing various feature classes used in the study; and
- A suitability map.

Input data for GIS are: slope, population density, and distance from roads, land-use, proximity to parking building and proximity to bus stations. These criteria were mapped and overplayed in GIS by using the criteria weights calculated from AHP. Data for station suitable sites analysis are prepared as shown in the issuing pages. The suitability analysis was carried out with the aim of highlighting areas that are best suitable for phase II LRT stations.

6.2.2 Geodatabase

Before any analysis was carried out, data were converted, edited and organized into a single personal geoatabase. A personal Geodatabase was developed and named **AALRT_System_Gotidatabase.mdb.** It was occupied with feature datasets such as LRT stations, LRT network, road network, population, and land-use and study area. The Geodatabase provides an easy and efficient way of organizing and retrieving data. The created Geodatabase is shown in figure 6.8 below as structure of the created Geodatabase.

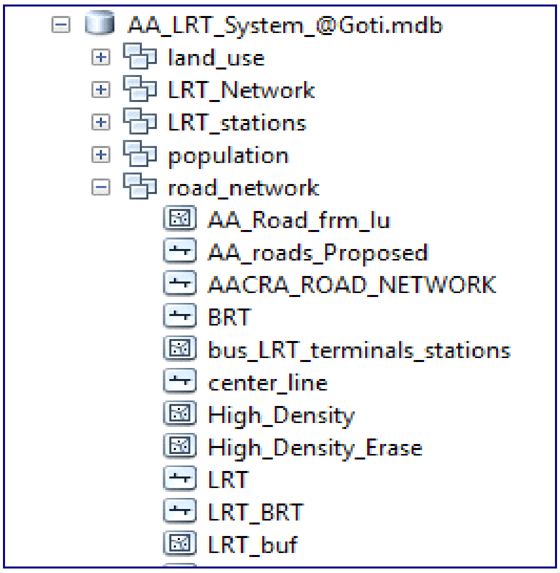

Figure 6.8: Structure of the created Geodatabase

6.2.3 Euclidean Distance Calculation

The Euclidean distance operation describes each cells relationship to a set of sources. The function gives the distance from each cell center to the closest set in the raster format data set. This function was used to calculate distances that are distance from bus station and parking building to the stations. The Euclidean distance output is a raster file format that has different layers or concentric rings from the point of reference. The distance is given in linear units meters, kilometers, miles etc. In this study case, Euclidean distance calculation was done for distance from road and from LRT lines.

6.2.4 Buffering

A buffer is an area formed from a locus of constant radius from a given point or along a linear feature. This analysis can be done on either points or lines and the result is always a new polygon layer. These buffer polygons define the inside and outside of a region which are typically distinguished by different codes in the attribute table. In this project, buffering was done on all the bus stops/stations and also on all Multi-storey parking buildings aimed at identifying proximate bus stops and parking building to LRT stations.

6.2.5 Rasterisation

Rasterisation (or vectorization) is the task of taking an image described in vector graphics format (shapes) and converting it into a raster image (pixels or dots) for output on a video display or printer, or for storage in a bitmap file format. And Rasterisation refers to conversion from vector to raster data.

6.2.6 Reclassification

This is the process of assigning weights to different classes of a raster data set. This process is aimed at showing how the different concentric layers are placed and how suitable are they. In this project the datasets reclassified were slope, Euclidean distance of railway road, Euclidean of LRT line, land use in raster, and population in raster format too. Values were assigned to each layer on a uniform scale of 1-5. This scale is thus referred to as the suitability scale. Since all the data was harmonized by this process, the suitability process was possible to be carried out.

6.3 Criteria Mapping and Spatial Analysis

6.3.1 Distance from Road

The Euclidean distances of road network within 1500m catchment from LRT routes were calculated with a standard cell size of 30. This is because bus and taxi can access stations from 1500m radius. It was then reclassified into five classes with 1 being the less suitable and 5 assigned the extremely suitable.

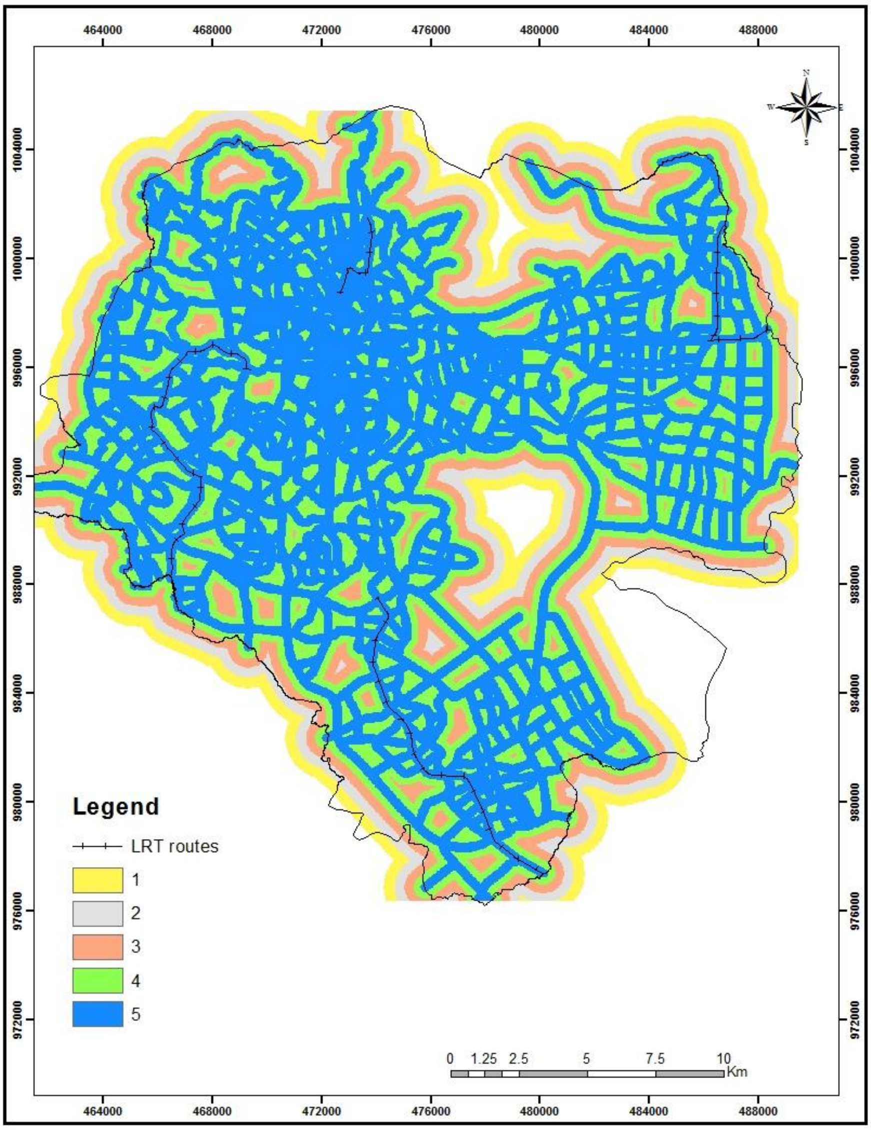

Figure 6.9: Reclassified Road Euclidean Distance

6.3.2 **Slope**

Slope was generated from the 30 meter DEM. It was then reclassified into 5 classes. Areas with gently sloping terrain were the most suitable while rugged terrain was the least suitable zone for the railway station. The slope was calculated in % of raise.

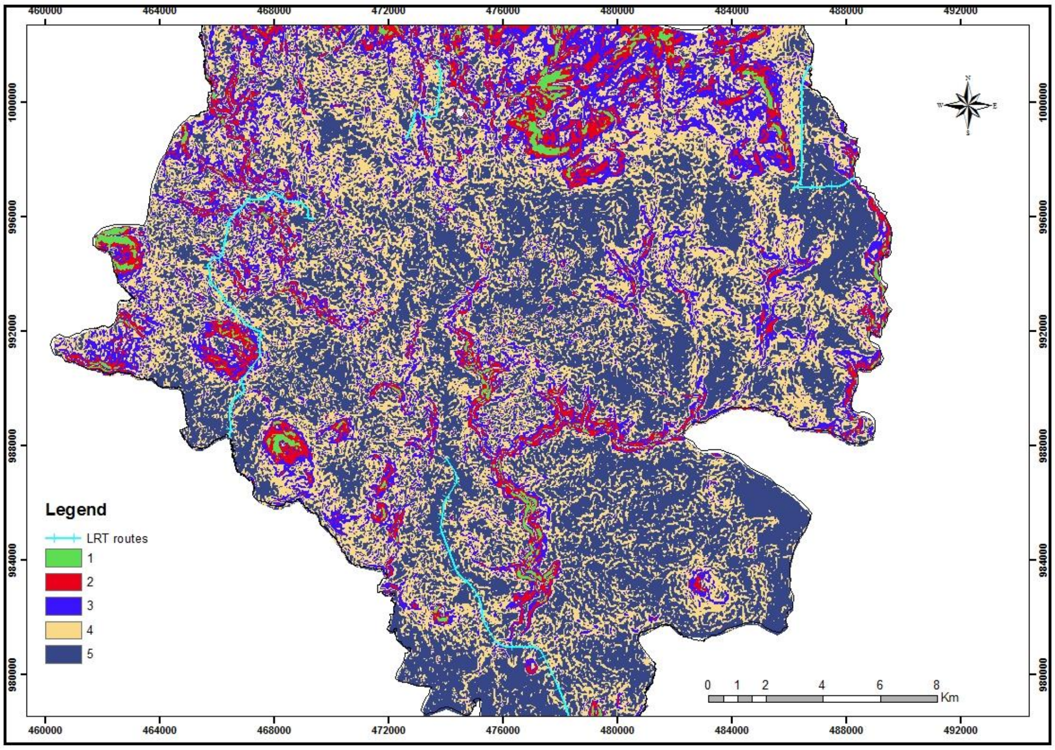

Figure 6.10: Reclassified slope

6.3.3 **Land-use**

The different land use types were converted to raster and reclassified into 5 classes with 1 being the least suitable while 5 being the extremely suitable land use type for laying out a new railway station. Figure 6.11 shows reclassified Land use types.

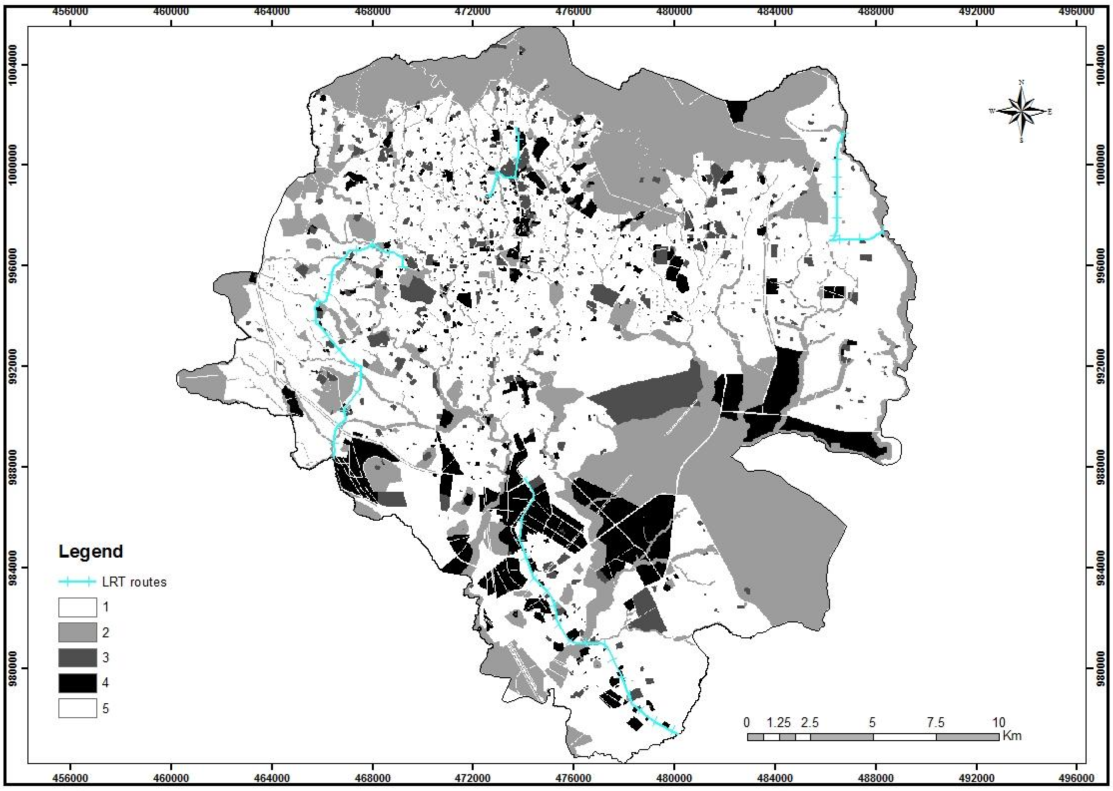

Figure 6.11: Reclassified Land use

6.3.4 **Population**

The population of the area of the study was first converted to raster by the conversion tool, and then reclassified. Five classes were assigned, with 1 being the least suitable while 5 being the extremely suitable location for routing a new station site. Figure 6.13 shows reclassified population density map while, figure 6.12 shows population density reclassification window in GIS.

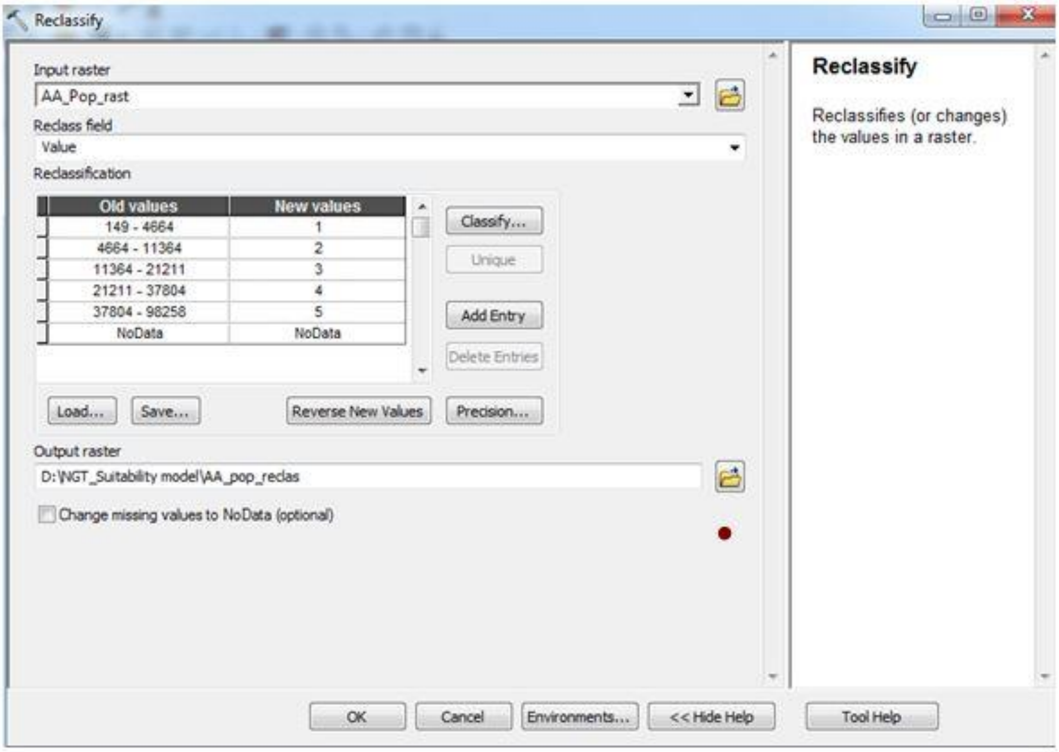

Figure 6.12: population density reclassification window

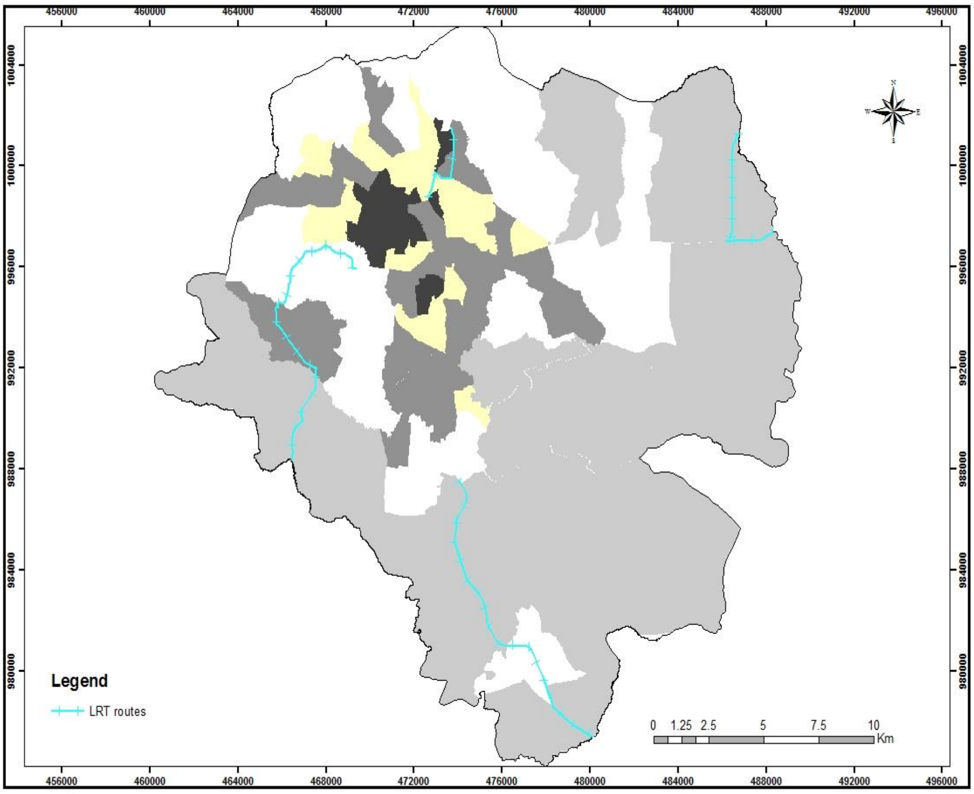

Figure 6.13: Reclassified population Density

6.3.5 **Proximity to bus stops**

Existing and planned bus stations were buffered with multi ring buffering tool and then converted to raster map. This raster map was reclassified into five classes with class 1 is least suitable location and class 5 is extremely suitable location for station site. Figure 6.14 shows the reclassified bus station proximity.

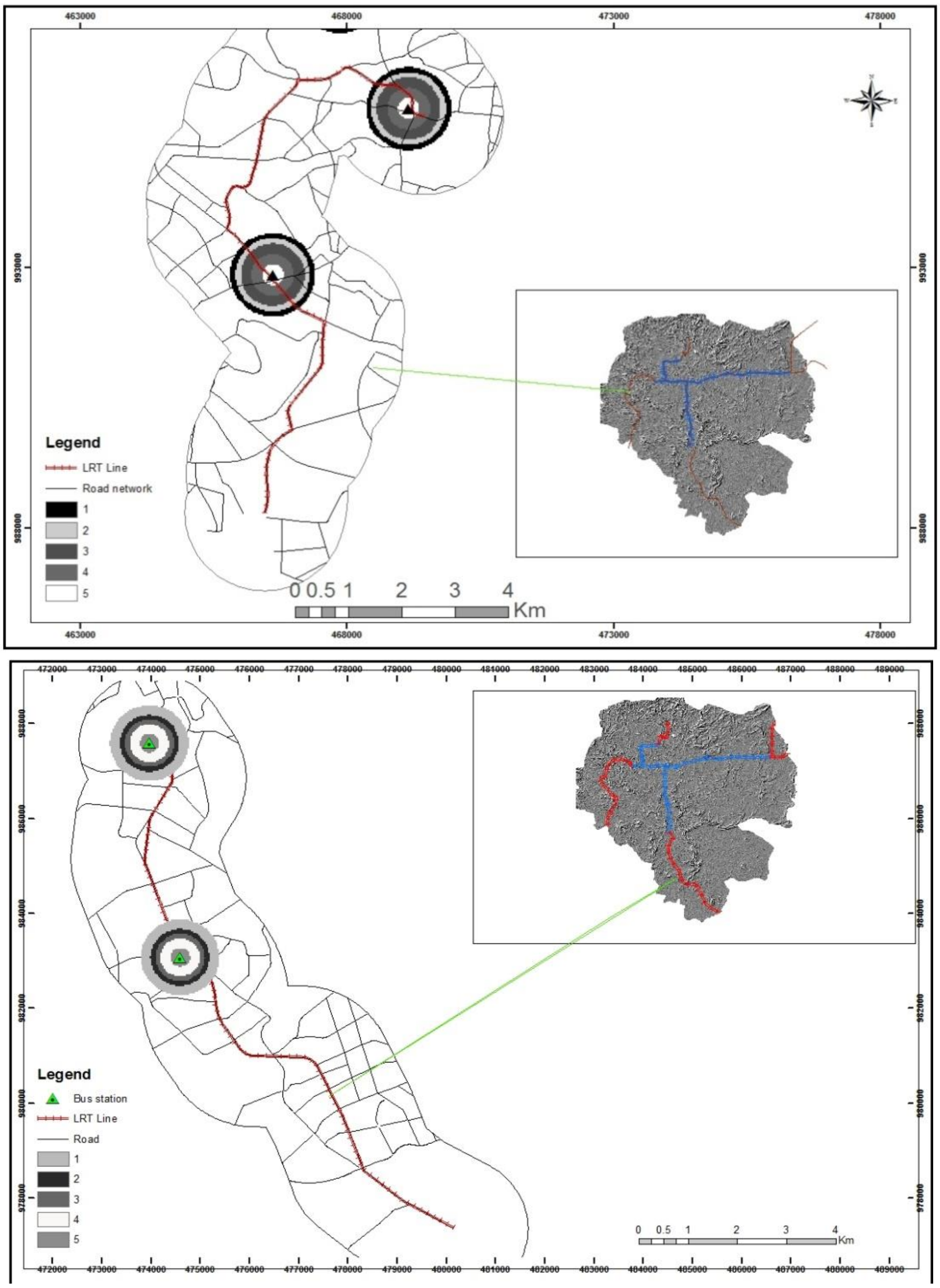

Figure 6.14: Reclassified Bus Station Proximity

Only the route extensions from Torhayloch – Sebeta National railway station and Kaliti – Akaki have bus station proximity within 800m catchment area. The other extensions do not have bus station proximity.

6.3.6 **Proximity to parking building**

Existing and planned multi-storey parking were buffered with multi ring buffering tool and then converted to raster map. This raster map was reclassified into five classes with class 1 is least suitable location and class 5 is extremely suitable location for station site. Figure 6.15 shows the reclassified parking building proximity. The Summit – Laga Tafo and Kaliti – Akaki routes has no proximity to parking building.

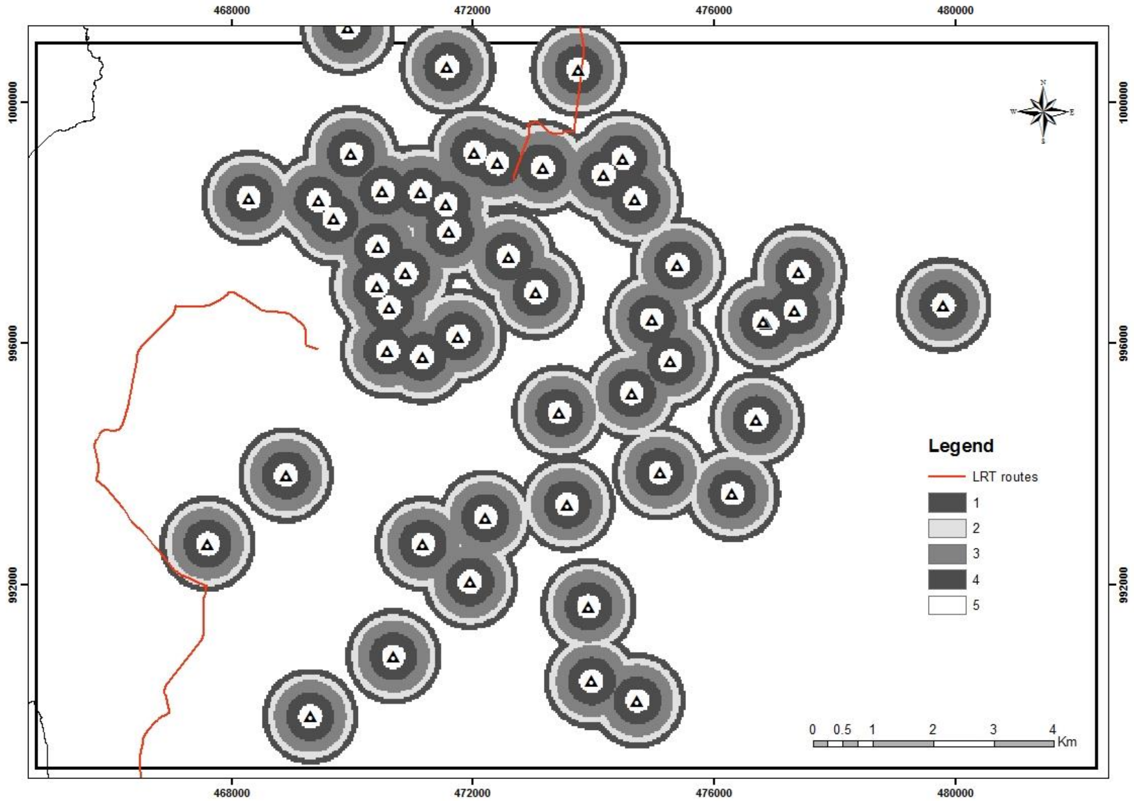

Figure 6.15: Reclassified Parking Building Proximity

6.3.7 **Weighted Overlay**

This was the last stage in the data analysis. This process was carried out by combining all the reclassified raster data sets and defining their respective percentages of influence. This process was best carried out by the model builder in ArcGIS. All the relevant raster datasets were assigned different influential weights. The total percentage influence has to add up to 100%.

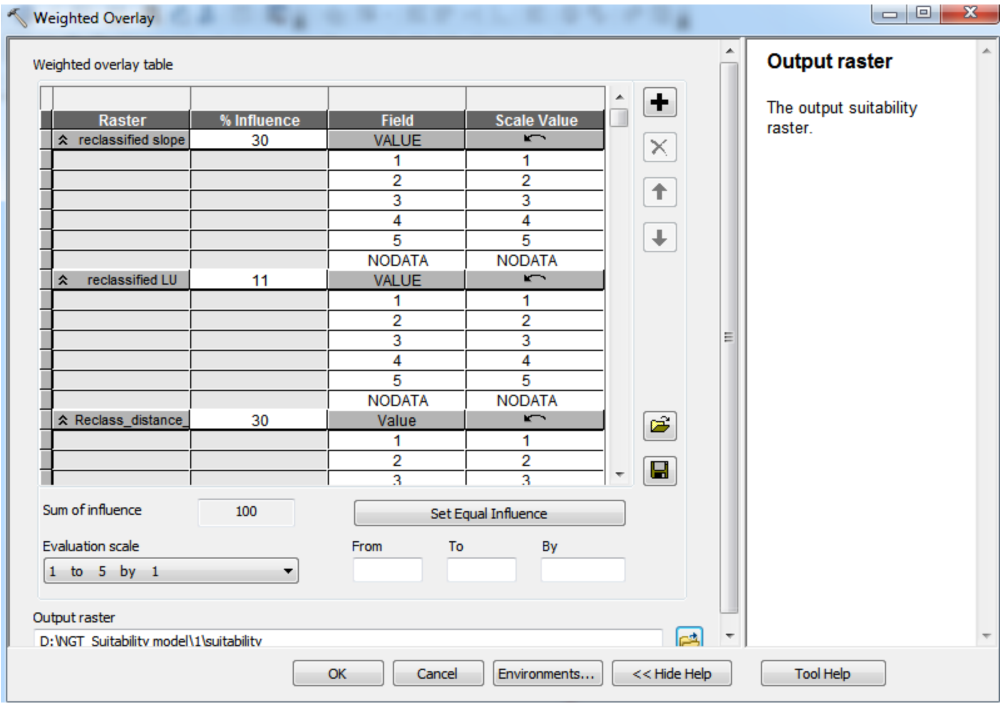

Figure 6.16: Weighted Overlay Window

6.4 Suitability Map

Suitability analysis in a GIS context is a geographic or GIS-based process used to determine the appropriateness of a given area for a particular use. The basic premise of GIS suitability analysis is that each aspect of the landscape has intrinsic characteristics that are in some degree either suitable or unsuitable for the activities being planned. Suitability is determined through systematic, multi-factor analysis of the different aspect of the terrain. Model inputs include a variety of physical, cultural, and economic factors. The results are often displayed on a map that is used to highlight areas from high to low suitability. (Dramowicz, 2005).

A GIS suitability model typically answers the question, Where is the best location? It involves finding the best location for a new station or pipeline, a new housing development, or a retail store. For instance, a commercial developer building a new retail store may take into consideration distance to major highways and any competitors' stores then combine the results with land use, population density, and consumer spending data to decide on the best location for that store.

6.5 Suitable Location Identification

This was done using model builder. Figure 6.17 shows the GIS processes (geoprocess) in suitability model building and Figure 6.18 shows station location suitability analysis model developed by using GIS.

Figure 6.17: Model Geoprocess

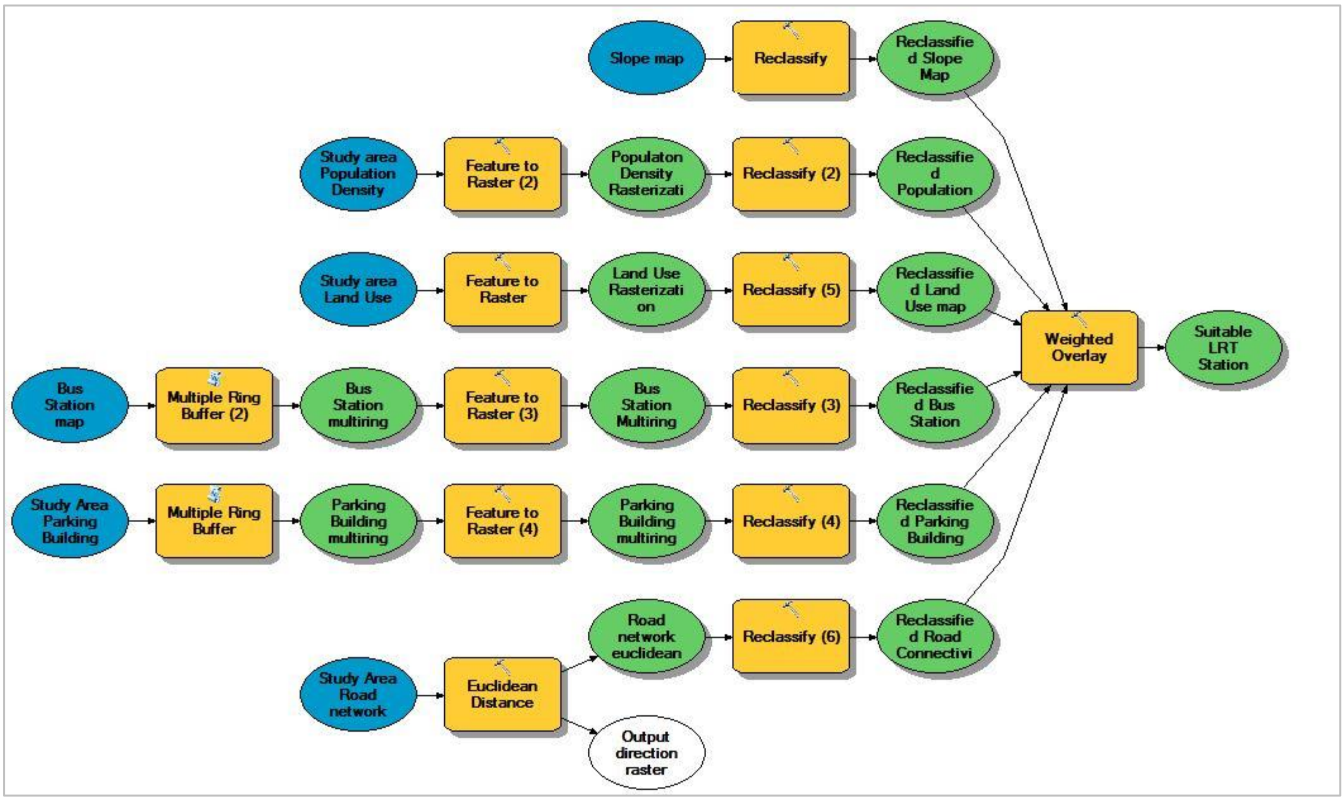

Figure 6.18: LRT station site suitability model

The output of this model was the map in next page which describes suitable intermodal and accessible light rail transit station locations that is optimized using GIS integrated with Analytical Hierarchy Process (AHP). Figure 6.19 – 6.20 shows station site suitability map.

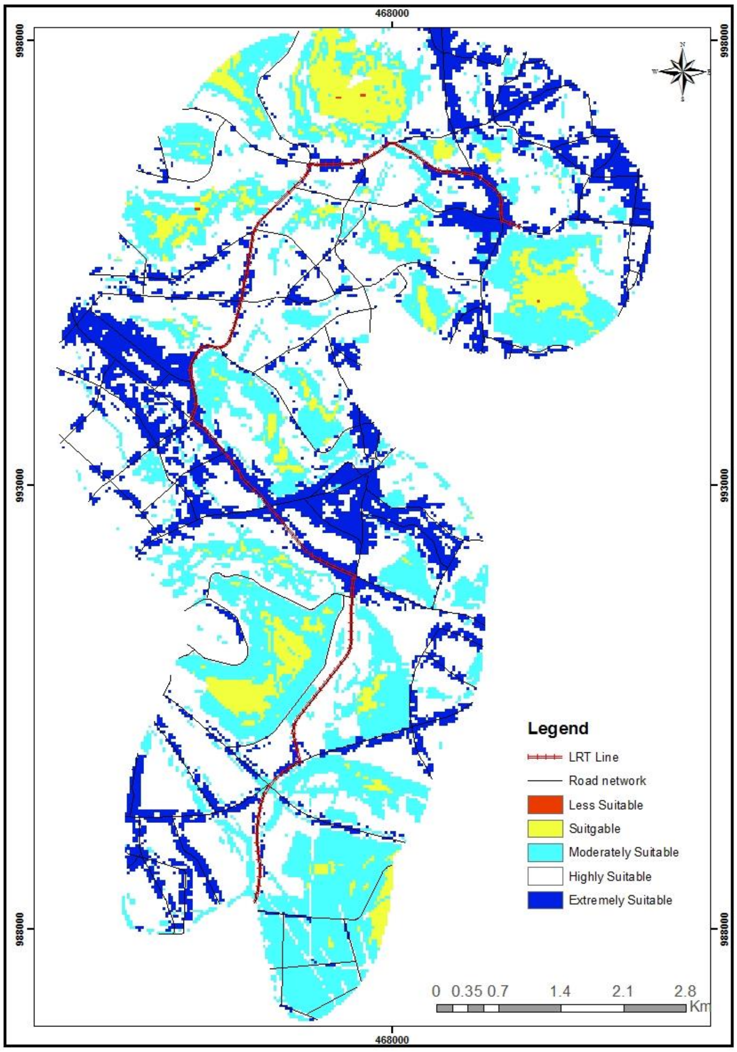

Figure 6.19: Station site suitability map for Torhaloch to Sebbeta National railway station

This station site suitability map is generated by overlying the six criteria mentioned at the beginning of this chapter. From the map, the black blue color shows sited that are extremely suitable to locate LRT station while, white color depicts highly suitable site and so on. So, while we locate LRT station location it is recommended to locate it at black color areas if possible. If not, the second suitable area for station location is the white area and the third suitable area is the white blue area. We can locate stations based on minimum and maximum station spacing at the same time by referring to this suitability map.

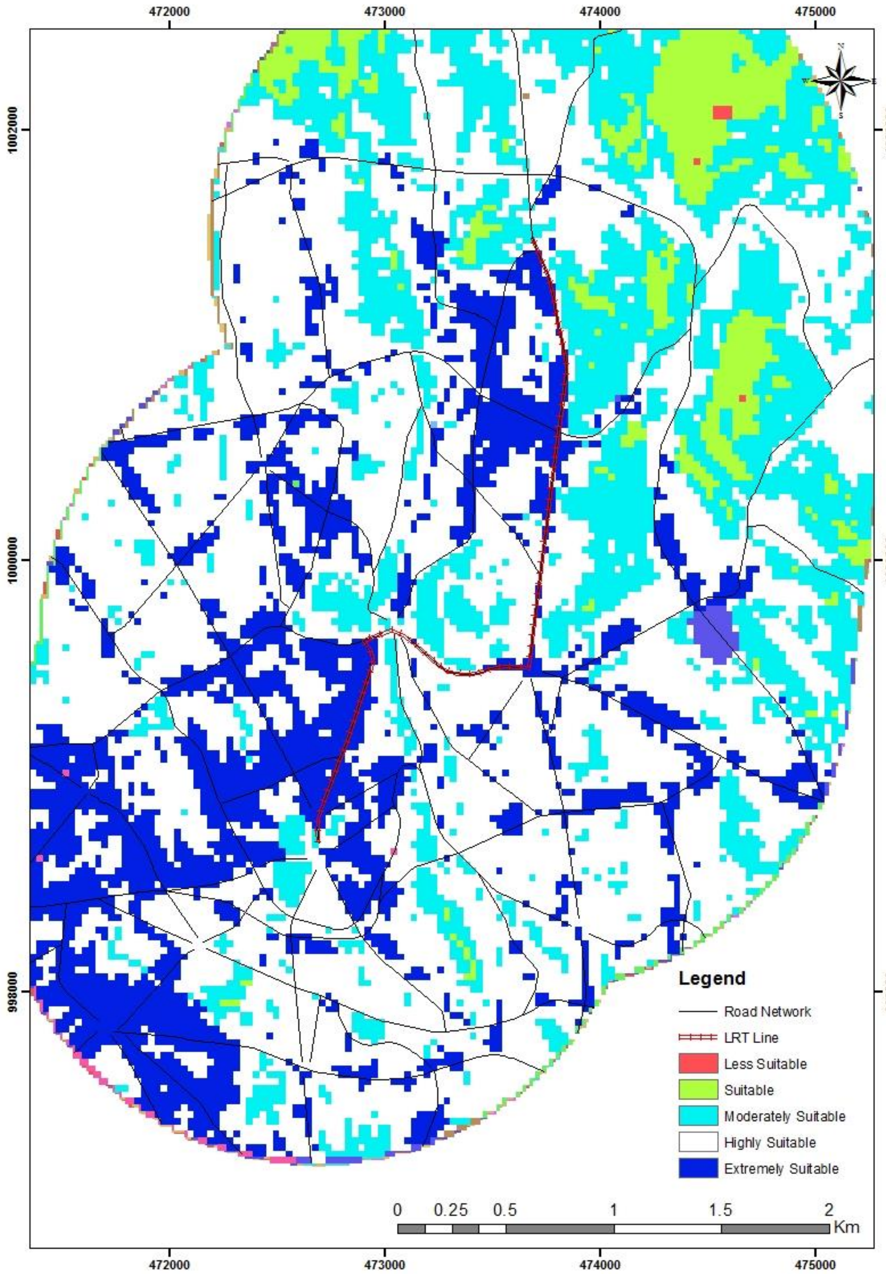

Figure 6.20 : Station site suitability map for route from Arada to Addisu gebeya

This station site suitability map is also generated by overlying these six criteria.

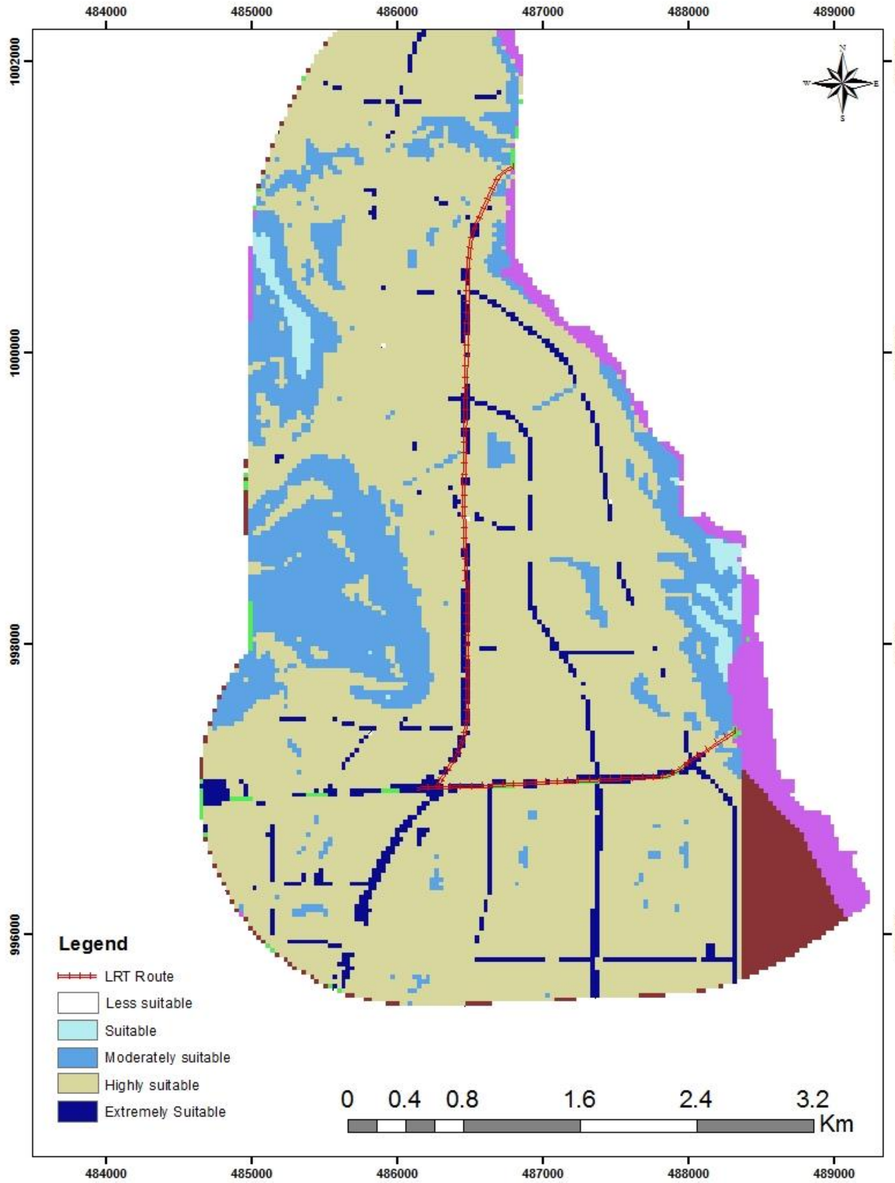

Figure 6.21: Station site suitability map for route from Summit to Laga Tafo

In this case, only four of the six criteria were used because there are no bus station and parking building in LRT route proximity of 800m. From the map, black blue area is extremely suitable. Since were only four criteria used, this suitability map may not be intermodal as the other maps.

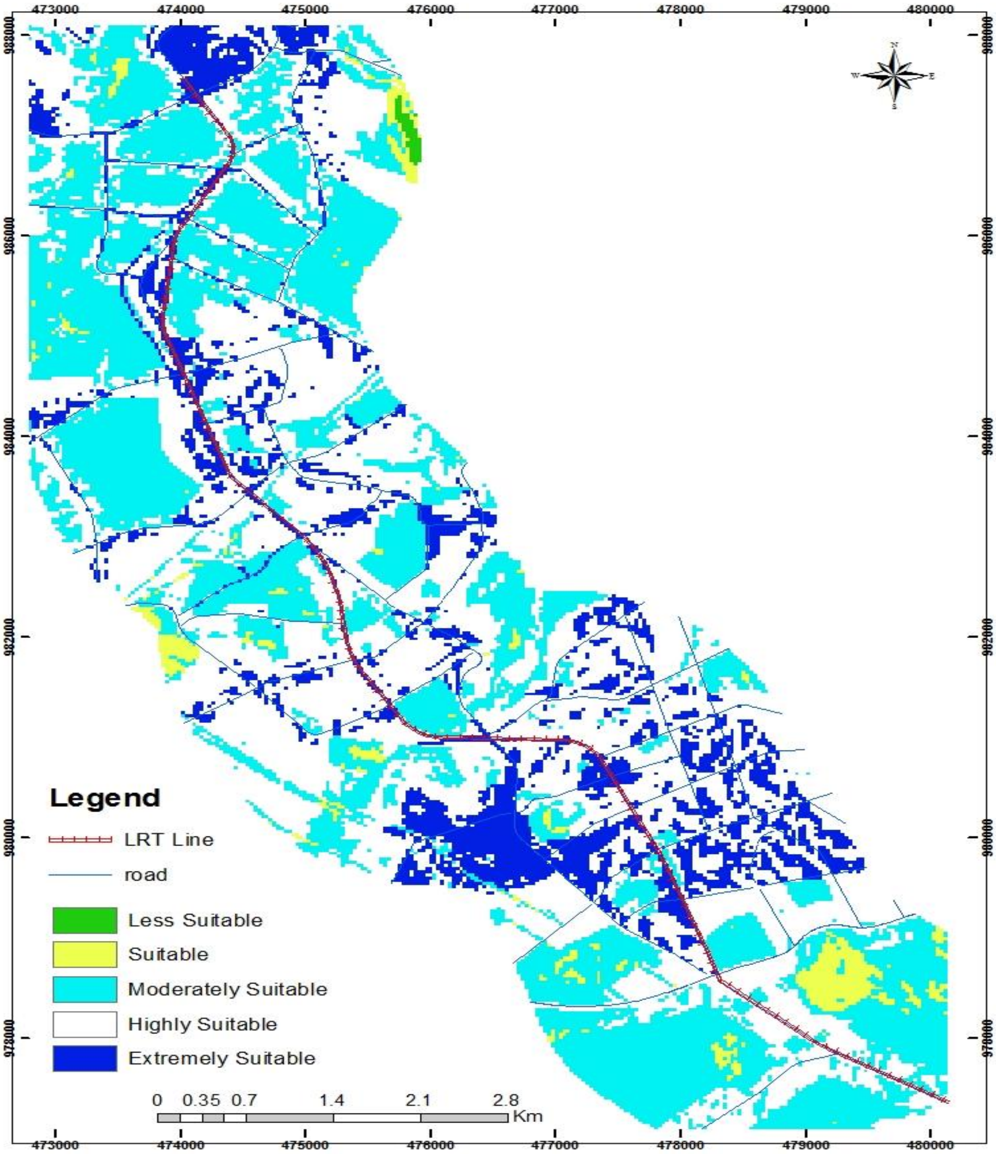

Figure 6.22: Station location Suitability map for route from Kaliti to Akaki

The purpose of the above maps is, to give an idea of potential station site during station location planning. After we get potential station sites that is determined by integration of multi-criteria or objectives, best station location can be selected by considering minimum and maximum station spacing and pedestrian walkable distance. As explained in above sections, this map is a result of GIS suitability analysis that process multi-criteria that have direct impacts in locating LRT stations. Proximity to road, bus station/stop, high density areas, areas of high ridership origins and land uses were among the criteria that have considered in this geo process. Therefore, one can refer or consult this suitability map for selection of optimal LRT station location.

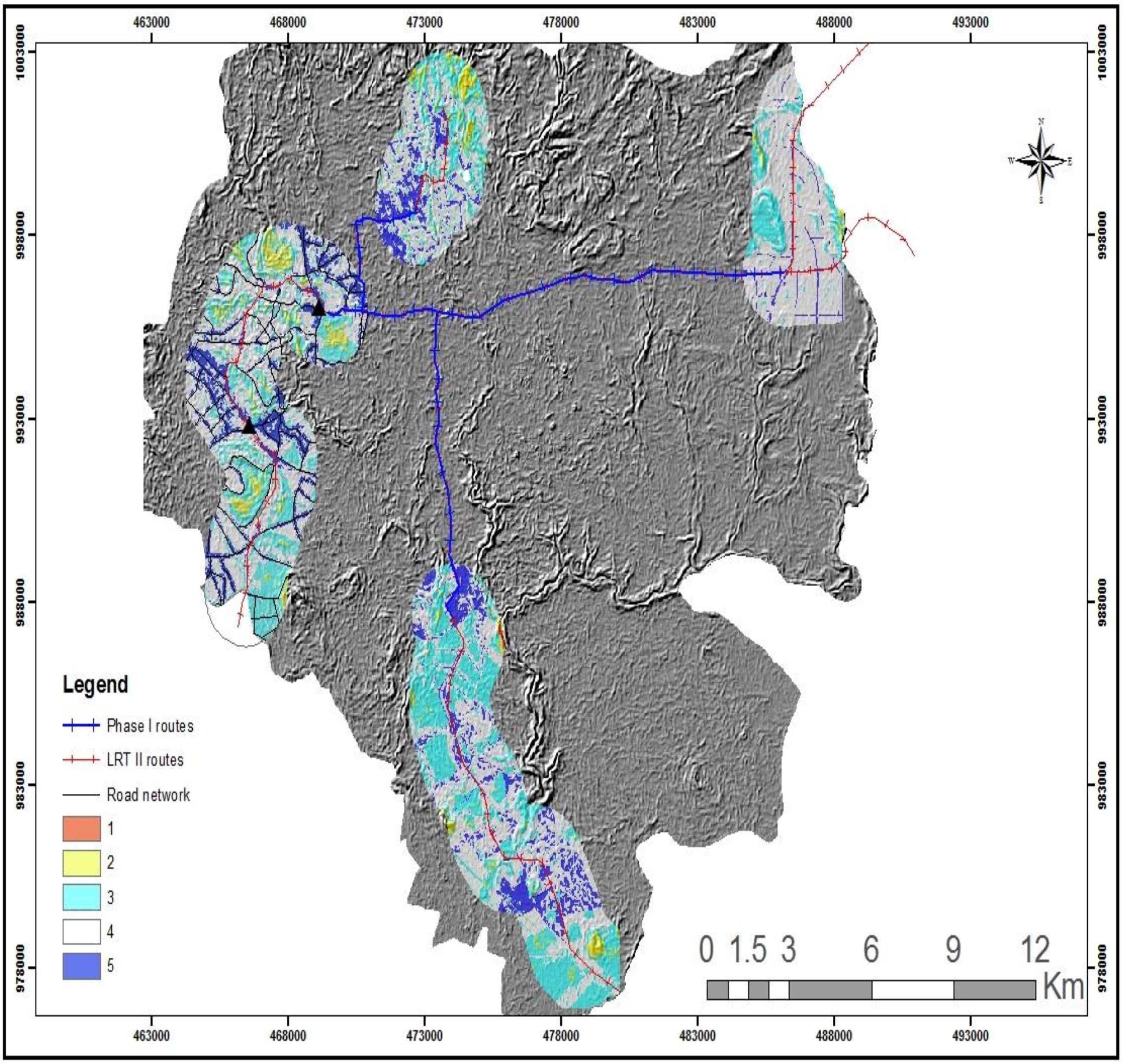

Figure 6.23: general station suitability map

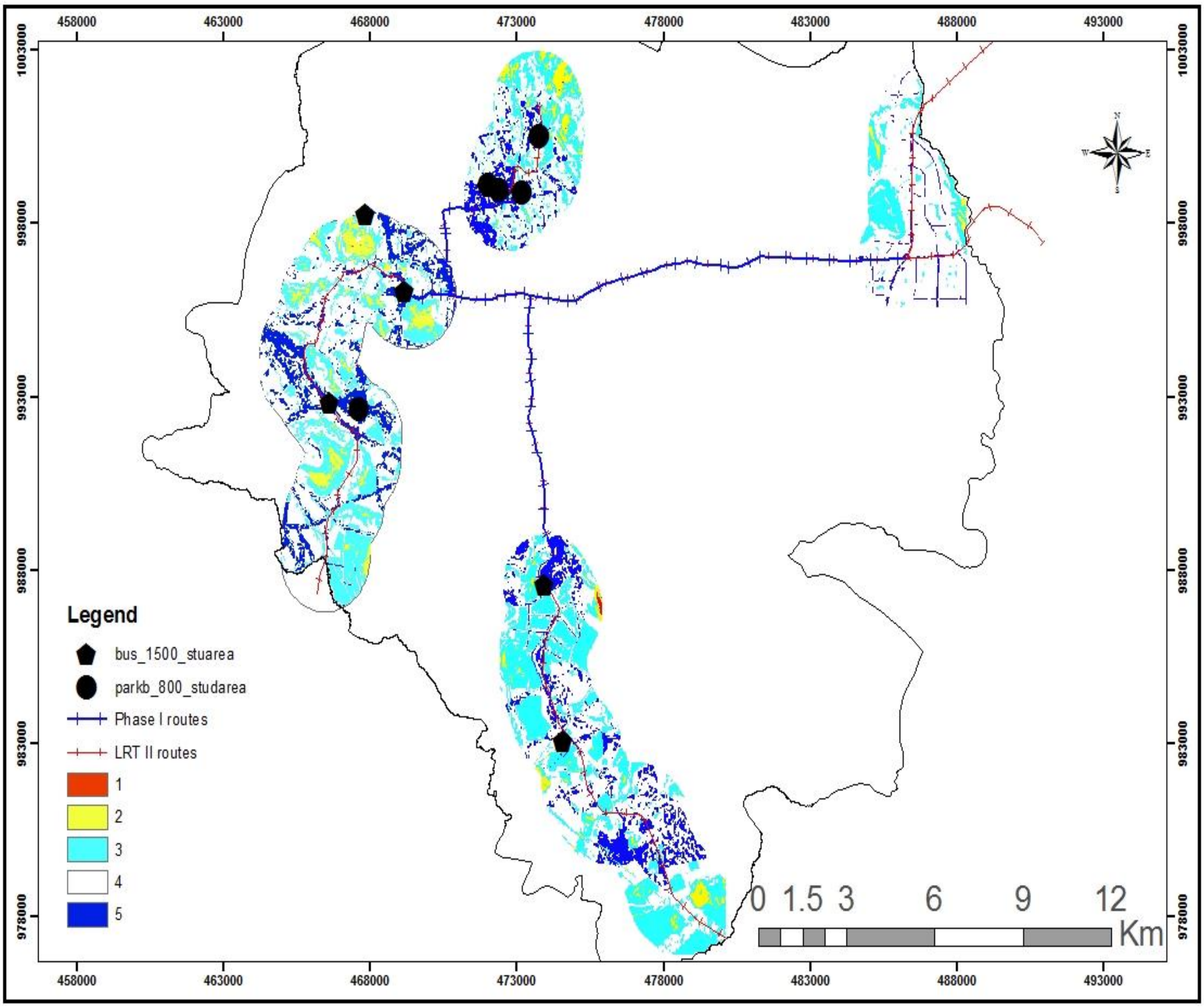

Figure 6.24: Potential Intermodal Station location

Based on this suitability map, minimum and maximum station spacing, and proximity to other access modes such as bus station, we can select intermodal LRT station location. All stations along LRT routes may not be needed to be intermodal station. This is because not all stations are at a location of mixed access mode availability. Intermodal stations that can accommodate all possible access or arrival modes are necessary to be designed for active transport system creation in this city Addis Ababa. That is why the study tried to identify suitable areas along LRT II routs.

CHAPTER 7

7 CONCLUSIONS AND RECOMMENDATIONS

7.1 Conclusions

The purpose of this study was to identify suitable station sites along imminent Addis Ababa Light Rail Transit (AALRT) routes. The study presents an integrated approach of GIS with AHP combination to assess the station suitability by matching the characteristics of an area with those attributes most appropriate for stations. These integrated approaches were able to handle complex and many issues related to accessibility.

The main contribution of this study was the identification criteria and factors of LRT station by applying the hierarchical structure of AHP in geospatial environment. It was started by the calculation of weighting and rating from the AHP analysis where experts were asked to determine the relative importance of each criterion and factor. The determination of criteria and classification of factors for the identification of station potential areas which were divided into three main categories: land-use compatibility, transportation connectivity and topography aspects. There were seven criteria in the form of GIS-based layers incorporated for location suitability of railway station.

The study has been successful in developing a methodology that identified LRT station sites using GIS and AHP techniques. Those criteria and factors are very important components in achieving station development as an integral part of the sustainable LRT system planning. Beneficially, the final outcome of this study was the identification of the sites which are best suited for intermodal LRT station in Addis Ababa along phase two routes. The study also tried to take advantage of Addis Ababa planned and under construction multi story buildings in identifying potential intermodal LRT stations.

Based on the outcome of the analysis, suitable intermodal station sites are mostly located at areas where multi-storey parking buildings and bus transfer stations exist. By taking advantage of surface and multi-storey parking, central stations can attract park-and-ride users in addition to pedestrians. This will help the Addis Ababa LRT system to compensate its expenses on high construction and operation-related costs.

In conclusion, a result of this study appears practically useful for the development of effective LRT station sites and facilities planning. Additionally, final output of this study could be used for generating candidate station location and prioritizing to select best station locations.

Finally, the application of the outputs of this research can be useful for managers, operators and planners working in transport-related fields.

7.2 Recommendations

The criteria and factors developed in this study can be used in planning and designing of station potential sites. The developed methodology can be used for future Addis Ababa metro intermodal stations site planning where intermodal station is demanded.

Since, light railway transit station location planning involves complex criteria in creating active, accessible and sustainable urban rail transit, further study should be done with the implementation of community/stakeholders participation in developing site specific station location selection criteria.

With respect to the techniques implemented in this study, the integration of AHP in GIS techniques has been proven beneficial for supporting decision-making. The methodology is useful for identifying priority areas for LRT stations and this integration of AHP/GIS methodology developed in this research can also be used for railway and highway alignment selection. While, GIS is the best tool that should be used in handling various railway-related data which will be easily accessed, edited and analyzed for railway station and alignment design and for railway operation management.

CHAPTER 8

8 FUTURE RESEARCH AREAS

This study should provide the motivation for the continuation of research and future investigation on sustainable development of railway station and alignment planning and design in Ethiopia.

Since, railway station and alignment design is a multi-criteria problem, integration of Analytical Hierarchy Process (AHP) for best decision making and Geographic Information System (GIS) for handling, analysis and calculation of spatial data related to the problem.

By using station site suitability map developed above, we can select many potential LRT station locations which will be further screened and prioritized to get best station locations along the route. Selection of optimum station locations from potential station locations shall take into consideration factors such as drainage, slope, cost and engineering works and traffic flow of the area.

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Appendix

Appendix 1: Questionnaire

Please take a few minutes to fill this criteria pair wise comparison on railway station site suitability analysis. I am conducting this to feed my research work for the fulfillment of MSc. degree in Railway Engineering. I am greatly thankful to you for your time and appreciate your cooperation. Your personal information will be kept confidential and will be solely used for my own study for the above mentioned research. Thank you for your participation.

Personal Information

Providing the following information is optional.

First Name: ____

Organization:____

Position/ Role: ________________________City: ____________

Telephone: _____________________ Gender: _____ Age: _______

Research title: LRT Station Site Suitability Analysis by GIS and AHP

In this research, the following criteria are considered in the selection of suitable Railway station location. These factors are grouped in to two: Main criteria and sub-criteria.

The relative importance of the criteria and sub-criteria has to be determined by experts from different professions related to the topic.

A 9 point intensity of relative importance scale is used for pair wise comparison of Main criteria and a 5 point importance scale for sub-criteria pair-wise comparison.

Criteria

- Land use compatibility
- Residential
- Industrial
- Commercial
- Education
- Institutional

- Public gatherings
- Transportation connectivity/multimodal link
    - Bus connectivity/ Proximity to bus, taxi stops/transfer station
    - Proximity to parking buildings
    - Connectivity to pedestrian walkways
    - Connectivity to road
- Population density
- Slope
- Elevation

Fill table2 below. Use 1 – 9 scales to evaluate their relative importance.

- Compare and determine relative importance of the following main criteria by pair-wise comparison and circle to the value you think in table2: below.

Use a 9 point scale relative importance comparison table 1: below and encircle the value 1 – 9 in table2:

Table1 1: A 9 point scale for pair wise comparison of Evaluation Criteria

Intensity of Relative Importance	Definition	Explanation
1	Equal importance	Two activities contribute equally to objective 1.
3	Moderate importance of one over another	Experience and judgment slightly favor one activity over another.
5	Essential or strong importance	Experience and judgment strongly favor one activity over another.
7	Demonstrated importance	An activity is strongly favored, and its dominance is demonstrated in practice.
9	Extreme importance	The evidence favoring one activity over another is of the highest possible order of affirmation.
2, 4, 6, 8	Intermediate values between the two adjacent judgments	When a compromise is needed

Sub-Criteria comparison

- For this detailed pair wise comparison, use the following 5 point scale given in table3 below and assign a score to these sub-criteria by comparing pair-wisely according to the 5 point scale given in table3: below.

Table2: a 5 point scale for pair wise comparison of sub-criteria scoring

Score	Class
1	Less Suitable
2	Moderately suitable
3	Suitable
4	Highly suitable
5	Extremely Suitable

Criteria that are highly suitable for siting light rail transit station relative to other criteria, will be assigned a value of 5; criteria that are partially suitable will be assigned a value of 3; and criteria that are lowest suitable for station sites relative to the other criteria, will be assigned a value of 1.

Pair-wise comparison of sub-criterion to Land-use factor Category, land use, score and class

Category	**Land use**	**Score**	**Class**
1	Residential		
2	Industrial		
3	Commercial		
4	Education		
5	Institutional		
6	Public gatherings		

Category, slope, score and class

Category, range, score and class Category	Range	Score	Class
1	0 - 4.0		
2	4.0 - 6.0		
3	6.0 - 8.0		
4	8.0 - 87.0		

Pair-wise Comparison of Distance from road Factor

Category	Range	Score	Class
1	0 - 100m		
2	100 - 200m		
3	200 - 400m		
4	400 - 600m		
5	600 - 800m		

Pair-wise comparison of proximity to Parking Building Factor

Category	Range	score	class
1	0 - 100m		
2	100 - 200m		
3	200 - 400m		
4	400 - 600m		
5	600 - 800m		

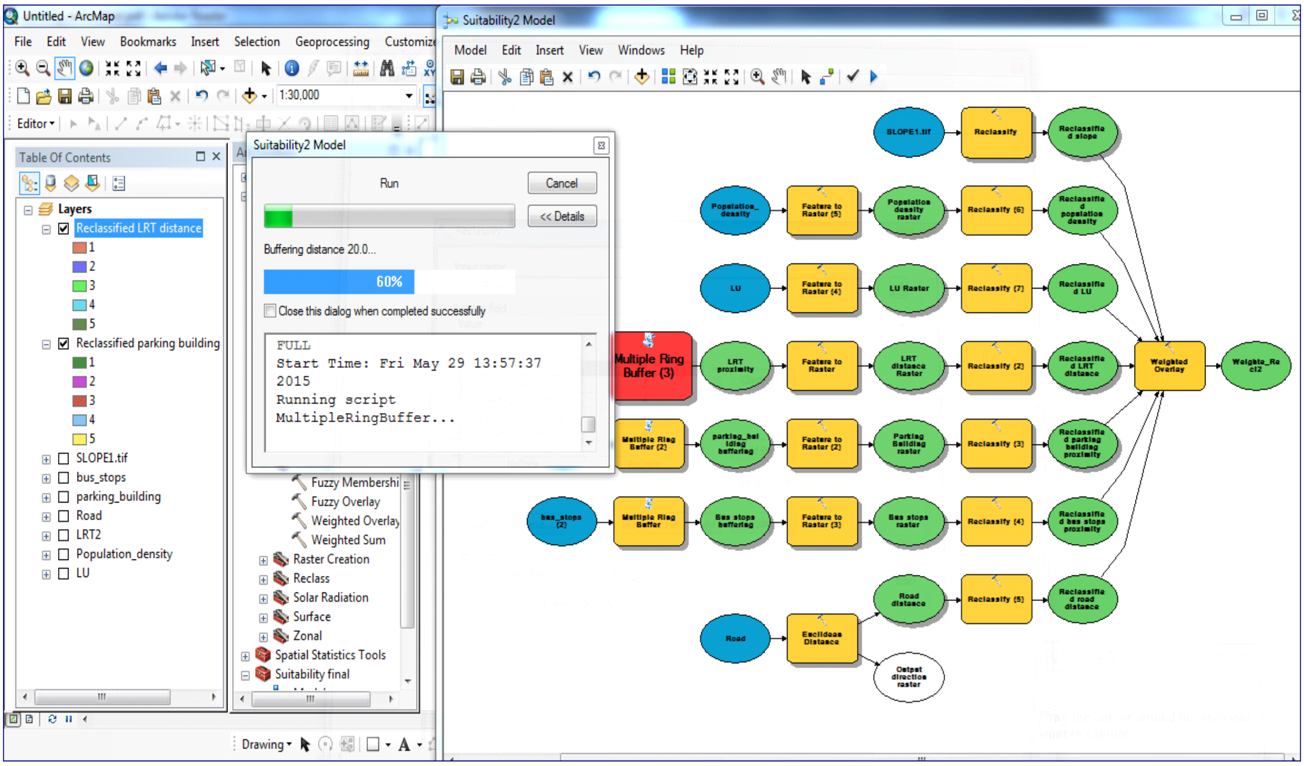
Pair-wise comparison of proximity to Bus Station Factor

Category	Range	score	class
1	0 - 100m		
2	100 - 200m		
3	200 - 400m		
4	400 - 600m		
5	600 - 800m		

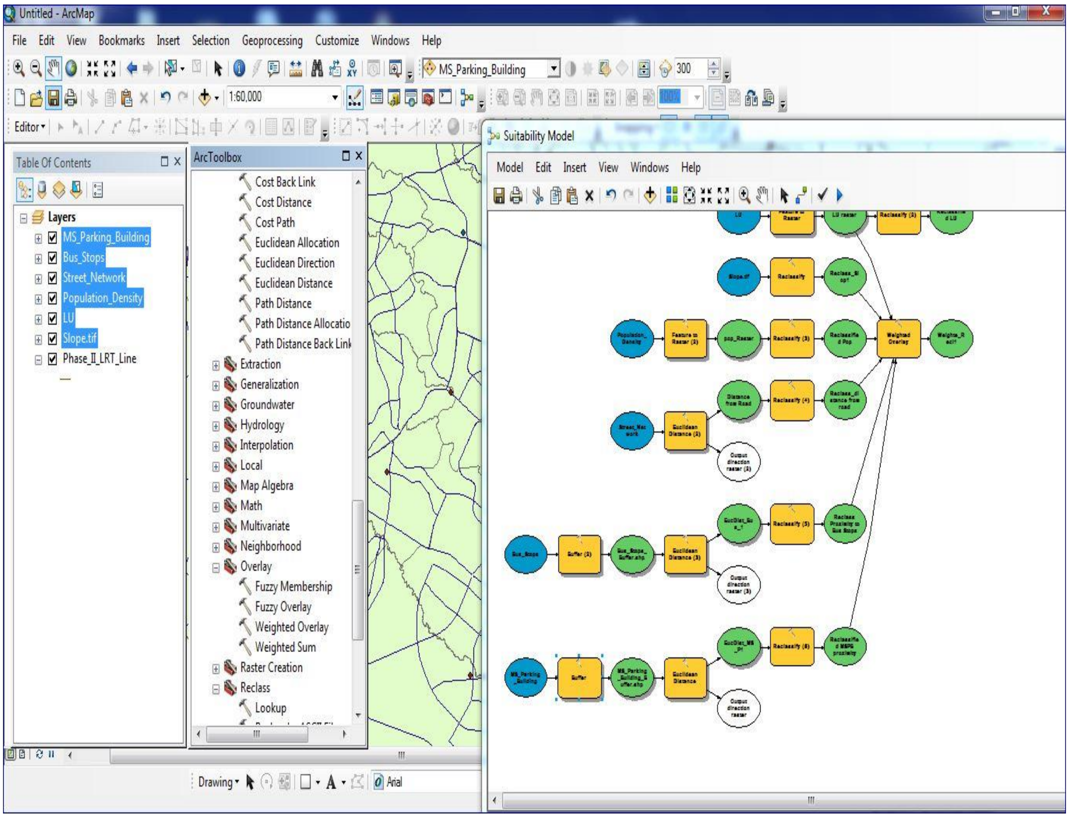
Pair-wise comparison of proximity to Road Factor

Category	Range	score	class
1	0 - 100m		
2	100 - 200m		
3	200 - 400m		
4	400 - 600m		
5	600 - 800m		

Appendix 2: Full Model Running window



Appendix 3: GIS tools used to build model for suitability analysis



Appendix 4: Participated experts list

Discipline	Profession	Education and Work Experience	Number
Transport Engineer	Civil Engineering/Railway	Msc. plus some years of experiences	2
Urban planning/designing	Urban Planning	MSc.>20years exprience	2
Economics	Economist	> 3years	2
Transport planner	Transport Engineering/Planning	>25 years work experience	2

Appendix 5: Addis Ababa population

FID	Id	Sub_City	Woreda	area_m2	Area_ha	pop_densit	kebele	populati_1	Pop_dens_1(pop/Km^2)
0	0	Kolfe_Kerar	10	1.25353072	1.2535307	19951.64505	12	13034	19951.64505
1	0	Addis Keten	5	1.27884131	1.2788413	19849.48622	19/20	19800	19556.76574
2	0	Addis Keten	6	0.61918489	0.6191849	40391.81281	14/21	28639	40391.81281
3	0	Addis Keten	7	0.48982018	0.4898202	51059.55426	13/15	23199	51059.55426
4	0	Addis Keten	1	0.76675898	0.766759	32617.81163	01-02-03	33259	32617.81163
5	0	Addis Keten	2	0.37844066	0.3784407	66086.97936	04—05	27143	66086.97936
6	0	Addis Keten	3	0.8906366	0.8906366	28081.03771	06—07-	29058	28081.03771
7	0	Addis Keten	8	0.99661078	0.9966108	25095.05262	10-11-12	32656	25095.05262
8	0	Addis Keten	9	0.76589947	0.7658995	31869.67335	16/17	28542	32654.41598
9	0	Addis Keten	4	1.19864686	1.1986469	20865.19464	08-09-18	33076	20865.19464
10	0	Arada	3	0.65590612	0.6559061	32323.22329	6	13669	32323.22329
11	0	Arada	2	0.58021285	0.5802129	36540.03864	04-/05	22010	36540.03864
12	0	Arada	4	1.10845629	1.1084563	19126.59998	07-/08	25303	19126.59998
13	0	Arada	5	0.95157772	0.9515777	22279.84069	03/-09	24725	22279.84069
14	0	Arada	1	1.50450852	1.5045085	14091.64503	01-/02	21436	14091.64503
15	0	Arada	6	0.90595383	0.9059538	23401.85484	11-/12	19861	23401.85484
16	0	Arada	7	1.31961321	1.3196132	16066.0714	13/14	28157	16066.0714
17	0	Arada	8	1.07972633	1.0797263	19635.53113	15/16	24627	19635.53113
18	0	Arada	9	0.99665802	0.996658	21272.09094	17	17394	21272.09094
19	0	Arada	10	0.39541788	0.3954179	53616.69599	10	13521	53616.69599
20	0	Gulele	9	1.97420962	1.9742096	13543.6479	10-/11	32704	13543.6479
21	0	Gulele	8	3.12349174	3.1234917	8560.291554	01-/09	31954	8560.291554
22	0	Gulele	7	4.70811493	4.7081149	5679.130693	01/-08	37066	5679.130693
23	0	Gulele	6	3.23980044	3.2398004	7654.218198	18	26123	8252.977449
24	0	Gulele	4	0.74800387	0.7480039	35745.80455	6	13264	35745.80455
25	0	Gulele	5	1.36805498	1.368055	19544.5361	01-/07	24495	19544.5361
26	0	Gulele	3	0.92360655	0.9236065	28949.5565	03-04-05	28124	28949.5565
27	0	Gulele	2	1.89773567	1.8977357	14089.42268	01/-02	20932	14089.42268
28	0	Gulele	1	7.85750383	7.8575038	3516.276229	19/20/21	29235	3402.861848
29	0	Gulele	10	5.35043824	5.3504382	4997.34766	13/14	23727	4997.34766
30	0	Akaki Akalit	6	3.63991272	3.6399127	7320.131139	12-/13	27082	6222.676678
31	0	Akaki Akalit	5	15.1567944	15.156794	3080.608655	10/-11	45831	1494.379309
32	0	Akaki Akalit	10	35.8729652	35.872965	1772.818541	gelangora	3903	631.3946972
33	0	Akaki Akalit	9	28.4605883	28.460588	795.8373781	kilinto/koye/feche(17/18/19)	5122	795.8373781
34	0	Akaki Akalit	2	13.2561956	13.256196	1708.635013	02-/04	13973	1708.635013
35	0	Akaki Akalit	3	2.3608919	2.3608919	9593.831894	05-/06	17580	9593.831894
36	0	Akaki Akalit	4	19.220047	19.220047	1708.45683	07-08-09	42311	1178.457056
37	0	Akaki Akalit	1	6.0145615	6.0145615	3765.860573	01-/03	25468	3765.860573
38	0	Bole	1	8.28431355	8.2843136	3387.969301	1	28203	3387.969301
39	0	Bole	2	1.17271846	1.1727185	23933.28064	2	8155	23933.28064
40	0	Bole	4	1.93944396	1.939444	14471.67362	04/-06	29029	14471.67362
41	0	Bole	5	1.52537541	1.5253754	18400.06058	08/-09	20228	18400.06058
42	0	Bole	6	3.16374776	3.1637478	11606.8671	01—12	24361	8871.440484
43	0	Bole	7	15.0236136	15.023614	8031.0849	14/15	81405	1868.192348
44	0	Bole	10	48.6296612	48.629661	1019.956436	16/18/21/22	13531	577.1580413
45	0	Bole	14	1.79807543	1.7980754	15609.46752	11	18441	15609.46752
46	0	Kirkos	6	1.18132368	1.1813237	17006.34659	10	11047	17006.34659
47	0	Kirkos	10	0.68373023	0.6837302	29382.93348	13/14	22694	29382.93348
48	0	Kirkos	5	1.21760617	1.2176062	16499.58794	08-/09	20935	16499.58794
49	0	Kirkos	11	0.71366982	0.7136698	28150.27246	11/-12	22870	28150.27246
50	0	Kirkos	3	1.3240146	1.3240146	15173.5487	4	12792	15173.5487
51	0	Kirkos	2	1.94778235	1.9477823	10314.29413	02-/03	24997	10314.29413
52	0	Kirkos	4	1.61769836	1.6176984	12418.87887	05-06-07	28467	12418.87887
53	0	Kirkos	9	1.0518698	1.0518698	19099.32204	20/21	20558	19099.32204
54	0	Kirkos	1	1.39418766	1.3941877	14409.82481	01-/01	18236	14409.82481
55	0	Kirkos	8	1.63859983	1.6385998	12260.46751	17/18	21506	12260.46751
56	0	Kirkos	7	1.87663784	1.8766378	10705.31543	15/16	17132	10705.31543
57	0	Kolfe_Kerar	1	3.10932411	3.1093241	13785.95428	02-/03	32866	13785.95428
58	0	Kolfe_Kerar	3	19.6700726	19.670073	3176.514329	4	55374	2179.198872
59	0	Kolfe_Kerar	4	6.91069913	6.9106991	13916.74095	01-/05	76076	6202.70094
60	0	Kolfe_Kerar	8	7.77526346	7.7752635	5512.996467	7	35621	5512.996467
61	0	Kolfe_Kerar	7	6.65008963	6.6500896	11879.89919	6	41751	6445.777782
62	0	Kolfe_Kerar	10	2.55104602	2.551046	23436.49957	08-/09	40714	16802.91128
63	0	Kolfe_Kerar	11	4.87304743	4.8730474	10305.28933	10-/11	51498	8796.343679
64	0	Kolfe_Kerar	13	2.13006652	2.1300665	14243.19292	13/14	37962	20123.78466
65	0	Kolfe_Kerar	14	8.01582715	8.0158272	19329.70697	15/16	43999	5347.545448
66	0	Lideta	9	1.60300082	1.6030008	23848.06297	07-/14	26387	13974.41584
67	0	Lideta	1	2.73731513	2.7373151	8183.566366	02-/03	21427	8183.566366
68	0	Lideta	10	0.98926776	0.9892678	22644.02102	15/16/17	14355	22644.02102
69	0	Lideta	6	0.30688052	0.3068805	72995.83683	11	13365	72995.83683
70	0	Lideta	7	0.48822764	0.4882276	45882.28526	12	17455	45882.28526
71	0	Lideta	5	0.43867064	0.4386706	51065.64719	09-/10	29171	51065.64719
72	0	Lideta	4	0.87876081	0.8787608	25491.57837	05/-08	28166	25491.57837
73	0	Lideta	3	0.58360006	0.5836001	38384.16315	04/-06	26810	38384.16315
74	0	Lideta	2	2.96264115	2.9626411	19338.8301	02-/03	24577	7561.15874
75	0	Nifassilk Laf	1	25.9282632	25.928263	1219.171516	1	31627	1219.171516
76	0	Nifassilk Laf	2	6.66131239	6.6613124	4745.461277	2	32224	4745.461277
77	0	Nifassilk Laf	3	4.41706146	4.4170615	7156.567847	03-04-05	34846	7156.567847
78	0	Nifassilk Laf	4	2.69493669	2.6949367	29248.76661	06-07-08	40364	11729.77461
79	0	Nifassilk Laf	7	3.65424683	3.6542468	17948.31144	01-/10	41299	8650.482982
80	0	Nifassilk Laf	8	1.05835281	1.0583528	29868.11186	11	16010	29868.11186
81	0	Nifassilk Laf	9	1.23049204	1.230492	17797.0037	01-/12	28023	25689.72336
82	0	Nifassilk Laf	11	7.08906804	7.089068	4459.119286	16/17	36081	4459.119286
83	0	Nifassilk Laf	12	2.00428704	2.004287	15771.69304	15	22280	15771.69304
84	0	Yeka	2	6.15370399	6.153704	5118.705749	03/-04	32346	5118.705749
85	0	Yeka	1	3.9419305	3.9419305	7990.754786	01-/02	27163	7990.754786
86	0	Yeka	4	1.07923761	1.0792376	29186.34396	5	13697	29186.34396
87	0	Yeka	3	3.49586516	3.4958652	9010.358959	06-/07	18843	9010.358959
88	0	Yeka	7	1.72208838	1.7220884	18291.16342	11-/12	21292	18291.16342
89	0	Yeka	5	6.81323367	6.8132337	4623.208528	01/-08	30422	4623.208528
90	0	Yeka	6	1.01440916	1.0144092	31051.57301	09/-10	27025	31051.57301
91	0	Yeka	8	1.4807919	1.4807919	21271.72634	13/14	23860	21271.72634
92	0	Yeka	10	18.738496	18.738496	2184.316991	16/17/18	55035	1680.978027
93	0	Yeka	13	29.0962529	29.096253	2189.024546	20/21	65127	1082.579263
94	0	Yeka	11	7.87260744	7.8726074	4001.088614	19	31854	4001.088614
95	0	Bole	12	29.4695896	29.46959	1141.974699	17/19/20	21623	952.4055274
96	0	Bole	3	5.37362577	5.3736258	6877.89237	03-/05	31757	5223.102838
97	0	Bole	13	2.84082652	2.8408265	6789.806811	10	32262	9879.871166
98	0	Nifassilk Laf	6	3.4720253	3.4720253	10104.54166	01-/09	33529	9104.484338

DECLARATION

I hereby declare that the work which is being presented in this thesis entitled **"ACCESSIBILITY AND SUITABILITY ANALYSIS OF LIGHT RAIL STATION LOCATION BY USING (AHP) AND GIS: CASE STUDY ON EXISTING AND FUTURE EXPANSION OF ADDIS ABABA LRT RESPECTIVELY"** is original work of my own, has not been presented for a degree in any other university; and that all sources of material used for the thesis have been duly acknowledged.

Gomeju Taye Abera	_______________	______________
(Candidate)	Signature	Date

Submitted to: **Addis Ababa University, Addis Ababa Institute of Technology**