ADAMA SCIENCE AND TECHENOLOGY UNIVERSITY

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DEPARTMENT OF GEOMATICS ENGINEERING

GIS Based Road Network Analysis for Locating Fire Stations and Emergency Response Analysis: Case Study in Addis Ababa, Ethiopia

By

YESHANBEL ALEBELE

Advisor

D/R EPHEREM G/MARIAM

Thesis Submitted to the School of Graduate Studies, Adama Science and Technology University in Partial Fulfillment for the degree of Masters of Science in Geodesy and Geomatics Engineering

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Candidate's Declarations

I declare that the work is being presented in the thesis " (GIS) Based Road Network Analysis for Locating Fire Stations and Emergency Response Analysis"; Case of Addis Ababa city in partial fulfillment for the requirement for the award of the degree of masters of science in Geodesy and Geometrics Engineering is reliable record of my own work carried out from June 2014 up to march 2015 under supervision of Dr Epherem G/mariam (PhD) and Mr Daniel Alemayehu (Msc) in the department of Geomatics Engineering Adama University, Ethiopia. This study is original and has not been submitted in any form to Adama University or any other institutions. Moreover, all relevant resources or information used in this thesis has been dully acknowledged.

Name	Signature	Date
Yeshanbele Alebele	…………….	………….

This is to certify that the above statement made by the candidate is correct to the best of our knowledge and believe. This thesis has been submitted to examination with our approval.

Name	Signature	Date
Dr Epherem G/Mariam	………………	……………
Advisor		
Mr Daniel Alemayehu	…………….	………………
Co- Advisor		

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By: Yeshanbele Alebele

Approved By Board of Examiners	Signature	Date
________________________ Chairman, Department (Graduate Committee)	__________	__________
________________________ Advisor	__________	__________
________________________ Co-Advisor	__________	__________
________________________ External Examiner	__________	__________
________________________ Internal Examiner	__________	__________

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At base, this thesis has been focused on finding ways to use geographic information systems at the local government level to the benefit of all citizens. Local government is often the creator and maintainer of the basic data layers that fuel GIS projects everywhere. Everyone seems to want that data because it is generally considered to be the most accurate and up-to-date thing available; In these case my sincere appreciation is extended to the Fire and Emergency Accident Prevention Agency workers and The Land and Immovable Property Registration office of Addis Ababa city for their help in the delivery of the relevant data and information.

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ABSTRACT

The growth of Addis Ababa is treated by fire and emergency accident a number of time per year with the annual average loss of 39,030 540 birr and 43.5 people lost their life annually too (AFEPS, 2014). To reduce this lost the location of fire stations should be determined scientifically and the time needed to reach the accident place should be minimized as match as possible. The research has an objective of selecting additional sites for unmeet demands and improving the time needed by creating a GIS based response system data base. The created data base can be used for locating accidents dynamically and selection of best routes. This study examines a methodology for calculating accessibility value of urban road networks and urban fire station site selection method with a case of Addis Ababa city. The primary research question centers on finding the accessibility value of road networks. Unmeet demand was identified to find optimal site to place a new fire station. Current fire services are accounted for by evaluating the effective service areas of existing stations. The evaluation uses network analysis based on the city's road network and response standard established by the ISO. Unmet need is identified as the address points that lie outside those service areas. Five factor criteria's (accessibility, high risk areas, unmeet demand, dense residential areas and areas subject to interventions) were selected to be analyzed by using AHP method. Simple enumeration with AHP the total demand points covered by potential demand sites are used to calculate the optimal solution. Application of the methodology resulted in road networks with identified accessibility value. After setting the accessibility level of road networks service area is calculated using existing fire stations and the coverage is found to be 46.5 %. After identifying unmeet demands three additional sites have been selected. Calculating service areas using the added new fire stations service coverage can be improved to 87.5 %. Finally a GIS based response system database is developed from which fire station workers and ambulance drivers can use it at the report of the accident.

Key words: - Network analysis, Accessibility value, demand points, AHP, Addis Ababa

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ACRONYMS AND ABBREVIATIONS

AAFEAPA: Addis Ababa Fire and Emergency Accident Prevention Agency

AARA: Addis Ababa Road Authority

AHP: Analytical Hierarchy Process

AS: Accident site

CBD: Central Business District

CI: Consistency Index

CR: Consistency Ratio

EFEAPA: Ethiopian Fire and Emergency Accident Prevention Agency

EMA: Ethiopian Mapping Agency

ESRI: Environmental System Research Institute

FS: Fire Stations

GIS: Geographic Information System

GNFS: Ghana National Fire Service

GPS: Global Position System

GSM: Global System for Mobile Communication

ISO: International Standard Organization

MCA: Multi Criteria Analysis

MCDM: Multi Criteria Decision Making

MCLP: Maximal Coverage Location Problems

NFPA: National Fire Protection of America

RI: Random Inconsistency Index

SCLP: The Set Coverage Location Problems

TAZ: Traffic Analysis Zone

UTM: Universal Transverse Mercator Projection

WATT: Weighted AverageTravel Time

CHAPTER 1: INTRODUCTIAON

1.1 General Introduction

With the ever increasing of urbanization the issue of developing an efficient strategy for urban fire risk mitigation has been considered in numerous scientific and technical works especially in the context of developing countries (Prateille & Brebbia, 2010). Urban fire is one of the most common problems not only for developing countries but also for developed countries (Nuisance, 2010).

In developing countries a very large amount of property and lives are unfortunately lost through fire annually. For instance, in the year 2006, the Ghana National Fire Service (GNFS) recorded one thousand nine hundred and eighty six fire outbreaks that destroyed properties worth thousands of Ghana Cedis (Aziz, 2007). The economic cost to the Nation is great since fire outbreaks tend to exacerbate the poverty level in the country. Emergency response service, especially in the area of fire disasters, is therefore important to save the country from losing scarce resources. This led to the establishment of the GNFS (Gana National Fire Service) in 1963 to control fire outbreaks in the country and, since its inception, GNFS has embarked on programs and activities to educate the public on fire safety and prevention measures while fire stations were established in the major cities. These stations were equipped with modern techniques to preserve lives, property, and natural resources for the sustainable development of the people of Ghana. Even today, in spite of these modern techniques of fire prevention and suppression, fires continue to damage properties especially in the Central Business District (CBD) of Kumasi and effective handling of urban fires within the CBD involves an effective planning response system on a regional scale.

In Ethiopia, Addis Ababa is treated by fire risk a number of times. The central part of Addis Ababa which contains the largest market place in Africa (Mercato) is treated by fire risk number of times per year numbers (Ethiopian Fire and Emergency Accidents Prevention Agency, proclamation number, 23/2009).

Of late attention has been given to the use of GIS network analysis in managing urban emergency services. In (Nisanci, 2010), this author used GIS through effective spatial data storage and query to produce dynamic fire maps. In the study, fire database is created based on

GIS and also carried out an analysis of fire hydrant location. That study has created fire information systems for urban area and highlighted the importance of this information system. This system was then used to determine the optimum distribution of hydrants, location of fire stations, classification of fire regions according to fire type and the creation of region specific early intervention plans. Similarly, (Chevalier et al, 2012) used an integrated GIS approach to locate fire stations in Belgium. The system was designed for an effective management of fire-stations locations and allocations. In their analysis, a multi-scale GIS which includes risk modeling approach was used to determine the optimal location and allocation model taking into account the queuing as well as staffing problems.

According to (ESRI, 2011), there are five reflex time sequence for managing urban fire: (1) Dispatch time, which is the amount of time that it takes to receive and process an emergency call; (2) Turnout time, which is the time from when units acknowledge notification of the emergency to the beginning point of response time; (3) Response time, which is the time that begins when units are in route to the emergency incident and ends (4) Access time, which is the amount of time required for the crew to move from where the apparatus stops to where the emergency exists; and (5) the amount of time required for fire department units to set up, connect hose lines, position ladders, and prepare to extinguish the fire. It is against this background that the research will undertaken to develop a GIS based fire emergency response services for Ethiopian Fire and Emergency Accidents prevention agency (EFEAPA) to help to manage urban fire in the Addis Ababa and to develop a cost analysis model in assisting the EFEAPA to identify the optimal route from its location to any fire incident within the Addis Ababa. Modeling of this will takes into account the distance of travel, time of travel, the locations of the roads and the delays in travel times. EFEAPA can also perform geospatial analysis on fire hydrants location. Spatial analysis on fire emergency response requires street network data, and pre-fire survey information such as floor plans or hydrant location and capacity data (ESRI, 2011). As stated earlier, in this study Addis Ababa was selected as the pilot area for the establishment of a spatial fire database based on GIS and as the basis of sample spatial queries in support of emergency fire response.

This study will use GIS network analysis technique for fire emergency response services for EFEAPA where time plays a crucial role. In establishing fire emergency response database, emergency preparedness planning is an important issue that can impact people lives. If planned properly and implemented quickly, it can save hundreds or thousands of human lives and mitigate some of the economic losses in affected areas. However, if planned poorly or not implement in a timely manner, the consequence can be extremely serious and could cost human lives (Nguyan, 2006).

1.2 Motivation and Problem Statement

In light of the for-going Addis Ababa, the administrative and financial center of Ethiopia is experiencing continuous growth and change. Change is experienced in all dimensions of the city but different parts of the city grow at different rates. Economically the city is transforming from a predominantly administrative and service center into an industrial and financial center. But this growth and transformation is affected by fire risk problems; even though previous research works did not done on this issue for the study area, fire risk problem is treating Addis Ababa city in a number of time per year; Addis Ababa fire and emergency accident prevention agency has reported that an average of 39,030 540 birr has lost and 16,195,840 birr has been protected from serious accident and 43.5 people lost their life annually by accident (AFEAPA, 2014). A fire risk if ones happen damages a lot of goods and services including human life; which leads to a meaningful economic loss in the city. So developing a fast response protocol is a mandatory issue in this case. But the main problem which hinders the fire station workers from giving a fast response is the location of fire stations and the travel time needed to reach at the accident place (An ESRI White Paper, 2007). Both the location of fire stations and the travel time are affected by the transportation network of the city. However the existing transport system is characterized by high accident levels, high traffic congestion, negative environmental impacts, unsafe public transport and low accessibility levels (yetenayete, 2012). Main cause for this problems linked with poor infrastructure including road and public transport network, poor interaction between land use and transport planning, inadequate road infrastructure and low transport network density all these factors increase the travel time from place to place including fire accident time.

The future anticipated goal in mitigating the fire accident is to use dynamic routing services using real time technologies (GPS/GSM) by considering congestion on the roads during peak hours (Pasha, 2010). But in developing countries like Ethiopia the use of GIS and other real time technologies for fire service is not started yet, even if the problem is treating and damaging a lot of resources per year (EFEAPA). From this it can be said that there is a great gap between the futures anticipated goal and the existing condition of the study area. So this study is the first bench mark to achieve the future anticipated goal in the study area. Time is a critical factor in an emergency and the ability of the response unit to provide appropriate and timely response in an emergency will affect the magnitude of adverse impacts. Knowledge of the exact location of emergency response units would enable estimation of response time with respect to areas likely to be affected and would enable an effective deployment of emergency responders. Based on this the objective of this paper is to use GIS based network analysis technique for fire emergency response service where AAFEAPA can identify the optimal route from their location to any fire incident.

1.3 Research Objectives

To study the existing road network in relation to fire stations and to select new fire station site for unmeet demands then to prepare a GIS based response system database which is to be used by Addis Ababa Fire and Emergency Accidents Prevention Agency.

Specific Objectives

- To set the accessibility level of road networks.
- To identify the current coverage (service) areas of fire stations.
- To select new fire stations by considering response time and existing facilities.
- To locate accidents dynamically.
- To find best routes from the nearest fire station to the accident place and to the nearest hospital.

1.4 Research Questions

From the research problems and objectives identified above the following research questions have been formulated.

- Which areas are under the service coverage of existing fire stations?
- Which areas are not will served (unmeet demands) by fire stations?
- Which method is used for selecting new fire stations?
- Which are the proposed new fire stations?
- Is it possible to find accidents on the road network map dynamically?
- Is it possible to find the fastest routes from fire stations to accidents and from accidents to hospitals?

1.5 Significance of the Study

In this study the assessment of road networks on accident response was evaluated, in addition to this suitable route and facilities was recommended in inadequacy cases. The final result of this thesis is also expected to help the fire station and ambulance service workers to improve their service based on generated fire information system. When accident happen the databases and the maps which indicate the shortest paths and the nearby fire station will minimize the time needed to reach the accident place.

1.6 Limitations of the Study

The study has some limitations of which the readers of the study should be noted in recognizing its findings. The congestion level of road networks could be determined accurately at any specific point of time using real time technologies (GPS & GSM). Due to shortage of resources and technical equipments the author is obligated to prepare interview questions for traffic police and other transport officers to know the peak hours of the road congestions. After knowing the peak hours shortest paths will be selected using minor roads during peak hours and using both types of road networks when it is not peak hours.

1.7 Conceptual Frame Work

The mission of the fire service is to protect life, property, and natural resources from fire and other emergencies. With increasing demands, the fire service must utilize the best tools, techniques, and training methods to meet public expectations. Risk management, preparedness, and mitigation have taken on new importance with challenges facing fire departments today. One emerging tool that is helping the fire service optimize emergency services delivery is Geographic Information System (GIS) Technology. Here time is main factor to reduce the level of risk. To reduce the amount of travel time the accessibility level of road networks and location fire stations are the two main determinant factors.

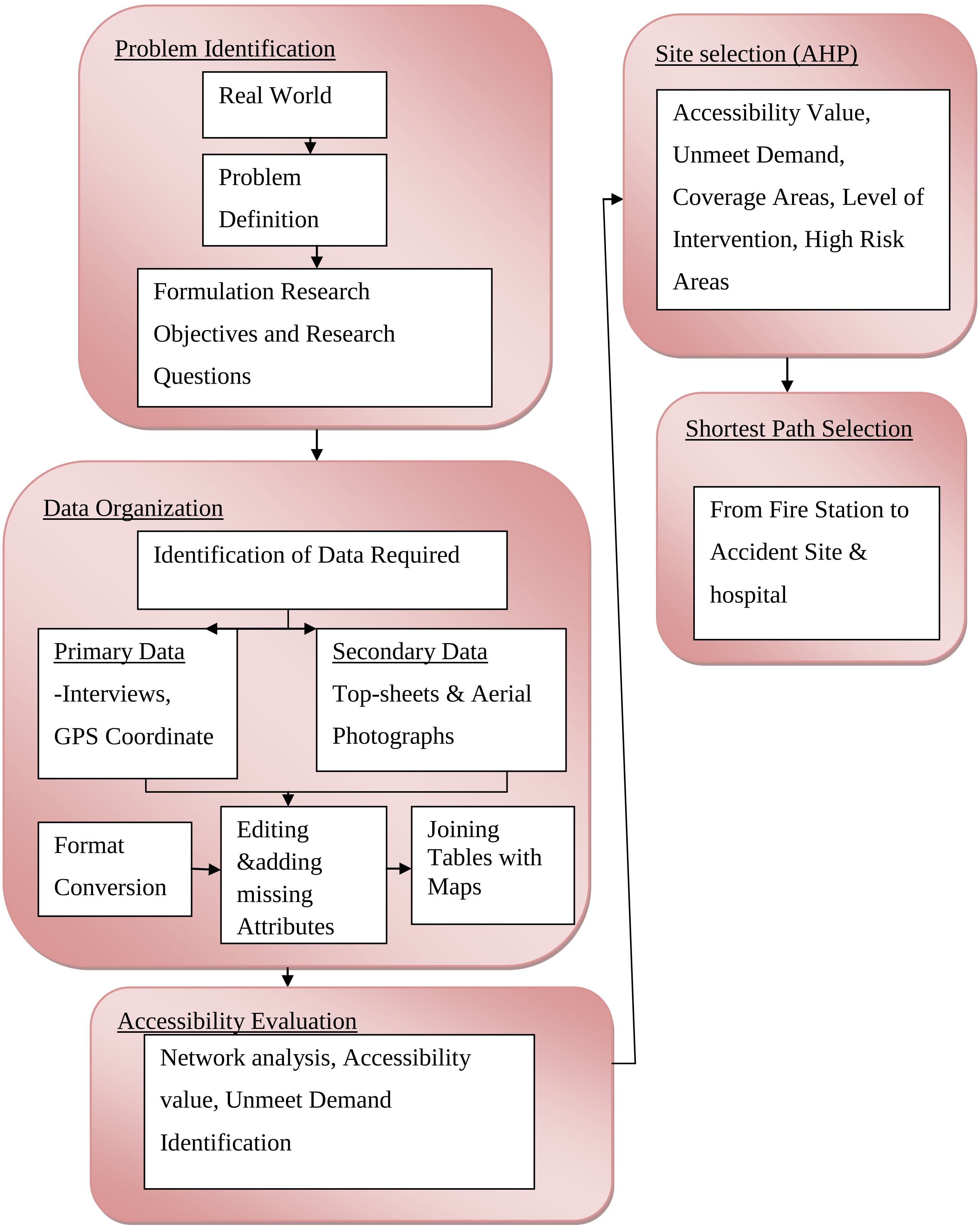

Figure 1.1 the conceptual framework flowchart

1.8 Organization of the research paper

The overall thesis is organized under five chapters as follows; Introduction, Literature review, the study area and Methods, Results and Discussion and Summery, Conclusion and Recommendations.

Chapter 1: Gives a brief introduction of the research, identifies research problems, define research objectives and questions related to the objectives.

Chapter 2: Briefly review literatures on accessibility analysis and different fire station selection methods proposed by other researchers to adopt here.

Chapter 3: Describe the study area based on topography and socio economic characteristics and explains briefly the methods applied to achieve the proposed objectives.

Chapter 4: Discusses the results briefly based on the identified method.

Chapter 5: Provides conclusions and recommendations based on the results of the research.

CHAPTER 2: LITERATURE REVIEW

2.1 Historical Background

Traditional planning methods for fire service have required the use of numerous maps, reports, table and historical record (Johnson, 2011). This documentation has cluttered the desk tops and filing cabinets of many offices. Computers have helped to eliminate the mounds of paper and related costs. Technology transition has accompanied the fire service history. At one time both horse drawn and motorized fire apparatus were housed in the stations next to one another (Coleman, 2010). Fire fighters as first responders have relied on experience, good equipment communication, and a teamwork to achieve successful emergency response (ESRI, 2010). As populations and building development increase, the role of the fire service becomes more demanding and complex (ESRI, 2010). Location and spatial distribution of fire stations are a top priority when evaluating driving times or response times for emergency calls. Historically, testing area coverage was accomplished by sending a fire vehicle equipped with a stop watch to drive an area and mark travel times over the street network (Johnson, 2011). In 2009 it was reported that "up to 20% of local government expenditures are spent on public fire protection" (Mirchandani, 2009). Although the range and complexity of responsibilities for fire service have change, this figure is consistent with current Dallas expenditures. In the Dallas Fire Rescue Activity 2002-2003 annual fire service report, Dallas Fire-Rescue budget was 19.9% of the overall city budget (Dallas, 2009). The fire service of today is a direct result of an evolution in the methodology, technology and responsibility of a service that has been vital to communities since the beginning of civilization (Coleman, 2010). GIS contributes to the speed with which emergency responders are able to locate, respond size up, and deploy to an emergency (ESRI, 2010). Many governments are now sharing geospatial information, reducing the expense and improve the overall quality of geospatial data and information for public- policy making (Baker, 2008). Mutual aid policies between cities enable city fire personal maximize resources. Agreements between municipalities allow fire station personnel and equipment answer alarms in locations outside of the city limits as long as these resources are not being used within the city itself in the event of large scale disasters (Snowden, 2007) Response Time Modeling allows users to identify station location, specify a travel time, and run a network analysis, utilizing a fire station layer and a street layer (ESRI, 2010).

A GIS based application for urban fire emergency response services has been developed to manage urban fire in the Kumasi Metropolis. It focuses on finding a way to quickly locate fire scenes using the residential addresses. Also a cost analysis model in assisting the GNFS to identify the optimal route from their location to any fire incident within the Kumasi Metropolis has been displayed. With this application, it is now possible to identify the optimal route in terms of the distance of travel, time of travel, the slope of the roads and the delays in travel times from a fire station to any fire location. In addition spatial database for fire hydrants was created to perform geospatial analysis for suggesting new locations for fire hydrants and perform a buffer for them in the study area. It is also possible to query the locations of the fire water hydrants and its conditions, whether functioning in high or low pressure or is disconnected from water source. The developed application provides a useful decision support system to determine the optimal route for emergency response and geospatial analysis on fire water hydrants (Fiano, 2013).

As indicated in the above literatures Network analysis is used for identifying the most efficient routes or paths for allocation of services. This involves finding the shortest or least-cost manner in which to visit a location or a set of locations in a network. The "cost" in a network analysis is frequently distance or travel time (Butry et al., 2010). Network analysis can also be used to optimize the allocation of resources by showing the amount of overlap between the service areas of two fire stations. Fire Services was therefore able to optimize their response times by forming a plan based on this information. Even in cases when relocating a distribution center is impractical, such information can prove valuable in forming protocols. In this study the current transportation network structure of central Addis Ababa sub city will be evaluated by using network to analyze the existing pattern of travel and structure of the network for fast response time protocol and station allocation. To do this the location of existing fire and health station will be evaluated by service area analysis then the shortest path will be selected between each service station.

2.2 Risk versus Response Time Standards

Some communities may elect to adopt several response time standards for various levels of risk in the community, or they may adopt one single response time standard for all risks. Here, a risk refers to a location where a response may be made and the characteristics (e.g., fire potential, occupant exposure) at that location. Providing several response/travel times based on the level of risk means that some areas will be reached in a shorter period of time than other areas. A single response time standard for the community or area served will provide approximately the same level of initial response to all areas of the community. Some of the risks that may be considered for various response/travel times as follow:

Sprinklered versus none sprinklred: - The fully sprinklered property theoretically is at less risk than the non sprinklered property. The community may elect to place fire stations closer to the non sprinklered property because of the ability of sprinklers to automatically put water on a fire.

Commercial versus residential: The community must decide, in this case, where the greater risk is located. Is there a greater risk with the commercial property? At what time of day is the risk greater? Is the risk greater in residential occupancies at night?

Multifamily versus single-family residential: Is the risk greater in multifamily residential areas than in single-family residential areas? Fire station location should be influenced by population factors. The risk questions should address:

- High life hazard (i.e., loss potential) or high dollar value
- High incident rate areas versus low incident rate areas
- High rate of incidents that require a high level of resources versus low rate

The community that chooses to provide various levels of service to different areas, based on the level of risk, will require a much more complex fire station location study.

2.2.1 National Standards

In Ethiopia there is no clear national standard for fire risk emergency response and response for medical damage but in other countries there is national standard. In USA there are three National Fire Protection Association (NFPA) standards that contain time requirements that influence the delivery of fire and emergency medical services. These are NFPA 1221, standard for the installation, maintenance, and use of emergency services communications systems; NFPA 1710, standard for the organization and deployment of fire suppression operations, emergency of medical operations, and special operations to the public by career fire departments; and NFPA

1720, standard for the organization and deployment of fire suppression operations, emergency medical operations, and special operations to the public by volunteer fire departments. NFPA 1710 contains time objectives that shall be established by career fire departments as follows:

- Turnout time: One minute (60 seconds) for turnout time.
- Fire response time: Four minutes (240 seconds) or less for the arrival of the first arriving engine company at a fire suppression incident and/or eight minutes (480 seconds) or less for the deployment of a full first alarm assignment at a fire suppression incident.
- First responder or higher emergency medical response time: Four minutes (240 seconds) or less for the arrival of a unit with first responder or higher-level.

So in this study response time of the study area with its constraints will be assessed based on these standards.

2.3 Selection of Service Station Locations

With the advent of modern software and computer technology, the selection of Service station locations can best be determined with a greater degree of accuracy using GIS. Unlike previous methods that employed grid and concentric circle analysis, GIS simulates the real road network of the area being analyzed. A high degree of accuracy is ensured by using actual travel distances, vehicle speeds, time delays for roadway conditions (e.g., congestion, turning radius, weather, and hills), accounting for one-way or unusable roadways, and implementing user-defined risk factors.

A comprehensive GIS-based fire station location study can be the central component for a master plan of fire station locations. This plan can show both the efficiencies and deficiencies of current fire station coverage for a specified travel time and provide a model for future fire station coverage using the specified or other travel time standards.

2.3.1 Location Problems

Selecting fire station sites for maximum efficiency is a type of location problem known as a covering problem. In covering problems, each facility covers demand within a defined proximity, such as the distance standards used in this study. There are many variants of the covering problem depending on the specific objectives. The Set Covering Location Problem (SCLP) involves covering all demand with the minimum number of facilities while the objective of the Maximal Covering Location Problem (MCLP) is to use a limited number of facilities to cover the maximum amount of demand (Marianov & Serra, 2009). Other location problems account for different scenarios, like the Maximum Available Location Problem, which attempts to account for “system congestion” or simultaneous calls to the same station (Ball, 2008).

2.3.2 Location Models

Models to optimize fire station site selection have been frequent research topics. (Toregas et al., 2009) introduced the Set Covering Location Model (SCLM), a solution to the SCLP for the location of emergency facilities such as fire stations. In their model, one set of points represents demand locations and another set represents potential facilities. A maximum distance or time from the station determines how many demand points are covered by each potential facility site, and the optimal solution is determined using linear programming and inequalities (Toregas et al., 2009). According to Ball and Lin, (2009), most fire station sitting studies include some form of the SCLM.

Public facility location in general and fire station location in particular are usually examined as maximal covering problems (Marianov and Serra, 2009). Church and ReVelle, (2009) first defined the MCLP as maximizing coverage (population covered) within a desired service distance *S* by locating a fixed number of facilities. They examined both heuristic algorithms and linear programming similar to the SCLM as potential solutions to the MCLP (Church and ReVelle, 2011). In their models both demand and potential facility sites were represented as sets of points, as they were in studies by Galvao and ReVelle, (2011) and Rosing, (2011). Other researchers proposed models with demand set as continuous throughout a region (Murray et al. 2008) and varying demand with point, line and polygon representation (Murray and Tong 2007).

Of specific interest in this study is the planar version of the MCLP where demand is represented by discrete points but potential facility sites are represented by a continuous plane. Potential facility sites can be identified with circular disks having a radius equal to the effective range of a facility or a radius of *R* and centered on the point of demand (Church, 2009, Meherez and Stulman, 2007). The calculations for placing one facility or many facilities to provide maximum coverage of demand begin the same way. Meherez and Stulman, (2007) proved that given a circle of radius *R* covering *N* points of demand, there must be a circle covering the same points with one of them being on the perimeter of the circle. They extended this to multiple points, stating that if a single facility can cover *N* points, then it can be placed at the point of intersection of the perimeters of two of the circles and still over the same *N* points, thus showing that an optimal solution can be found within the finite set of intersection points. For a single facility, the point or points that maximize demand covered are optimal solutions.

Multiple facilities, a simple iteration can be undertaken through the intersection points starting with the one covering the highest number of demand points and ending either when available facilities run out or when all demand is covered (Meherez and Stulman, 2007). Church, (2007) took that a step further limiting the set of intersection points through the use of a dominance test. His approach began by assuming two intersection points, one covering a set of demand points and second covering the all same points and possibly more and thus being the dominant point. A smaller set of potential sites which still contains the optimal solution can then be calculated by eliminating all dominated points (Church, 2009).

2.4 Service Areas

For studies like this one with existing stations to consider, defining demand begins with an assessment of the effective response area for each of those stations, usually by using time or distance limits. Most researchers chose to create the response area as a straight-line or Euclidean buffer rather than a network buffer because of computation time (Liu et al., 2006) or because the necessary network data was unavailable (Murray and Tong, 2009). In a thorough comparison of the two methods, Euclidean buffers were found to over-estimate service areas (Gutierrez and Garcia-Palomares, 2008). This was especially true in locations with a low density of stations or with sparse road networks, situations common to rural environments. In attempts to address this issue, some researchers have focused on non-circular service areas. For example, Matisziw and Murray, (2009) studied the Planar MCLP with continuous demand and irregular service areas based on road networks.

In this study the existing fire station locations can be examined using SCLM (set coverage location problem) which is by using the maximum distance or time from the existing station determines how many demand points are covered by each potential facility site. Here meet and unmeet demands will be selected by the above standards. Then after identifying the level of demand new stations will be selected using AHP (Analytical Hierarchy Process).

2.5 Building Block Theorems for the AHP

2.5.1 Linear Algebra Review

Definition 1. *An **Eigen vector** of a square matrix A is a vector **v** such that*

$$A \times \mathbf{v} = \lambda \mathbf{v} \quad (1)$$

Definition 2. *An **Eigen value** is the scalar λ associated with an eigenvector **v**.*

Note that if we multiply both sides of equation 1 by a scalar, we get the same eigen value, but a different eigenvector, which is simply a scalar multiple of our original *value*. All scalar multiples of v will have the same eigen value (and so are all in the same eigen space), and so it may be a little ambiguous to determine which eigenvector we are dealing with when we discuss a given Eigen value. With an understanding of eigenvectors and Eigen values, we can now present a few definitions and theorems we will use later in the paper. We present the theorems here without proof, since presenting the proof would do little to help the understanding of the AHP, which is beyond the goal of this paper.

Definition 3. *The **rank** of a matrix is the number of linearly independent columns of that matrix.*

Theorem 1. *[6] A matrix of rank one has exactly one nonzero Eigen value.*

Definition 4. *The **trace** of some matrix A, denoted Tr (A), is the sum of the entries in the Diagonal.*

Theorem 2. *[6] The trace of a matrix is equal to the sum of its Eigen values.*

2.4.2 The Hierarchy

Each decision problem can be broken up into three components, defined here.

Definition 5. *The **goal** of the problem is the overarching objective that drives the decision problem.*

The goal should be specific to the problem at hand, and should be something that can be examined properly by the decision makers. For instance, in the example of hiring a new employee, different departments would have very different goals, which could steer their decision problem to different outcomes. Moreover, the goal should be singular. That is, the decision-makers should not attempt to satisfy multiple goals within one problem (in practice, these multiple goals would be broken into separate criteria, as defined below). An example of a goal with regards to buying a jacket could be determining the jacket that best makes me look like a Hell's Angel", which is specific, singular, and something that can be determined by the decision maker.

Definition 6. *The **alternatives** are the different options that are being weighed in the decision.*

In the example of hiring a new employee, the alternatives would be the group of individuals who Submitted an application.

Definition 7. *The **criteria** of a decision problem are the factors that are used to evaluate alternatives with regard to the goal. Each alternative will be judged based on these criteria, to see how well they meet the goal of the problem.*

2.5.2 The Use of AHP in Research and Publications

There are growing body of literatures that is advancing the use of GIS in conjunction with AHP as multi-participant multi-criteria framework that takes into account multiple views and consensus (Erkut and Moran, 2007).

Kontos et al. (2005) used AHP in conjunction with GIS in order to find suitable sites for land fill for an island in Greece using 10 suitability criteria taking in to account both environmental and social variables and an individual site constraint.

Lee and Chan, (2007) adopt the analytical hierarchy process (AHP) to work out the most suitable design proposal for an area undergoing urban renewal. AHP is a robust multi-criteria decision making (MCDM) method for solving social, governmental and corporate decision problems. Since there is lack of published papers demonstrating systematic and effective way for urban renewal proposal assessment this paper attempts to fill the gap with the help of AHP.

Otha et al., (2007) developed several alternative site plans for a new neurosurgical emergency hospital in Sapparo, japan. Hospitals, population data, routes and the numerical information for the analytic hierarchy process computations were input into geographical information system. They conclude that the integration of GIS and AHP constitutes a powerful tool for analyzing traffic conditions in mid-sized cities and for suggesting city planning to improve prognosis of stroke.

So this study tried to integrate analytical hierarchy process model and index overlay method in GIS to present a model for fire station location planning and to select most appropriate sites.

2.6 Accessibility of Road Networks

Hansen proposed the accessibility concept for the first time, defines it as the transport network in various nodes interaction opportunity (Hansen, 2012). Hereafter, the accessibility widely applied in research and road network plan, construction, and evaluation. In the transportation system, the road network accessibility evaluation has taken as an important problem. But accessibility does not have a unification concept till now. Generally speaking, the accessibility is the weight of a place to another place's simple degree and efficiency. Yang and Zhou thought that the accessibility is a place's convenience degree which arrives from other place. It can be a spatial distance, topological distance, trip distance, travel time or transportation costs (YANG Jiawen, ZHOU Yixing, 2008). The accessibility has both spatial and time features. It displays the convenience degree of a place as a spatial entity; and time is the main impedance factor of accessibility.

In this study evaluation of accessibility is required because it enables to know the amount of impedance between facilities and demand points the network which connects facilities; so as to know the least impedance value route in the network between two facilities.

CHAPTER 3: THE STUDY AREA AND METHODS

3.1 Description of the Study Area

Addis Ababa is the capital city of Ethiopia. Due to its historical, diplomatic and political significance for Africa, it is referred to as "The Political Capital" of Africa. Geographically it is located at the center of the country. It is located in the plateau mountain ranges at a height of 2000 to 5000m above mean sea level. Its topography ranges from rolling to hilly areas with relatively steep gradient and numerous rivers and stream valleys. Addis Ababa city administration extends over 540 sq.kms with10 sub cities and 99 *Keble's* for administrative purpose. As per the master plan from (2004/2006) the administrative units further subdivided into 131 TAZs. The city has experienced spatial spread mostly towards the southern, eastern and south western parts of the main city. The spatial spread is mainly guided by topography and road network development. After the construction of the ring road new settlements' were observed around south eastern parts of the city. In the past decades Bole and *Nefasilk Lafto* have experience a substantial development. But others like *Addis ketema* and *Arada* are very old. Recently the city has experiencing a continuous growth and change. Change is experiencing in all dimensions of the city, but this change is not uniform in all parts of the city. For example in *Arada* and *Addis ketema*, even if they are old there is no an efficient transport system that can handle the existing congestion. Due to this the road networks are not expected to be an efficient in handling the transport system especially at accident times.

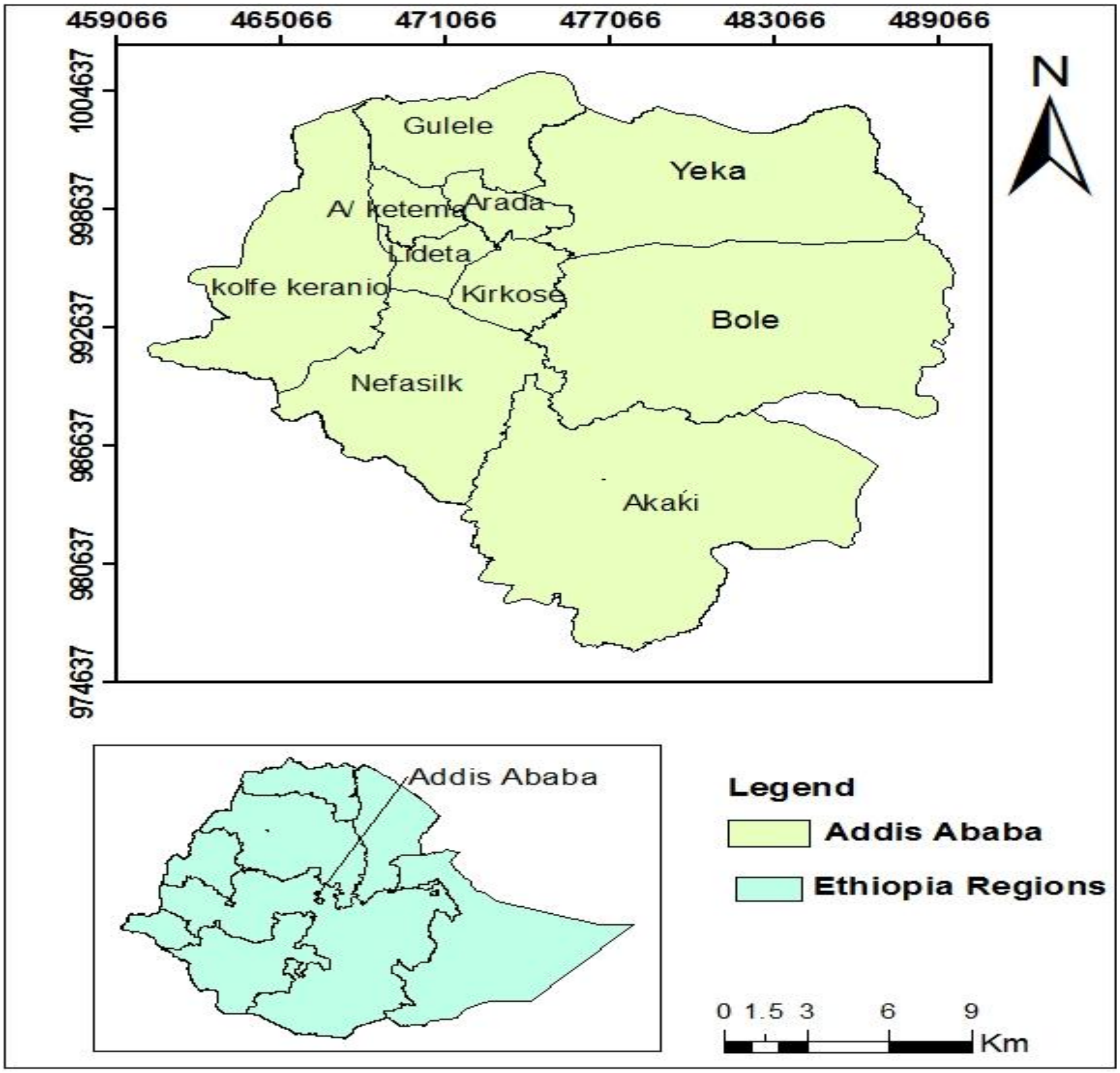

Figure 3.1 Location map of the study area within the national boundary (Source:- Authors manipulation on Ethio-GIS data by using ArcMap version 10.1)

3.1.1 Population and Socio-economic Characteristics

The level of fire risk depends on the socio-economic status and demographic characteristics. Therefore understanding these two factors helped to understand how match the delivery of service is to the standard. Studying the socio-economic and demographic characteristics of the study area also describes the level of congestion of the road; since congestion affect our fast travel to the accident place.

3.1.2 Population

Based on census data in 2007, the population of Addis Ababa was 2.7 million out of the national population 73.7 million. The total administrative area is considered to be urban; therefore this accounts 23 % of the national urban population (inception). The population of the city is compared with the total population of Ethiopia is shown in table 3.1. This data shows that the population has doubled. The last population estimates indicate that the population growth of Addis Ababa is maintained at 2.1%.

Table 3.1 the population of Addis Ababa as compared to Ethiopia

	1984	1994	2007	2010
Addis Ababa	1.4	2.1	2.7	2.9
Ethiopia	39.9	53.1	73.9	77.5

Source Yeteneyet Ayalneh, (2012)

3.1.3 Description of the Road Network and Facilities

The main component of Addis Ababa transport system are, the road network city bus, minibus taxi, private vehicles and large pedestrian. The road network provides the means for travel trough the city. The problem associated with transport in the city, especially lack of proper transport planning and management of traffic are felt to be pressing. According to urban transport study (2004/2006) the availability of road is poor. The share of the roads in land use pattern is low at about 7% where an efficient system requires 20 to 25%, (Yeteneyet Ayalneh, 2012). The road network also suffers from inadequacies like absence of balanced hierarchy, capacity limitations and low connectivity (Ethiopians Roads Authority, 2004/2006).

In the CBD including the study area specifically there is an intense generation of traffic by all modes; links capacity is limited due to destined traffic volumes on street and on street parking. As it is stated by (AARA, 2014) design manual the existing road in the city can be categorized into four; Arterials, Sub-arterials, collectors and local or residential roads. Each road category can be defined as follow:

Arterial roads: - As per the master plan these roads have a varying widths ranging from 30m to 60m. These roads are expected to provide fast movement of traffic due to possibility of physical segregation of local and bus/public vehicle traffic from general traffic stream. The ring road is included in this category.

Sub arterial roads:-These roads are links of lower hierarchy with proposed width of 20m and 25m. The sub arterial roads will operate as single or dual carriage way roads with constrained lane width of 3m, having direct implication the speed and capacity. These roads seem to be of lower width than expected for the nature of traffic operation expected roads of this category.

Collector roads:-these roads are further lower categories in the network hierarchy and are proposed to function as connectors as per the master plan.

Local road: - these are accesses links to residential or business areas.

The methodologies used for road network analysis part has three phases which are data acquisition and integration, road network data set creation and accessibility analysis. After the road network analysis is done site which are accessible and inaccessible are identified then this accessibility value is used in site selection procedures. `After accessible and inaccessible area identified new fire station sites will be selected using AHP method.

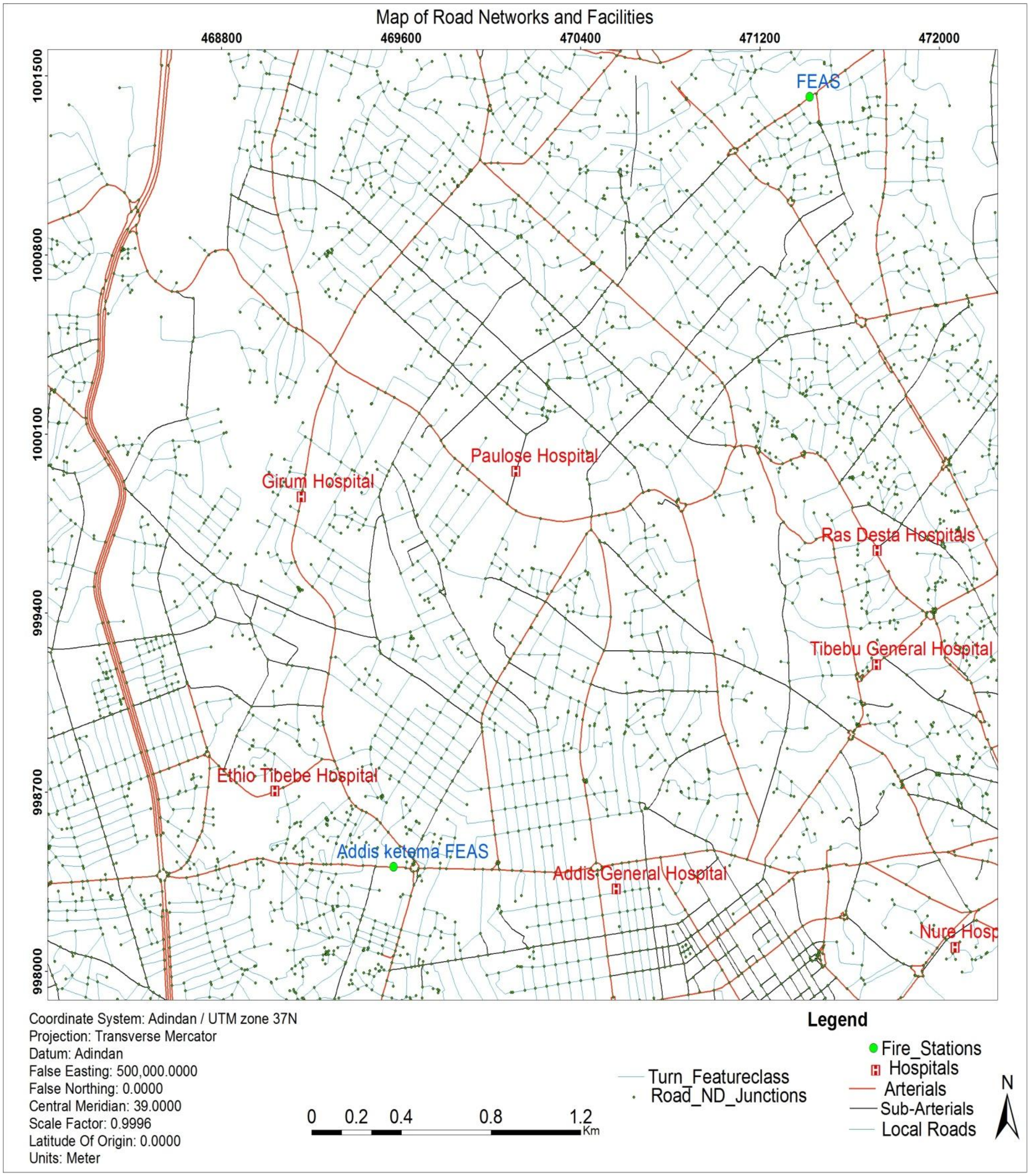

Figure 3.2 Map of road networks and facilities (part of Addis Ababa)

3.2 Data Source and Software

In the previous topics the problems related to fire risk and the accessibility of road network for short emergency response time are identified including literatures that are used to develop the method. GIS is increasingly becoming a useful tool in a network and service location analysis which helps to make sound decisions about certain spatial interactions. The capacity of GIS in handling huge real world data makes it versatile to process and analyze service area problems and shortest path identification. Spatial data was gathered and interviews were made with different government officials and professionals to gather information about the current practice of fire risk mitigation and capacity and accessibility of road networks at the response time.

The manipulation and analysis of data in a geographic information system is not automatically achieved. The users are required to be involved in the specification of the necessary functions and performance levels of the systems (Aronoff, 2010). In this case, most of the layers of the study are digitized and clipped from the georefernced Arial photograph of Addis Ababa city which is prepared by land and immovable property registration office of Addis Ababa. The road networks and top sheets are collected from Ethiopian Mapping Agency (EMA).The software employed here are ArcGis10, Erdas Image 9.2 and Google Earth.

Almost all the maps derived from the raw data were in Shape file vector format. Erdas Imagine 9.2 and ArcGIS 10 are applied throughout the whole process. They are used together and crosswise to derive what the exact data needed. AHP is specifically used for the weight setting of factor criteria.

3.2.1 Methods of Data Sampling

The basic issue in scientific research is how to determine optimum samples for both quantitative surveys and qualitative participants of research process that needs great care to avoid inappropriate samples. As statements of Bartlett et al., (2010), inappropriate and inadequate or excessive sample sizes can influence the quality and accuracy of research output. To escape from this output inaccuracies, it is imperative to select optimum sample sizes that fulfill the requirements of efficiency (Wilkinson & Bhandarkar, 2009), representativeness, reliability and flexibility; and which yield unbiased, efficient and consistent point estimators (Andersonet al., 2008). Using data sampling techniques one or two sub cities will be selected and used to represent the whole city for this study but the fire stations in each sub city has no strict boundary on their demand coverage (no service area boundary). The whole city of Addis Ababa is selected as study area in this case because demand cannot be specified individually for each sub city and each fire station. Using simple random sampling techniques two accident one *kirkose* and the other *addiss ketema* sub city were selected. The selected accident was used to compare the existing response system with the proposed ones.

3.3 Data Acquisition and Integration

3.3.1 Primary Data

The primary data will be collected by visiting relevant offices; governmental and private consulting offices in Addis Ababa. Interviews with government officials and professionals will be conducted to acquire experience on the current practice of accident response and the efficiency of the network for this purpose. The first visit will be made to Ethiopian Road Authority Addis Ababa branch which is responsible organ for planning, design and implementation of the road networks in the city. Interviews will be made for government officials and professionals is conducted to acquire experience on the status of the current road network for fast response time, the criteria used to evaluate the transport network, location of infrastructures with low capacity and area which are suffering from inadequate infrastructure will also interviewed.

3.3.2 Secondary Data

The required secondary data that were used in this study include socio-economic data, demographic data, traffic analysis zone data for each sub city, current road network; master plan road network historical accident rates & respective response time will be collected on each respective government and professional consultancy offices.

3.3.3 Data Preparations

After gathering all the necessary data the first requirement is to prepare the data for analysis. Since the data will be collected from different sources and period, converting them to the same form and analysis period is essential to obtain accurate results in latter stages; this will be done by unifying data, changing data formats, building the road network and obtaining the shape files of service areas, updating the demographic and socio-economic data, joining with maps and adding missing attributes to the road network. In this study since the analysis is going to be done with Arc GIS 10.1 software all the available data in AutoCAD and other formats was converted into ESRI shape file formats and the observed errors in the conversion and collection of the data was corrected and reported.

3.3.4 Accuracy and Reliability of the Data

The quality of data sources for GIS processing is becoming an ever increasing concern among GIS application specialists. With the influx of GIS software on the commercial market and the accelerating application of GIS technology to problem solving and decision making roles, the quality and reliability of GIS products is becoming under closer scrutiny. Much concern has been raised as to the relative error that may be inherent in GIS processing methodologies. While research is ongoing, and no finite standards have yet been adopted in the commercial GIS marketplace, several practical recommendations have been identified which help to locate possible error sources, and define the quality of data. The following review of data quality focuses on three distinct components, data accuracy, quality, and error.

Accuracy

The fundamental issue with respect to data is *accuracy*. Accuracy is the closeness of results of observations to the true values or values accepted as being true. This implies that observations of most spatial phenomena are usually only considered to estimates of the true value. The difference between observed and true (or accepted as being true) values indicates the accuracy of the observations.

Basically two types of accuracy exist. These are positional and attribute accuracy. Positional accuracy is the expected deviance in the geographic location of an object from its true ground position. This is what we commonly think of when the term accuracy is discussed. There are two components to positional accuracy. These are relative and absolute accuracy. Absolute accuracy concerns the accuracy of data elements with respect to a coordinate scheme, e.g. UTM. *Relative* accuracy concerns the positioning of map features relative to one another. Often relative accuracy is of greater concern than absolute accuracy. For example, most GIS users can live with the fact that their survey township coordinates do not coincide exactly with the survey fabric, however, the absence of one or two parcels from a tax map can have immediate and costly consequences.

In this research both relative and absolute accuracy was considered. Every spatial data used in this paper are referenced with uniform Universal Transverse Mercator projection (UTM).Which is the absolute accuracy. In terms of relative accuracy the locations of street, facilities and houses with relative to each other are checked using high resolution area photograph and field observations.

Before acquiring the data that will be used in this research, the data's that are useful, the type of data and availability of data is evaluated before field work did commences. The first phase is dedicated to the data acquisition and integration in what concerns the preparation of the geographical information. The most important information is the one that describes the road network. In this case, as in many others, the original information was structured according to a classification that was not suitable for the project needs. More, the geometrical detail was corrected and prepared the purpose of this study. Fire stations and hospitals were collected using hand held Global Positioning System (GPS) So, the two first steps were the line weeding of the road network and its reclassification and the creation of road network data set by including fire stations and hospitals. The final road network was classified based on Addis Ababa Roads Authority (AARA) speed classification which gives the following structure:

Table 3.2 Addis Ababa road type classification (AARA, 2006)

Road type	Level	Speed limit
The ring road (Arterial)	1	80 kmph
Two sided road (sub arterial)	2	60 kmph
Local road (collectors)	3	50 kmph

The types of data that will be used in this research comprises of two types, i.e. primary data and secondary data (more descriptions is given in the next sections). The data identified is given in the table 3.3 below the following sections focuses on the description of the data used and it's preparation for further analysis.

Table 3.3 type of data collected and their source

Non spatial data	**Available maps and shape files**	**Instruments and materials**	**Data Source**
population data	Land use from top sheets (2012)	GPS ARC GIS 10 Software	Municipalities
	Arial photograph		Municipalities
	Existing road network		Municipalities and private consulting firms
	Location of service area		GPS survey

3.4 Factor Criteria Setting Using (AHP)

AHP, which was proposed by Satty (2009), 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 from the pair-wise comparisons of the relative importance between each two criteria (the sum of the weights equals to 1). Saaty and Vargas (2009) portrayed a scare for the pair-wise comparisons, where the judgments are represented by a degree of importance (table 3.4). The reciprocals of the numbers are adopted to represent the inverse relationship (Mohammad et al., 2009).

The five stage AHP process proposed by professor saaty (2009) is summarized as follow

1. Define the problem and determine the objective
2. Development of the hierarchy from top (the objective from general viewpoint) through the intermediate levels (attributes and sub attributes on which subsequent levels depends) to the lowest level (the list of alternatives).
3. Employ simple pair-wise comparison matrices for each of the lower levels.
4. Under take consistency test
5. Estimate the relative weight of the components

In the first stage the decision makers need to break down the complex multiple criteria decision problems into its component parts of which every possible attributes are arranged into its component parts of which every possible attributes are arranged in to multiple hierarchical levels. The criteria and sub criteria are not each equally important to the decision at each level of hierarchy and each alternative rates differently on each criteria.

One note that two elements being compared at given time greatly reduces the conceptual complexity of analysis. This simplification involves an assumption that satty, (2009), and others (Mularidhar et al., 2011; Prtovi, 2011) considered reasonable. Given a pair-wise comparison, the analysis involves three tasks (1) developing a comparison matrix at each level of the hierarchy starting from the second level and working down. (2) Computing the relative weights for each element of the hierarchy and (3) estimating the relative consistency ratio to check the consistency of the judgment.

The 9 point scale used in typical analytical hierarchy studies is ranging from 1 (indifference or equal importance) to 9 (extreme importance). This pair-wise comparison enabled the decision maker to evaluate the contribution of each factor to the objective independently, thereby simplifying the decision making process.

Table 3.4 scale for pair-wise comparisons (Saaty & Vargas, 2007)

Intensity of importance	Description
1	Equal importance
3	Moderate importance
5	Strong or essential importance
7	Very strong or demonstrated importance
9	Extreme importance
2,4,6,8	Intermediate values
Reciprocals	Values for inverse comparison

Elements in each level are compared in pair wise with respect to their importance to an element in the next higher level. Starting at the top of the hierarchy and working down, the pair-wise comparisons at a given level can be reduced to a number of square matrices $A=[a_{ij}]_{nxn}$ as in the following.

$$\begin{pmatrix} a_{11} & a_{12} \ldots\ldots a_{1n} \\ a_{21} & a_{22} \ldots\ldots a_{2n} \\ \ldots\ldots & \ldots\ldots \\ a_{1n} & a_{2n} \ldots\ldots a_{nn} \end{pmatrix}$$

The matrices have reciprocal properties, which are;

$$a_{ji} = \frac{1}{aij}$$

After all pair-wise comparison matrices are formed, the vector of weights, [w_1, w_2………w_n] is computed on the basis of satty's (2009) eigen vector procedure. The computations of the weights involve two steps. First the pair-wise comparison matrix is normalized by equation one (1) and weights are computed by equation two (2).

$$a_{ij} = \frac{aij}{\sum_{i=1}^{n} aij} \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (1) \quad \text{For all } j = 1, 2\ldots n$$

$$Wi = \frac{\sum_{j=1}^{n} aij}{n} \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (2) \quad \text{For all } I = 1, 2\ldots\ldots n$$

Satty (2009) showed that there is a relationship between the vector weights, W and the pair-wise comparison matrix, A, as shown in the flowing equation.

$$AW = (\lambda_{max})\, W \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (3)$$

The λ_{max} is an important validating parameter in AHP and is used as a reference index to screen information by calculating consistency ratio (CR) of the estimated vector. To calculate the CR, the consistency index (CI) for each matrix of order n can be obtained by the following equation.

$$CI = \frac{\lambda max - n}{n-1} \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (4)$$

Then CR can be calculated using equation 5.

Table 3.5 Random inconsistency indices (RI) for n=10

N	1	2	3	4	5	6	7	8	9	10
RI	0	0	0.58	0.9	1.12	1.24	1.31	1.41	1.46	1.49

Source Satty (1980)

$$CR = \frac{CI}{RI} \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (5)$$

Where, RI is the random consistency index obtained from a randomly processed pair-wise comparison matrix. Table 3.5 shows the values of the RI from matrices of order 1 to 10 as suggested by satty (2009). Pof Satty (2009) has proved the formula R.I = $\frac{1.98\,(N-2)}{N}$ using five hundred samples and he also indicates if CR< 0.1, then the comparisons are acceptable. If, however, CR >= 0.1, then the values of the ratio are indicative of inconsistence judgments. In such cases, one should reconsider and revise the original values in the pair-wise comparison matrices A.

The AHP was adopted in education, engineering, government, industry, management, and manufacturing, personal political, social and sports (Viadya and Kumar, 2006). The wide applicability is due to its simplicity ease of use and great flexibility. It can be integrated with other techniques, for instance, mathematical programming in order to consider not only the quantitative and qualitative factors but also some real world resource limitations. This method integrated with index overlay method.

3.5 Factor Criteria's

3.5.1 Accessibility

Accessibility is weight of a place to another place's simple degree and efficiency (Hu Weiping & Wu Chi, 2012). So this accessibility concept has great importance for fire risk mitigation purpose since to reduce the risk of fire accident the fire risk workers has to reach the accident place as fast as possible.

Some of the important regulations (considerations) are as follows.

1. Fire stations must have direct and quick access to arterials and sub arterials road to avoid any traffic congestion.
2. To have a better response the stations should not sited in one sided or parallel routes, as lack of connectivity in local and one sided streets decrease the access of the stations.
3. The station should not locate in the corner or adjacent to the crossroads which are subject to traffic congestions. To calculate the accessibility of road networks first there should be integrated road network data which is to be used for network dataset creation.

3.5.1.1 Network Data Model and Accessibility of Road Networks

After the data collection the real networks will be built in Arc GIS; generally the following activities was done while building the network data set:

Those road networks in AutoCAD and other formats was converted to ESRI shape file format; next step is define the network topology and cleaning the data; after this building the network dataset and later building a Geo-database by including the shape files of the service areas.

The routing solvers within Network Analyst:-Namely, the Route solver, Closest Facility, and OD Cost Matrix solvers are based on the well-known Dijkstra's algorithm for finding shortest paths. Each of these three solvers implements two types of path-finding algorithms. The first type is the exact shortest path, and the second is a hierarchical path solver for faster performance. The classic Dijkstra's algorithm solves a shortest-path problem on an undirected, nonnegative weighted graph. To use it within the context of real-world transportation data, this algorithm is modified to respect user settings such as one-way restrictions, turn restrictions, junction impedances, barriers, and side-of-street constraints while minimizing a user-specified cost attribute. The performance of Dijkstra's algorithm is further improved by using better data structures such as d-heaps. In addition, the algorithm needs to be able to model the locations anywhere along an edge, not just on junctions.

The key issue in accessibility measurement is the definition of the cost. This cost can be created reporting to many different cost units (distance, time, currency, or any other unit) and by many different methods, and it establishes the impedance for crossing each unit distance. In this case we have used travel time measured in minutes as unit and road category as main classifier without any territorial barrier.

The first step is to establish the average speed according to the road category and then to calculate the unit distance crossing time by using the following equation as discussed by (Rui Pedro Juliao, 2010). The average speed is taken from Addis Ababa Roads Authority speed classification as indicated in table 3.2; then using this speed unit distance travel time is calculated.

$$UDT=\frac{Dx60}{TSx1000}$$

Where:

UDT - Unit distance crossing time (minutes)

D - Unit distance (in meter)

TS - Travelling speed (Km/h)

To properly model time-based travel, a slope correction factor for steep streets was developed. The slope adjustment, together with global turn rules, was applied to post speed limits to calculate valid travel times and define optimal response areas. It takes twice as long to climb or descend a 10 percent slope as it does to travel on flat street segments (Hu Weiping & Wu Chi, 2012). Slope adjusting factor = 1+ $[\frac{slope}{10}]^2$.

From the roads topography; roads can be classified as flat or horizontal slop with zero elevation difference between nodes, steep or up slopes and down slopes. For the same length of road the time taken to move in the up slope and down slope is different from the horizontal plane with zero percent slopes. Here time adjustment is required to add additional time for steep slope by using formula 1+$[\frac{slope}{10}]^2$. Slope adjusted UDT = UDT * slope adjusting factor.

Second Weighted Travel Time (WTT). The weight represents the importance of a link in the road network; it can be calculated by population density or economical indexes. The WTT value is mainly related to the link's position in the road network. The link in the central region usually has a smaller value because of congestion (Hu Weiping, Wu Chi, 2012). The model expression is WTT = slope adjusted UDT X Weight value. Locations of roads can be classified in to three 1.Those roads who found in the central region, 2. Roads who found between the periphery of the city and the central region 3.those roads who found in the periphery. These roads had been given the weight value of 1, 2, and 3 respectively.

Third Accessibility Index, It is a normalized index for the shortest travel time and the weighted travel time. The formula is: Ai = weighted travel time / mean value of weighted average travel time. The mean value of weighted average travel time can be calculated by summing the weighted average travel time and then divide it by total number of links.

3.5.2 Unmeet Demands (Nearby Stations)

3.5.2.1 Bases to Identify Unmeet Demands

Site selection plays a vital role for both social and economic activities, from the habitat choice of our human ancient ancestors to all kinds of present commercial site selection. Everybody knows that inappropriate site selection leads to heavy losses, but may not very sure what is the exact importance. Take the business operations as an example, site selection is the first key factor and directly related to the customer groups, capital investment and recovery development strategy. Therefore, making good preparations and analysis on the parameters of the site selection is absolutely necessary. In the early stage, site selection was usually mixed up with large amount of statistics, written narrative, questionnaires as well as some simple geographic methods. Probably the typical geographic approach was using Tieseen polygon. Voronoi diagram is a process to decompose a specific given space in the basis of distances and objects. These objects are usually called sites. The principle of this diagram is to produce regions whose boundaries define the area in which the distance of any location to the given site is not greater than the distance to other sites (Reem, 2009). It is well-known in computer science and employed in all kinds of fields, such as natural science or even art. In geographic category, the famous climatologist Thiessen, (2008) introduced the diagram initially. He evaluated the average precipitation cover grand areas through allocating proximity polygons to sites. The aim of this study is to select a new hospital site in Haidian District using GIS-based MCA. To throw out a minnow to catch a whale, it will be interesting that if the Teiseen polygon is firstly adopted here to further explain the site selection in a conventional way.

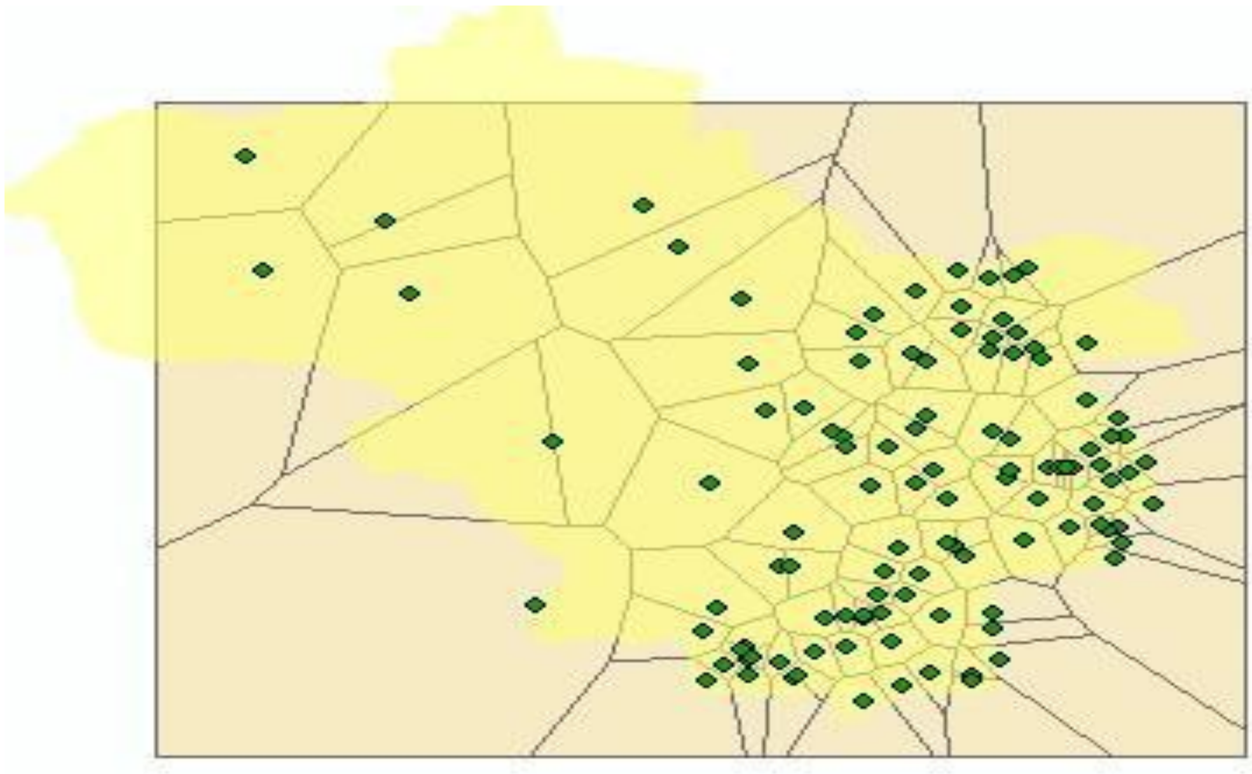

Figure 3.3 Thiessen polygons created by hospital points (Source; Lina Zhou et al, 2012)

Every point (hospital) has their domain area. People who live inside one of the area probably prefer going to the only point (hospital) to see the doctor, People who live in the boundaries can choose one of the two hospitals freely, since the distance is same. Whereas, the purpose here is to build a new fire station in order to balance and improve the response time to each candidate accident place. It is not appropriate just to consider Thiessen polygon in simple sense, therefore a deeper method of Thiessen polygon which is largest empty circle is taken into account here. It is an issue to find the largest radius circle whose interior does not overlap with any barrier (Shamos & Hoey, 2009).The definition indicates that the center of the circle could either be any vertex of the polygon or the junction of a polygon edge. For this case, the center must be inside for both the study area and Euclidean plane.

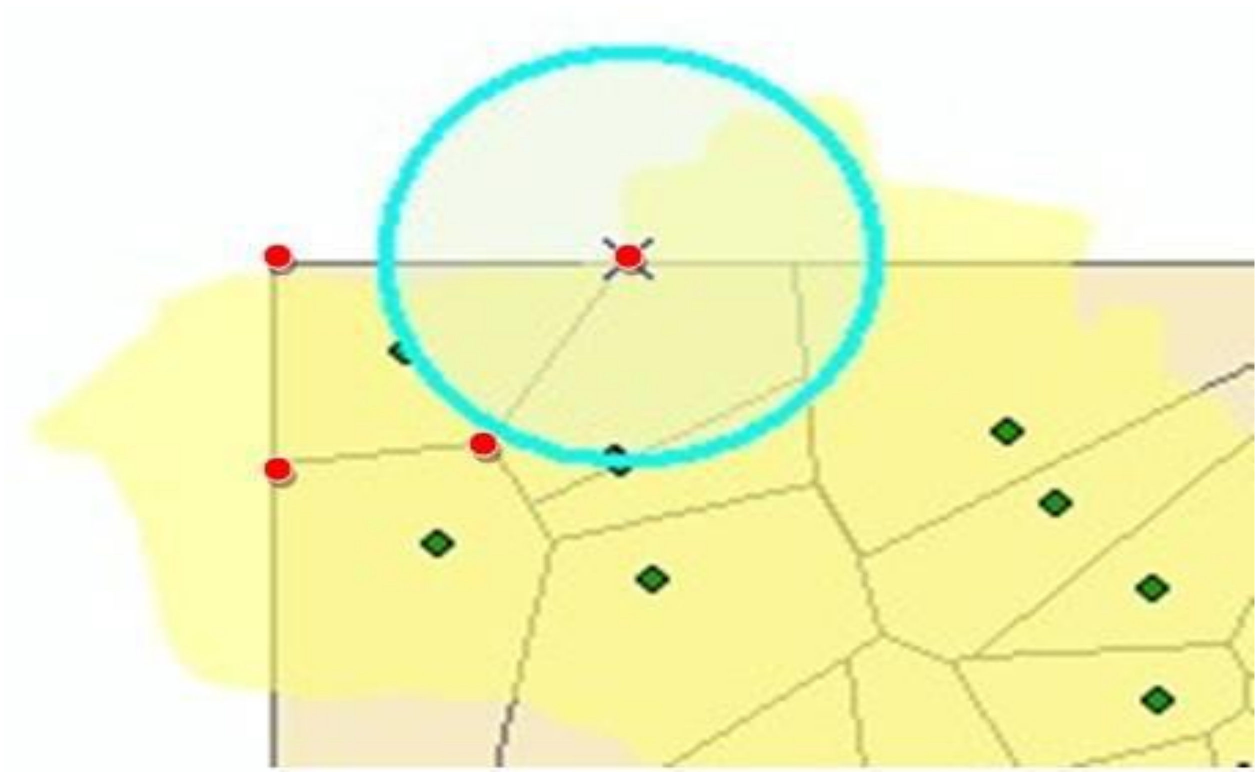

Figure 3.4 Largest empty circles in the Thiessen polygons (Source; Lina Zhou et al, 2012)

Taking the left four junctions (colored by red) as an example, the center of the 9 circle is the intersection of the boundary of the polygon and the edge of the Euclidean plane. There is a problem with the distribution of these junctions. Obviously, there are a large number of junctions in the case, but there isn't a specific standard to distribute them in a fair way. In general, the method of largest empty circle is an efficient and conventional way to build a new site as far as possible from existing ones. Nevertheless, except existing hospitals, other point layers such as residential areas and fire stations will also be included in this study. If it considers all possible point layers, according to Reem (2010), a small change takes place in the shape or the location of the sites could give rise to the change of corresponding Thiessen cells. Thereby, it is very difficult to find the circles with the cells' change. Even though the circles can be found luckily, there are poly line layers (road) and polygon layers should be taken into account for this study as well, Thiessen polygon is a method based on points, when dealing with the multi-criteria, the drawbacks will follow close to another. Know Thiessen polygon method has been installed on GIS technology. Based on this foundation idea unmeet demand in this study was identified by considering existing fire stations as central point for calculating service polygon; areas out of this polygon are assumed to be unmeet demand.

3.5.3 Coverage Areas of Existing Fire Stations

Utilizing a fire station layer and a street layer, response time analysis can be performed. A street layer is often represented in GIS as a series of lines that intersect on the map, creating a GIS street network. Each street line segment between intersections contains attribute information such as road type, distance, and travel speeds (miles or kilometers per hour). This allows users to identify a station location, specify a travel time, and run a network analysis. The result was displayed by an irregular polygon around the station that illustrates where the fire apparatus could travel in any direction for the specified time. This analysis is performed on a single station or simultaneously on all stations to analyze gaps in coverage (unmet demand), establish run orders, and more.

In summery some of the regulations (considerations) of existing stations include.

1. It is necessary to study the coverage limits of the existing stations and their potential to response in the area. Then by acknowledging these services the new stations should be planned.
2. After receipt of a call for assistance, the fire department will respond with a unit to that location, within four minutes, to 90 percent of area served as it is stated in the literature sourced from NFPA standards.

3.5.4 High Risk Areas

Some of the land uses are more hazardous and impose huge loose of life and financial resources and have a quick flashover. For example gas stations, hospitals, urban amenities and market places are some expected high risk areas. So this area was digitized and identified using high resolution aerial photograph and field observations.

3.5.5 High Density Residential Areas

The dense residential area is to represent the resident population, so that the nearer to the residential area, the better. Here are two reasons for taking the residential data to replace the population data. First, the latest detailed population data at *kebele* and sub *kebele* level is not available. Second, the population data need to be converted to geo-referenced thematic map, if not detailed enough, the map will tend to show an average population level in a comparatively large area. Thus it will lead to a less precise result. On the other way around, the location and density of the residential areas can compensate these temporary drawbacks to some degree.

3.5.6 Level of Interventions

Sites with higher potential of interventions are not good for positioning new fire stations since it is difficult to know what kind of land use will happen on the candidate site. Sites which are subject to interventions are digitized and identified. Old and shanty houses buildings and vacant areas are sensitive to change and interventions.

3.6 Locating Accidents and Best Route Selection

In this paper the accessibility of road networks is evaluated and calculated; accessible and inaccessible roads are identified. After the calculation of accessibility value the service areas of existing fire stations is evaluated using accessible road networks; here areas which are not well served (unmeet demand areas) are identified. Then by using AHP method the new sites are selected by considering unmeet demands, accessibility value and other factor criteria's (dense residential areas, high risk areas and areas out of interventions). After selection of the a new site; areas which are parts of the city are assumed to be equally serviced but to reduce the travelling time from fire station to accident site and to nearest hospital shortest and effective paths should be selected using computerized system rather than simple judgments of the ambulance driver; to do this the existing land marks are used for finding accident site on a map using geo-coding searching tools.

3.6.1 Best Route Selection

The classic Dijkstra's algorithm solves the single-source, shortest-path problem on a weighted graph. To find a shortest path from starting location S to destination location D, Dijkstra's algorithm maintains a set of junctions, S whose final shortest path from S has already been computed. The algorithm repeatedly finds a junction in the set of junctions that has the minimum shortest-path estimate, adds it to the set of junctions S**,** and updates the shortest-path estimates of all neighbors of this junction that are not in S**.** The algorithm continues until the destination junction is added to S**.**

The flow of information used in finding the accident location, and fastest route from nearest fire station to accident, and fastest route from accident to nearest Hospital. The condition applies when the accident occurs during peak hours such as fastest routing on both the major and minor roads. If it is peak hours fastest paths will be selected using both major and minor roads since at peak hour's major roads will be congested and using minor roads with small traveling speed is beneficial; but if it is not peak hours only major roads will be used for fastest path selection. Best route selection procedures are described in the figure below.

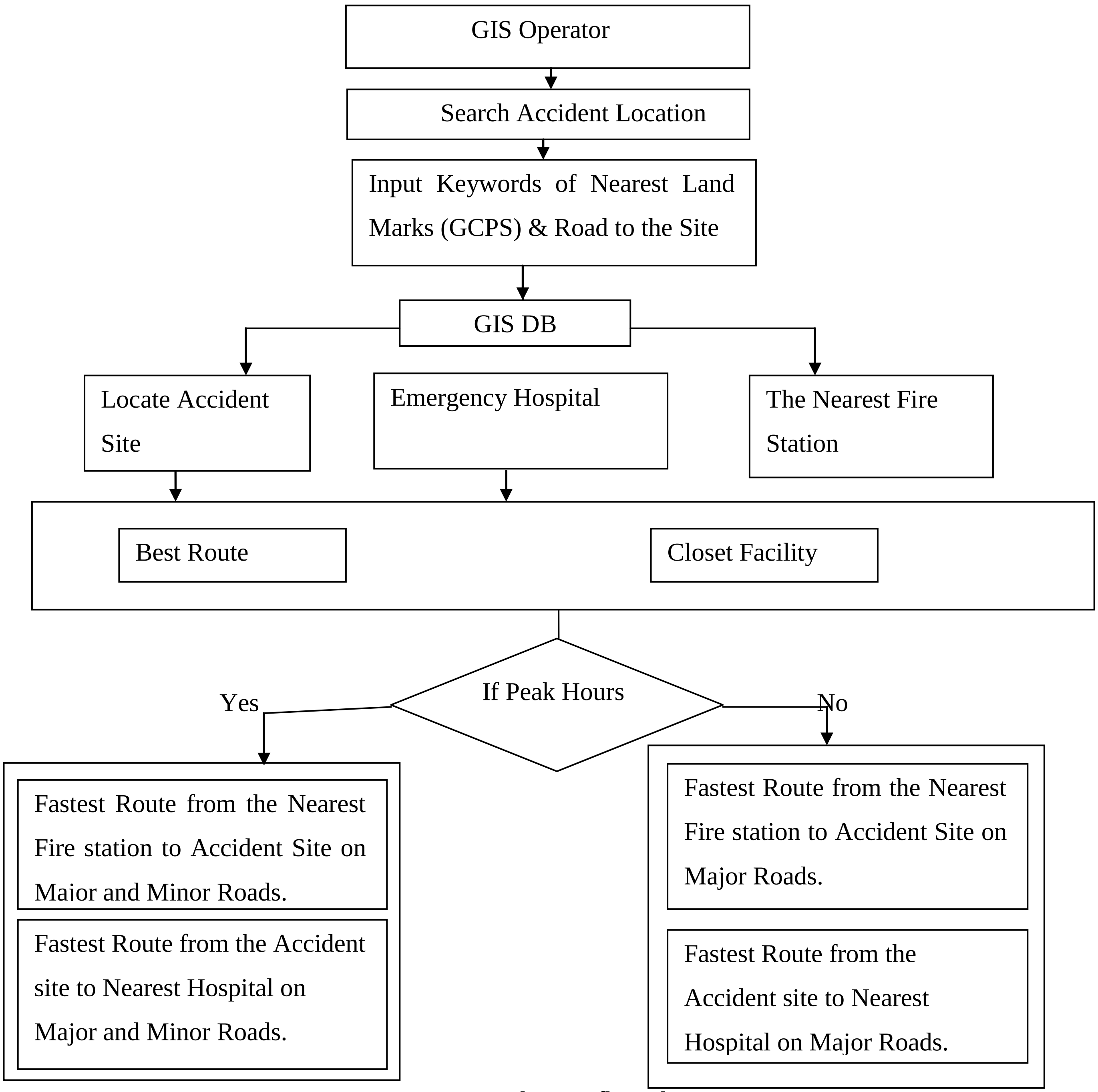

Figure 3.5 Best route selection flow chart

3.5 Summary of the Method

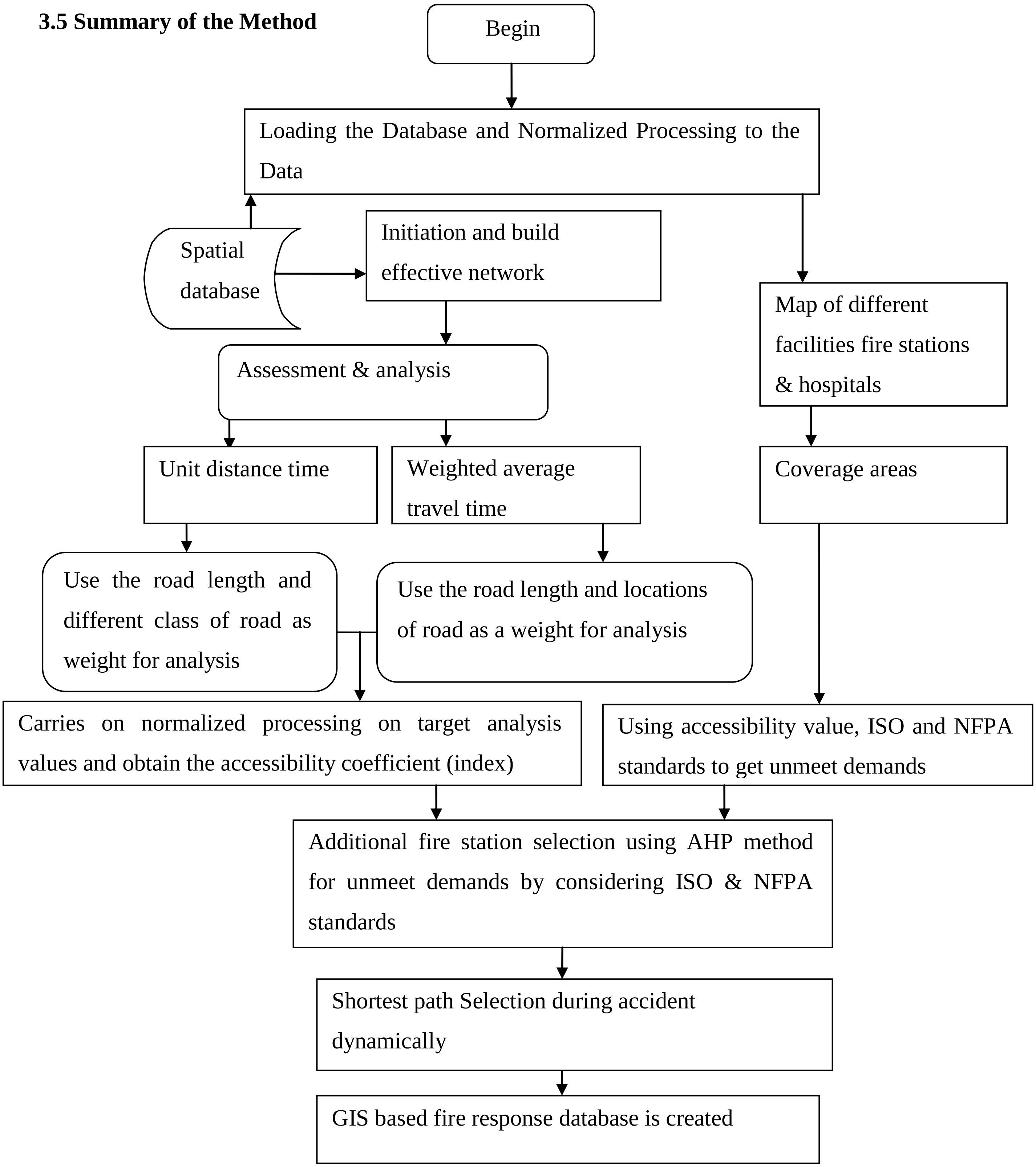

Figure 3.6 Summery of the method

CHAPTER 4: DATA ANALYSIS, RESULTS AND DISCUSSIONS

4.1 Data Analysis and Result

4.1.1 Accessibility Values of Road Networks

Calculating accessibility value of road networks is to know appropriate travel time which if we use this time fire risk can be manageable; so us to classify road networks based on this manageable time. Since the main objective is to minimize travel time by identifying road network links which are easy to cross to the next link with the most possible shortest time. First the unit distance crossing time is calculated using formula UDT=$\frac{Dx60}{TSx1000}$, now each link has UDT value. After calculating UDT for each link the slope adjustment factor is calculated by 1+ $[\frac{slope}{10}]^2$.

Slope Adjustment result: - In the Streets - Slope table, calculate slope adjustment factor by Inputting the following equation. 1 + ([Slope1]/10) ^2 Slope_Adj1 is a multiplication factor that increases travel time for steep slopes. Table 4.1 shows the empirical slope factors in 1 percent intervals. Notice that it takes twice as long to climb or descend a 10 percent slope as it does to travel on flat street segments. Now, calculate the slope-adjusted travel time in minutes by [Minutes_R] * [Slope_Adj1] = Slope adjusted UDT.

Table 4.1: Travel time multiplier for 1% slope interval

Slope (in percent)	Travel Time Multiplier	Comments
0	1	Base time
1	1.01	
2	1.04	
3	1.09	
4	1.16	
5	1.25	1.25 as long
6	1.36	
7	1.49	
8	1.64	
9	1.81	
10	2	Twice as long
Etc		

Next to this weighted travel time has been calculated for each link. Then the accessibility index is calculated by $\frac{Weighted\ travel\ time\ for\ each\ link}{The\ mean\ value\ of\ weighted\ average\ travel\ time}$.

The mean value of weighted average travel time = $\frac{\sum Weighted\ travel\ time}{Total\ number\ of\ links}$; the total number of links in the road network dataset is 36585 and by summing the value of each link WTT value total WTT becomes 10024.29. Then the mean value weighted average travel time become $\frac{10024.29}{36585}$ = 0.274. The accessibility value of each link has been calculated by dividing each link weighted travel time to 0.274. Depending on the size of the room, contents of the room, and available oxygen, flashover can occur in less than 2 or more than 10 minutes. Flashover occurs most frequently between 4 and 10 minutes. The accessibility of roads is the concern of minimizing travel time (5 minutes); it did not concern other times like detection of fire, report of fire, dispatch turn out and setup time because these time depends on the existing personnel rather than the accessibility of the roads. To say roads accessible and inaccessible five minutes is used as reference; because if we use this time fire is manageable and the risk can be reduced Other times like detection of fire, report of fire, dispatch turn out and setup time can be achieved and reduced by developing GIS response protocols like geo-coding and other accident finding methods on the map.

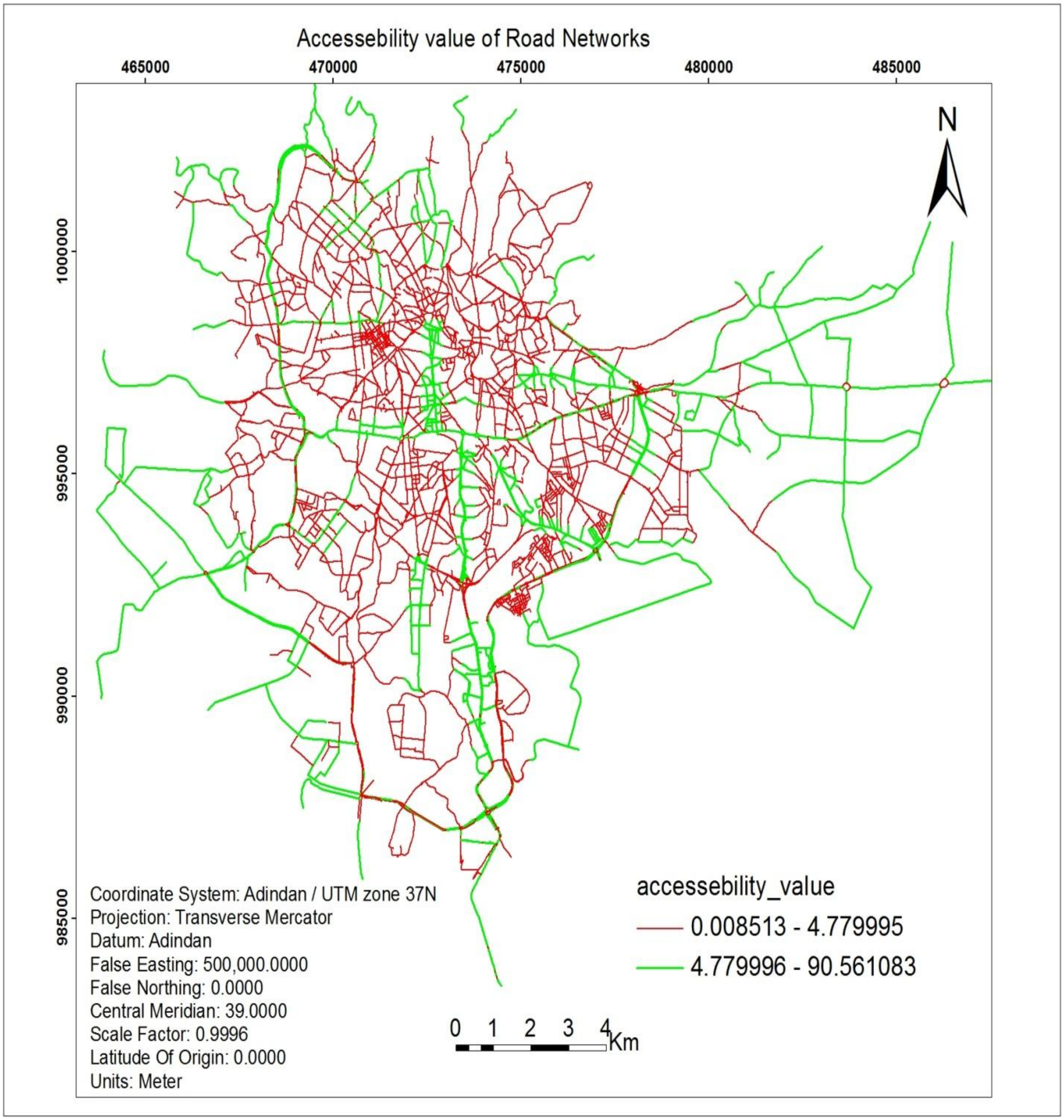

Figure 4.1 Accessibility values of road networks

Based on the calculated accessibility results 43.5 percent of road networks founds to be accessible (accessibility value>= five minutes) for locating new fire stations while the remaining

56.5 percent (accessible value <= five minutes) are not preferred for locating new fire stations. Here the accessibility concept is used interims roads prefer ability for the travel of fire trucks and ambulances and to locate new fire stations. Time is the critical element when an emergency is reported. Fire growth can expand at a rate of many times its volume per minute. Time is the critical factor for the rescue of occupants and the application of extinguishing agents to minimize loss. Based on this; time has been classified as following graph for each sequence of events by using time intervals needed for each activities after accident has been reported.

Regardless of the speed of growth or length of burn time, all fires go through the same stages of growth. One particular stage emerges as very significant because it marks a critical change in conditions and it is called flashover. Measuring the time to flashover is a function of time and temperature. Fire growth occurs exponentially; that is, fire doubles itself every second of free burn that is allowed (NFPA, 1221). This can be plotted on what is known as the time and temperature graph by using NFPA 1221.

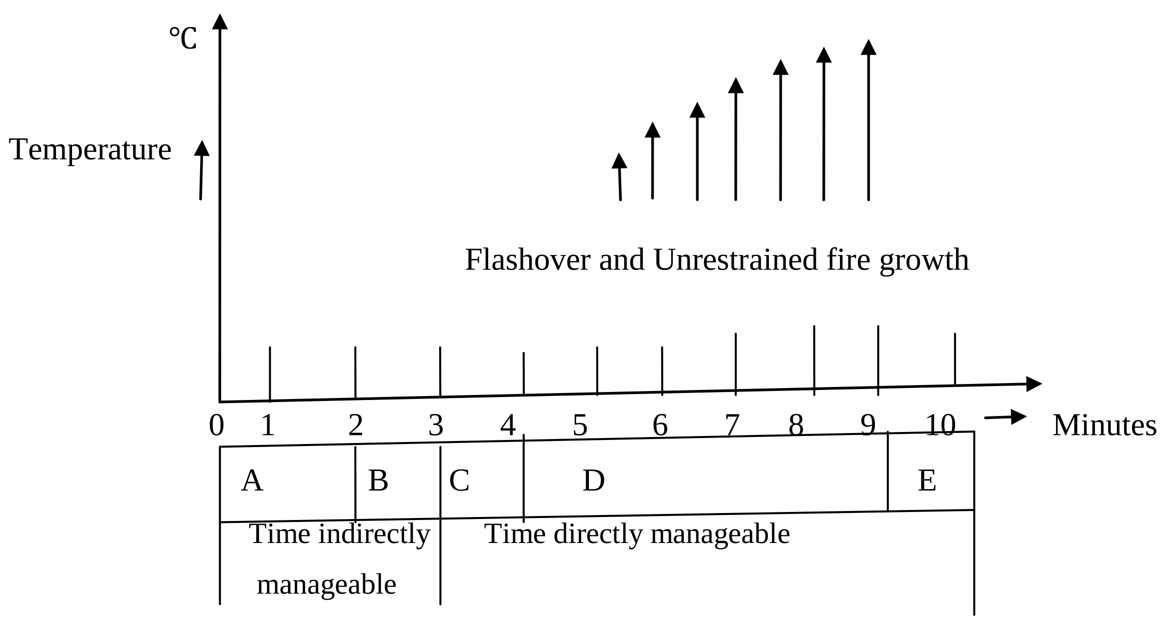

Figure 4.2 the growth of flashover over time and temperature

Keys for the above figure A = Detection of fire B = Report of fire D = Travel time C= Dispatch turn out time E= Set up time

The higher the accessibility values the better because higher accessibility value indicates the following factors.

1. Higher accessibility value indicates it is ring roads or high way because they have higher speed to reach the accident place.

2. It indicates it is not cross road, local roads and cross roads at the central region because low value is given for these areas when weighting.

Based on this the accessibility value of road networks is calculated and mapped as shown in the following map and it is used for computing the service areas of fire stations. The service area of fire stations should be computed after evaluating the accessibility value of road networks; because the service area should be computed using accessible roads with accessibility >= 5 minutes. Otherwise if inaccessible and local roads are used for computing service areas it will not show the true service area of each fire station. Roads who found in the central region are less accessible with accessibility value of <= 4.78 while high way roads, ring roads and those roads in the periphery of the city found more accessible with accessibility value of >= 5. These results indicate the new fire station should be located on the accessible region which is near to high ways and ring roads. After calculating the accessibility of each links; then roads who have accessibility value of >= 5 minutes are selected. Fire stations have to be located beside the Arterial or sub Arterial roads (<= 500 m) for best reflex time Habibi (2008). Multiple ring buffer is created for those accessible roads because fire stations should be located near to high way (<=500m) and accessible roads. The buffer created is to the inside buffer which means the distance from the center line of the road to the outside until 500 meter.

4.1.2 Unmeet Demands (Fire Station Service Areas)

Utilizing a fire station layer and a street layer, response time analysis can be performed. A street layer is often represented in GIS as a series of lines that intersect on the map, creating a GIS street network. Each street line segment between intersections contains attribute information such as road type, distance, and travel speeds (miles or kilometers per hour). This allows users to identify a station location, specify a travel time, and run a network analysis. The result is displayed by an irregular polygon around the station that illustrates where the fire apparatus could travel in any direction for the specified time. This type of analysis is performed on a single station particularly and simultaneously on all stations to analyze gaps in coverage, establish run orders, and more. To get unmeet demands the NFPA standards can be used. The NFPA standard says 99 percent of alarms shall be answered in 40 seconds, and the dispatch of the emergency response agency shall be completed within 60 seconds to 95 percent of the time.

As it is explained in figure 4.2 dispatch times is the amount of time that it takes to receive and process an emergency call this includes the reporting of fire accident and the dispatch turn out time and the whole process should not take more than 2 minute. Response time on the other hand is the time from when units acknowledge notification of the emergency to the starting point of giving response on the accident site. The whole process should not take more than 8 minutes.

Five minutes (travel time) is required to move from on fire station to accident location then additional three minutes are required for reporting of fire and dispatch time. The service area of fire stations is calculated using eight (8) minutes since a total of eight minutes are required to reach the accident site from the report of the accident. Based on this standards meet and unmeet demand areas are identified as shown in the map below.

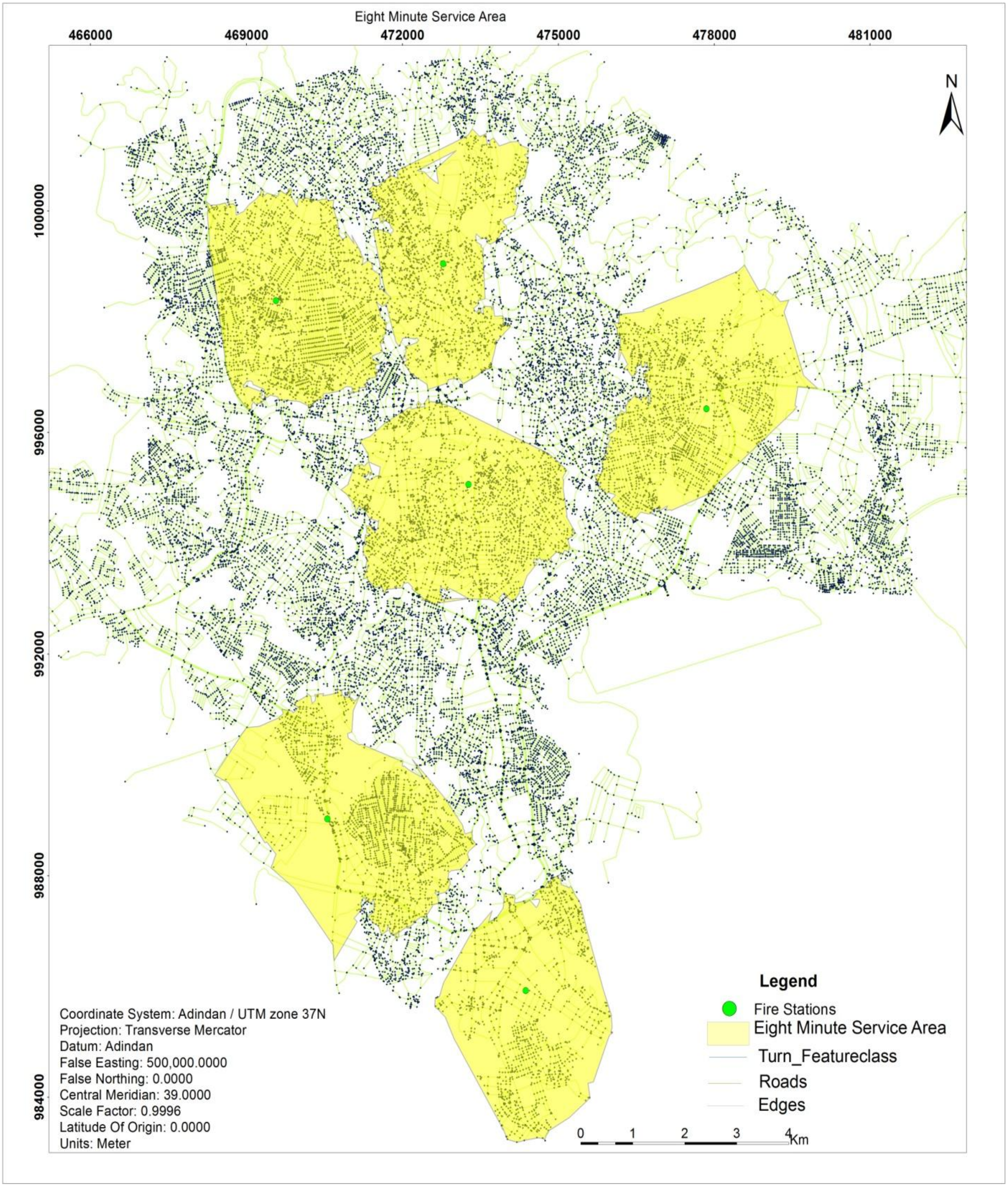

Figure 4.3 Eight minutes service areas of fire stations

Generally speaking when we see the fire service of Addis Ababa city based on the standards putted on this paper only 46.5 % the city is on service while the remaining 53.5 % is served below the standard. By assuming this 46.5 % as a total serviced area then the share of each station is described as follows.

Station 1 (*Arada* Sub City):- Based on the putted standards this station shares 13 % of the serviced area; Station 2 *(Addis Ketema* Sub City) shares 14 % of the serviced area; Station 3 *Kirkose* Sub City) covers 16 %; station 4 *Kolfe Keranio* covers 7 %; station 5 (Bole sub city) shares 18%; station 6 (*Nefasilk lafto*) shares 18% and station 7 (*Akaki kality* Sub City) shares 14 % of the serviced area. Since 53.5 % the city is serviced below the standard; additional sites should be selected for this unmeet demands.

Using ISO/NFPA standards a single fire station should serve within 8 minutes service area from its geometric intersection. The service areas of fire stations are identified and polygons created are overlaid with the Arial photograph and areas out of the polygons digitized and represent unmeet demands. These unmeet demand areas are used in the creation of the union with other factors.

4.1.3 High Risk Areas

High risk area include market places, gas stations and museums which are identified and digitized using high resolution Arial photograph (scale) and top sheet map of Addis Ababa with scale of 1:25,000 which indicate all this features on the map clearly. The digitized high risk areas (refer the map in the appendix page 78) are used in the creation of the union of all the factors without doing a multiple ring buffer because the geometric intersection of each high risk area should be used and weighted.

4.1.4 High Density Residential Areas

High density residential areas are digitized on similar data used with high risk areas. These areas are identified and digitized by overlying the land use map and Arial photograph of the city (refer the map in the appendix page 81). High dense residential areas are selected to represent population data because of the following two reasons.

1. The absence of latest, recent and detailed population data at Keble and sub Keble level.
2. If the existing population data used and converted to geo-referenced thematic map it will represent average value in large areas this will hide highly populated priority areas.

4.1.5 Areas Subject to Interventions

Areas subject to interventions include shanty houses and open areas; these areas are not comfortable for locating new fire stations. Areas subject to intervention are identified and digitized using top sheets and Arial photographs (refer the map in the appendix page 80) then a multiple ring buffer is created outside the polygons which represent areas outside the digitized intervention areas. The buffered areas represent areas which did not include intervention areas and are used for the creation of the union.

4.2 Factor Criteria Weights

Table 4.2: Factor criteria setting

Factor	Setting
Accessibility value	The higher accessibility value >= 5 minutes the better
High Risk Areas	Inside the area =1, outside =0
High Density Residential Areas	The nearer to residential area the better and Inside area=1 and outside = 0
Nearby stations (Coverage Areas)	The further away from the existing fire station (>8 minutes; unmeet demands), the better
Level of Interventions	Areas out of interventions are the better inside=0 outside=1

After data preprocessing has been done, then reclassifying, stretching processes are conducted to make the layers ready for the MCA process. After service area of existing stations are identified; the remaining demand areas are digitize by overlying the service areas on high resolution aerial photograph of the city. Figures in the appendix C shows the final factor map of existing stations and other four factor maps.

4.2.1 Weight Setting (AHP)

As discussed before Analytical Hierarchy Process (AHP) is one of the Multi Criteria decision making method that was originally developed by Prof. Thomas L. Saaty, (2009). In short, it is a method to derive ratio scales from paired comparisons. The input can be obtained from actual measurement such as Weight, Payload, Precision, Cost, Life of robot, Process etc., or from subjective opinion such as satisfaction feelings and preference. AHP allow some small inconsistency in judgment because human is not always consistent. The ratio scales are derived from the principal Eigen vectors and the consistency index is derived from the principal Eigen value.

Table 4.3: Pair wise comparison values

Verbal judgment preference	Numerical rating
Extremely preferred	9
Very strongly preferred	7
Strongly preferred	5
Moderate preferred	3
Equally preferred	1

The pair wise comparison matrices in the table 4.3 are developed by matrices formula. In the matrices ordered pair $a_{ij\ =1}$ for matrices of similar variable that means the variables are both i = accessibility and j = accessibility value or different variables like high density residential area and areas subject to interventions which are supposed to have equal importance for new station selection; these kind of variables have similar numerical rating value and are equally preferred in the selection process then $a_{ij\ =1}$ and its inverse is $a_{ij} = \frac{1}{aji}$ =1. The inverse value indicates the inconsistency of the judgment since AHP allow some small inconsistency in judgment because human is not always consistent in their judgment. If a place found in high risk area and its accessibility is >= 5 it is very strongly preferred because it is found in high risk areas and have good accessibility value so locating stations in these areas is well preferred. Then $_{aij\ =\ 7}$ and its inverse value is $\frac{1}{7}$ which represent the amount of inconsistency in the direct value. If a place found with accessibility value >= 5 and dense residential area it is moderately preferred and have value of 3 based on judgmental value with its inverse value of $\frac{1}{3}$. If a place has accessibility value of >= 5 and service areas of the nearby stations is > 5 minutes then both are equally preferred and has judgmental value of 1 and its inverse $\frac{1}{1} = 1$. Then lastly if a place has accessibility value of >= 5 and it is found in areas which are subject to innervations it is also equally preferred and has value of 1 and its inverse $\frac{1}{1} = 1$; like wise all factors are compared as putted in the table 4.3. The numbers 10, 8, 6, 4, and 2 represent intermediate values between each judgmental value.

Table 4.4: Pair wise comparison matrix result

Factors	Accessibility Value >= 5 minutes	High risk areas	High Density Residential Areas	Nearby stations > 4	Subject to Interventions
Accessibility Value >= 5	1	7	3	1	1
High risk areas	1/7	1	1/7	1/5	1/5
High Density Residential Areas	1/3	7	1	1	1
Nearby stations	1	5	1	1	1
Subject to Interventions	1	5	1	1	1

4.2.2 Criterion Weights Obtained in AHP

After all pair wise comparison matrices are formed, the vector weights, W= [w1 w2 w3…. w_n] is computed on the basis of satty's (1980) eigenvector procedure. The computations of the weights involve two steps. First the pair wise comparison matrices is normalized by $aij^* = \frac{aij}{\sum_{i=1}^{n} aij}$ and weights are computed by $Wi = \frac{\sum_{j=1}^{n} \text{aij}*}{n}$.

Table 4.5: Criterion weight obtained in AHP

Factors	Accessibility Value >= 5 minutes	High risk areas	High Density Residential Areas	Nearby stations (unmeet demands)	Subject to Interventions	Average (Weight)
Accessibility Value >= 5 minutes	0.29	0.28	0.48	0.23	0.23	0.31
High risk areas	0.041	0.04	0.02	0.04	0.04	0.04
High Density Residential Areas	0.09	0.28	0.16	0.23	0.23	0.2
Nearby stations (unmeet demands)	0.29	0.2	0.16	0.23	0.23	0.23
Subject to Interventions	0.29	0.2	0.16	0.23	0.23	0.23

Table 4.6: Finalized weight value

Factors	Weight
Accessibility Value >= 5 minutes	0.31
High risk areas	0.04
High Density Residential Areas	0.2
Nearby stations (unmeet demands)	0.23
Subject to Interventions	0.23

4.2.3 Checks for judgments and weights in AHP

The level of inconsistency in both decision and pair wise compression matrix has been checked. Consistency ratio (C.R) which is a comparison between consistency index and random consistency index, or in formula

$CR = \frac{CI}{RI}$ where $CI = \frac{\lambda max - n}{n-1}$ where n is the number of comparisons or factor criteria's which are five in this study and $R.I = \frac{1.98\ (N-2)}{N}$ where N is the number of factors considered. $\lambda_{max} = \sum_{i,j=1}^{k} CjVi$ where Cj is sum of comparison matrices in j direction .and Vi is weight value in the i^{th} direction. The sum of each pair wise comparisons matrices in the j^{th} direction are 3.476, 25, 6.143, 4.2, 4.2. Vi = 0.31, 0.04, 0.2, 0.23 and 0.23 in the i^{th} direction.

$\lambda_{max} =$ 3.476(0.31) + 25(0.04) + 6.143(0.2) + 4.2(0.23) + 4.2(0.23) = 5.44

$CI = \frac{\lambda max - n}{n-1} = \frac{5.44-5}{5-1} = 0.11$ where N =5 for five factors considered.

$R.I = \frac{1.98\ (N-2)}{N} = \frac{1.98(5-2)}{5} = 1.18$ then $CR = \frac{CI}{R.I} = \frac{0.11}{1.18} = 0.09$ which is 9 % and found acceptable.

Check 1 the sum of weights equals to 1

Check 2 prof. saaty; T. (1980) proved that if the value of consistency ratio is smaller or equal to 0.1, the inconsistency is acceptable. If the consistency ratio is greater than 0.1, we need to revise the subjective judgment. Based on these the results are acceptable; two of the checks are satisfied with sum of weight =1, consistency ratio (C.R = 0.09). So the judgments and weights are acceptable.

4.3 Site Selection

In the site selection process weighted overlay analysis will be used and the weight values found in AHP will be used as a weight for selecting the site. The formula for selecting the final site is (Accessibility) 0.31 + (high risk areas) 0.04 + (high density residential area) 0.2 + (unmeet demand) 0.23 + (subject to innervations) 0.23

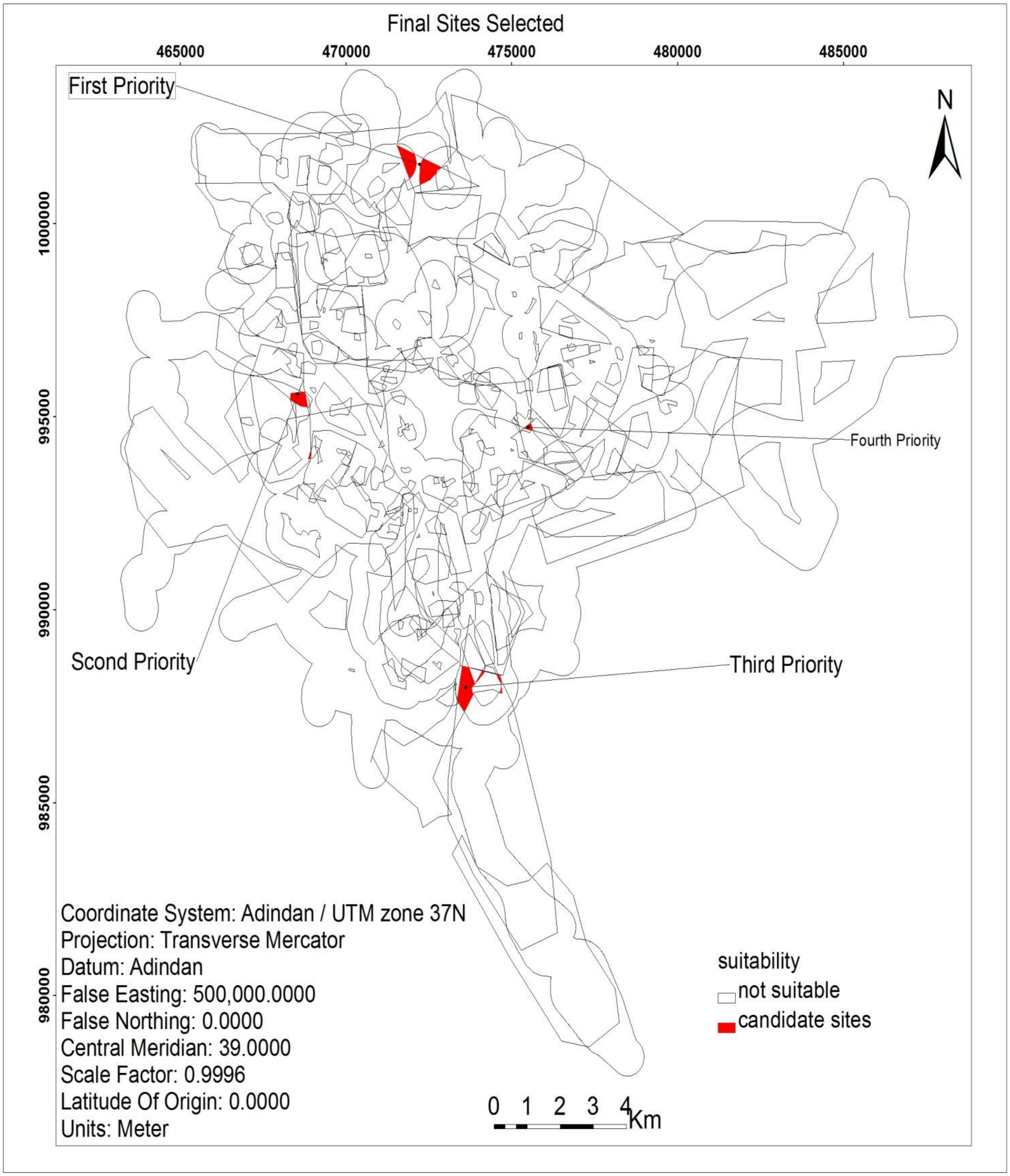

Figure 4.4 Final sites selected

4.4 Service Area Coverage after Additional Sites Selected

Addis Ababa city administration has planned to add two additional sites on the upcoming years; while based on the standards used on this research paper three additional sites founds to be necessary. After three additional sites have been selected the following service area map is produced. Having added three additional sites the service coverage of the city can be upgraded to 87.5 % based on the putted standards here.

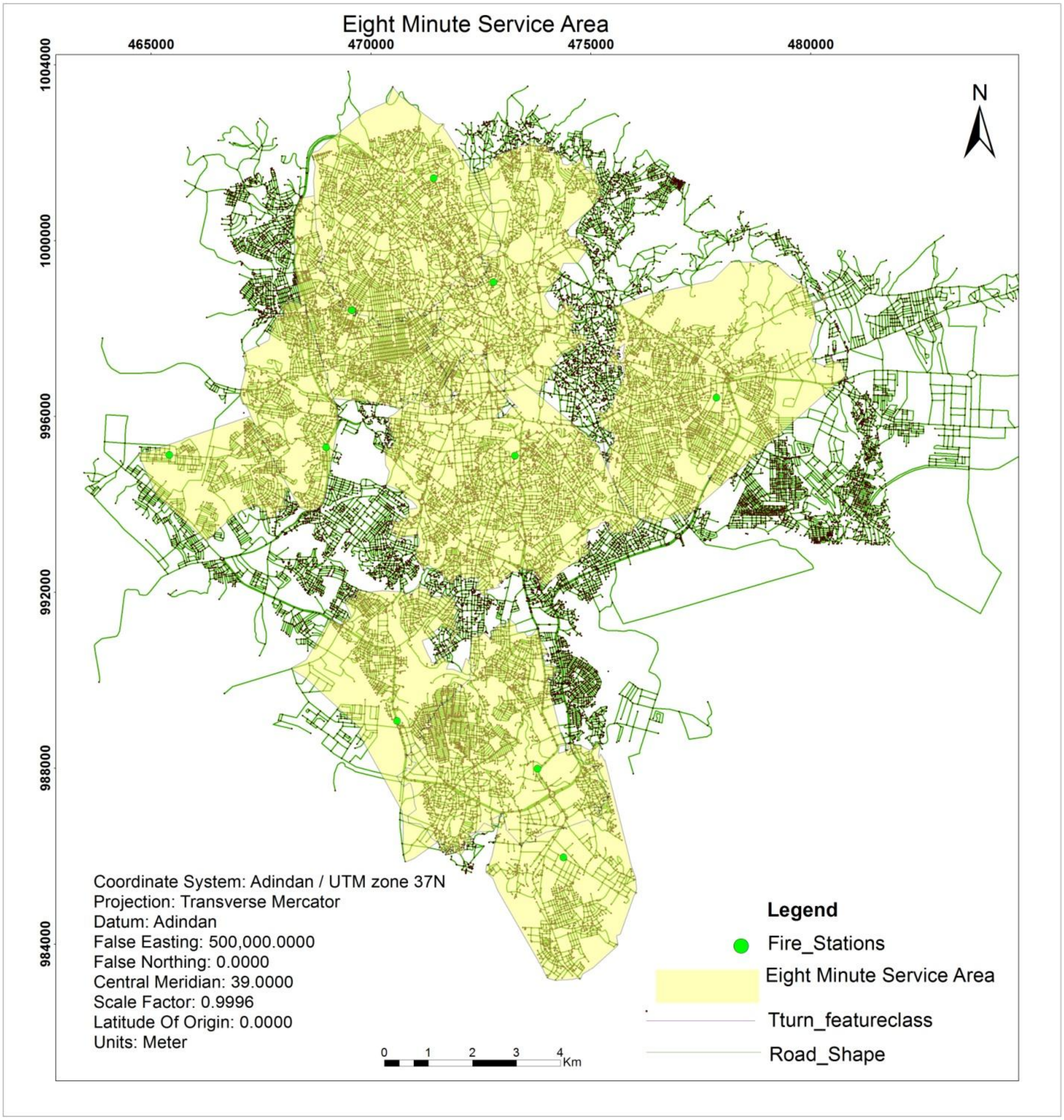

Figure 4.5 Eight minute service area after adding additional fire stations

4.5 Geo-coding and Best Route Selection

As indicated in the maps the optimum number of fire stations has been selected and accessibility level of the road networks has been sated. If the fire truck/ambulance driver did not use the shortest route during the travel to the accident the time needed to reach the accident site will increase. The dispatch and controlling officers are allowed only to use a maximum of two minutes to finish accepting of calls and ordering of ambulances and fire trucks to the accident site. To achieve this GIS system data base with a geo-coding tools are used. The truck/Ambulance drivers are expected to follow the selected route and direction to reach accident site as fast as possible. In the usage of geo-coding tools land marks found in Addis Ababa city are used as input for searching the accident site. When call comes from the accident place the fire station worker can search the exact accident place using GIS software and the nearest land mark of the accident place. The customer who is reporting the accident is expected to know and report the name the nearest land mark in surrounding locality. Using geo-coding search tool the nearest land mark will be displayed on the map and this will be used as accident place. Fastest routes will be selected from the fire station to the accident place and to the nearest emergency hospital.

Addis Ababa fire and emergency accident central office with its officer will accept calls from accident sites. The caller will also inform the accident with its nearest land mark. By using the nearest land mark the GIS officer in the central office will find the nearest fire station. The nearest fire station informed through call will search the accident using the nearest land mark. Shortest routes to the accident site and the nearest hospital will be selected at this stage. Finally ambulance and fire trucks will have best routes as maps and directions and they will follow that route to reach the accident site.

Based on the interviews given to traffic polices and ambulance derivers 80 % of the respondents given that the peak hours of traffic congestion time are 5:30 am to 2:30 pm in the afternoon session and 8:00 am to 3:00 am in the morning session. If the accident is reported during peak hour's selection of best routes will be done using minor roads but if the accident is reported out of peak hours selection of routes will be done using both major and minor roads. so that the road network dataset is created using both major and minor roads.

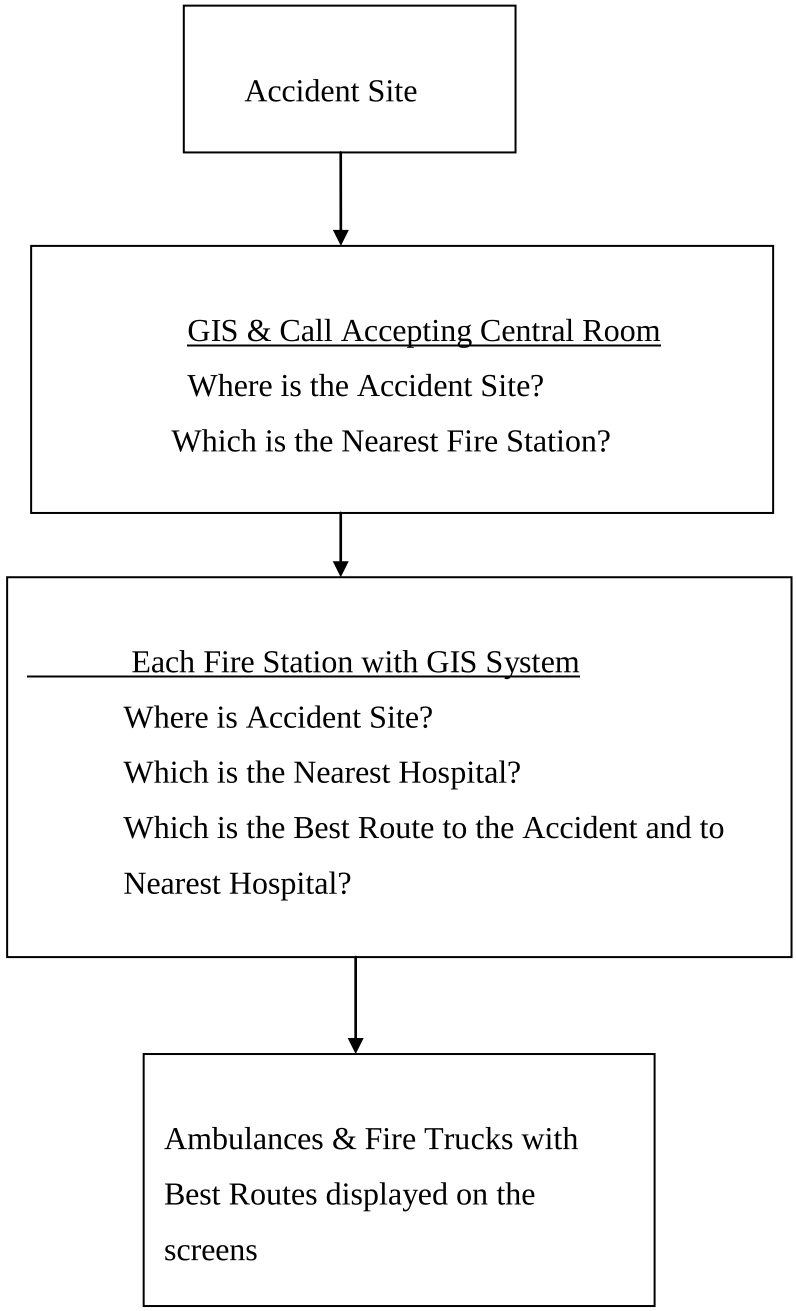

Figure 4.6 the proposed dispatching procedures

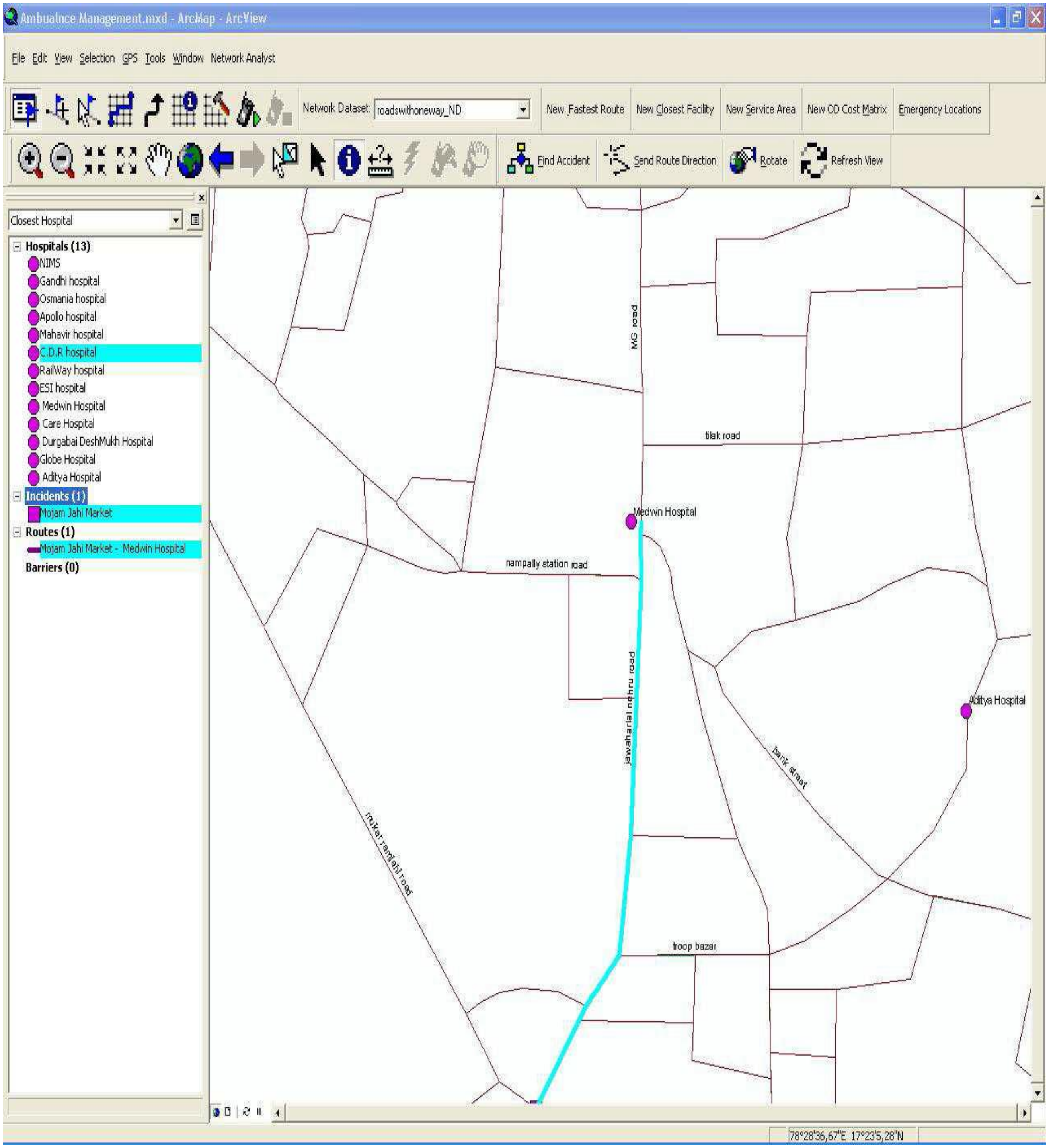

Figure 4.7 the best route selection process

4.6 Comparisons of Existing and Proposed Response Systems

To compare the developed emergency response system with the existing response system two accidents sites were selected. The accidents sites were one in *Addiss ketema* sub city and the second *Kirkose* sub city were selected.

Accident 1 *Kirkose* sub city *woreda* 5 around mixco: - The cause for fire accident was contact of electric city wire and the property lost was around 100,679.120 birr. No death but there was body injuries.

Cause for burning = electric city contact

Time of reporting = 7:25 afternoon

Time used for dispatching = unknown

Amount property lost = 100,679.120 birr

Total time needed for travel = 7 minutes.

To Hospital 6 minute

In the following figure 4.8 the yellow line indicates the routes used during accident which uses seven minutes to travel to the accident site and it uses 6 minutes to travel from the accident sit to the nearest Hospital. The blue and pink colored line indicates the routes used from fire stations to accident sites and from accident sites to the nearest hospital and they are selected using the fire database developed in this study. By comparison the yellow route has a length of 2.1 kilometers (from fire stations to accident site) and 0.7 kilometer (from accident site to Hospital); while the blue and pink routes have a length of 1.8 and 0.6 kilometers respectively. The fire truck/ambulance travels the longest distance and uses seven minutes to finish the journey. Using the fire database developed here the travel distance can be reduced to 1.8 kilometers and the time needed can be reduced to four minutes. Movements to the hospital can be reduced by 0.1 km in distance and 3 minutes in time. The comparison of distance and time is putted in the following table.

Table 4.7 comparison of used and proposed routes for accident 1

Unit of measurement	Used route		Proposed route	
	From FS to AS	From AS to HO	From FS to AS	From AS to HO

Length (km)	2.1	0.7	1.8	0.6
Time (minutes)	7	6	4	1

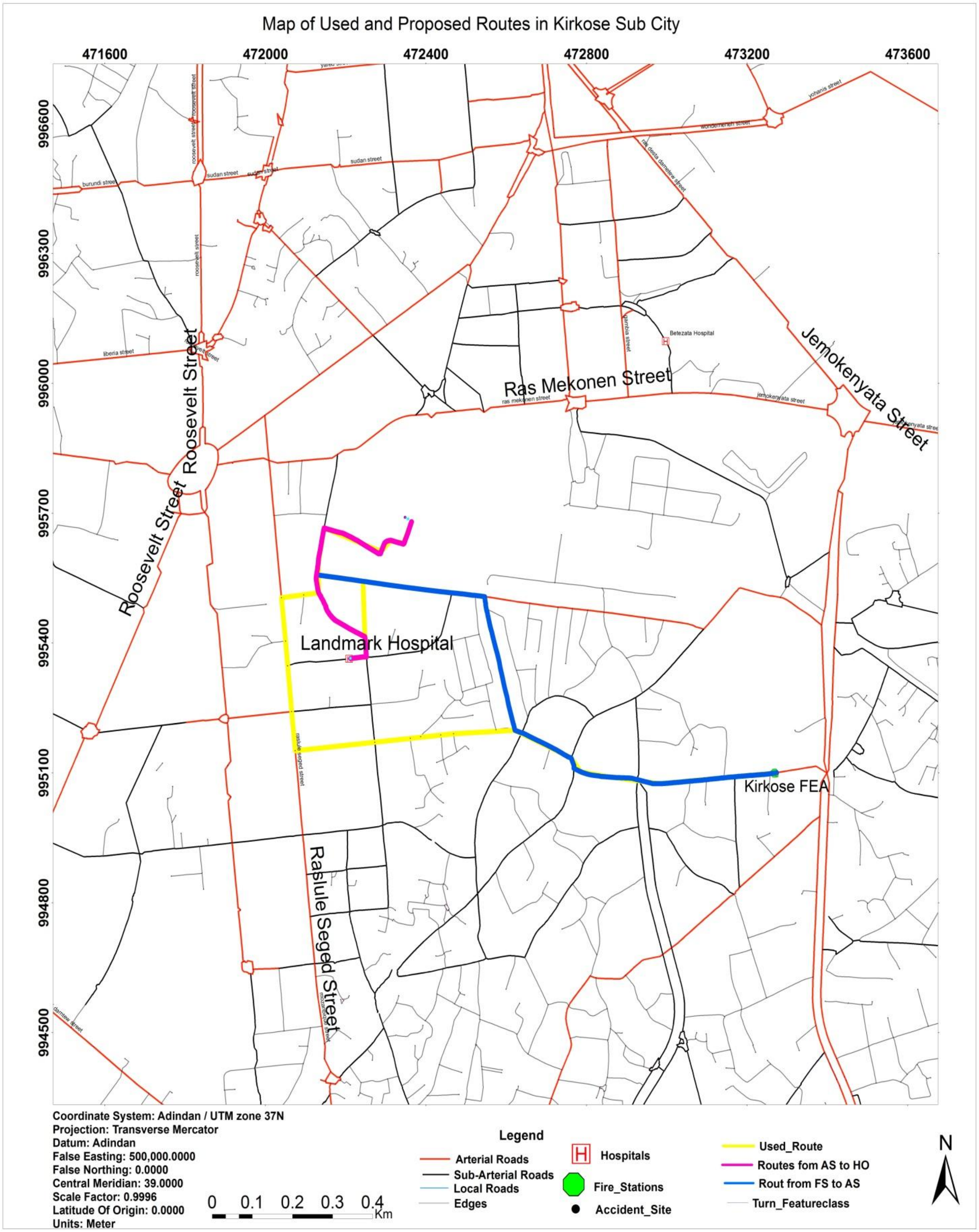

Figure 4.8 Used routes (yellow) and proposed route (blue & pink) in *kirkose* city

Accident 2:- *Addis Ketema* sub city around central *Mercato* this is afire accident which is caused by electric line contact. In this accident 168,575.168 birr property is lost and one death with three injuries of people was recorded.

Cause for burning = electric city contact

Time of reporting = 12:47 afternoon

Time used for dispatching = unknown

Amount property lost = 168,575.168 birr

Total time needed for travel = 8 minutes

To hospital 7 minutes

By asking the truck/ambulance driver specifically on the above accidents the location of each accident were obtained by using hand held GPS. The route used for travelling was also digitized. By asking the fire truck/ambulance driver and digitization on the road network, the routes used for travelling are mapped. In the following figure 4.9 the yellow line indicates the routes used during the accident time which uses seven minutes to travel to accident site. The blue and pink lines indicates the proposed routes from fires stations to the accident and from accident site to hospital respectively and they are selected using the fire database developed in this study. By comparison the yellow routes have a length of 1.17 kilometer (from fire station to accident site) and 1.41 kilometer (from accident site to hospital); While the blue route has a length of 1.66 kilometer (from FS to AS) and 1.16 kilometer (from AS to HO). The time taken to finish the yellow line is eight minutes (from FS to AS) while it takes only three minute to finish the blue route using the proposed system. The main reason for this time difference is the yellow route pass through cross roads and it also cross many junctions; while the blue route pass out of cross roads and cross less junctions. Time from fire stations to accidents is reduced by five minute and from accidents to Hospital is reduced by five minutes.

Table 4.8 comparison of used and proposed routes for accident 2

Units of measurement	Used route		Proposed route	
	From FS to AS	From AS to HO	From FS to AS	From AS to HO
Length (km)	1.17	1.41	1.66	1.16
Time (minutes)	8	7	3	2

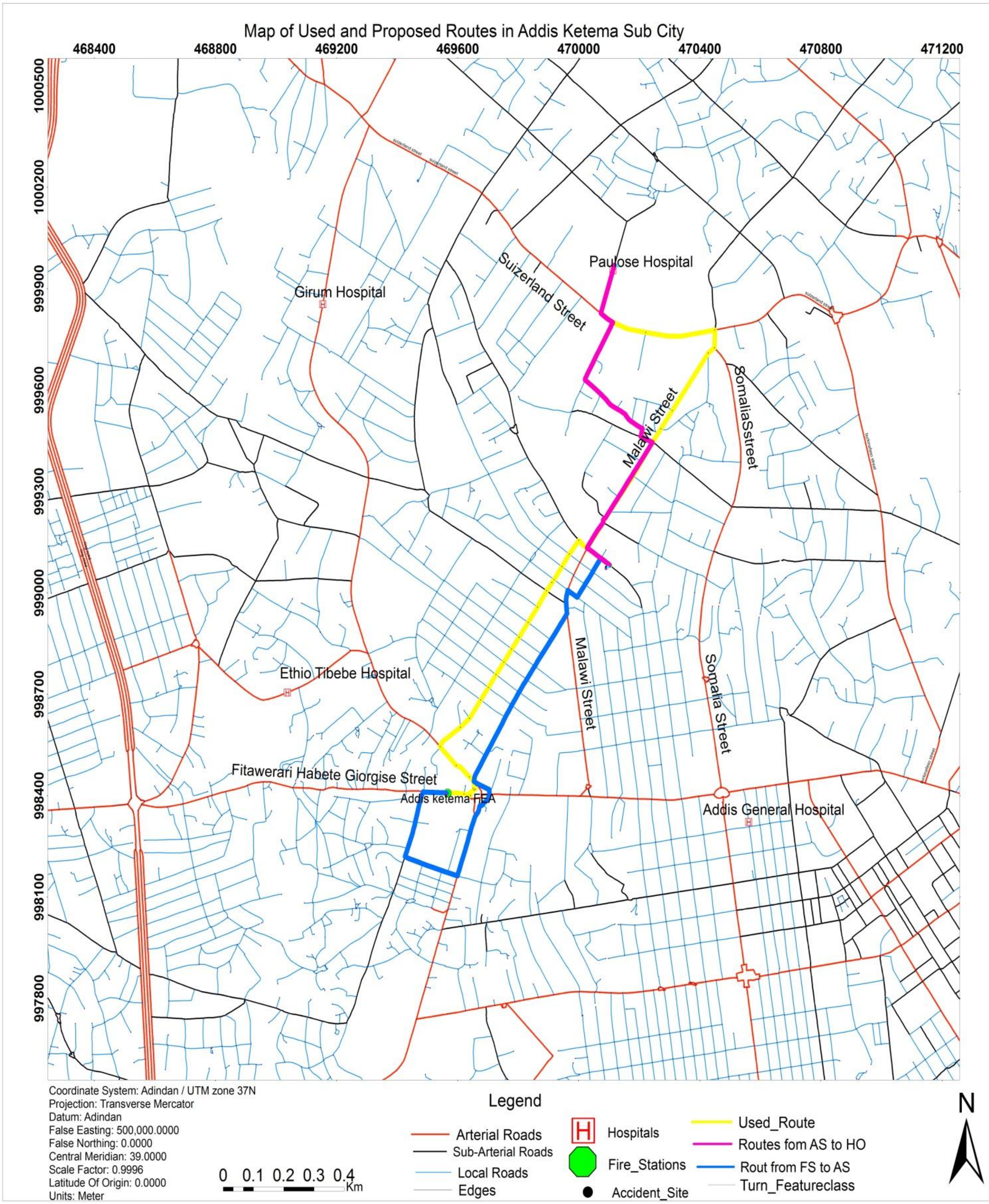

Figure 4.9 Used routes (yellow) and proposed route (blue and pink) in *Addis ketema* city

By using the fire database developed here with arc GIS geo-coding tools the total time needed to manage accident one in *kirkose* sub city can be reduced to four minutes. While in accident 2 at total time of 8 minutes is used by the existing system while three minutes can be used by the proposed systems.

4.7 Discussions

The study has an objective of exploring and evaluating the level of fire and emergency service delivered to Addis Ababa city then to select new facilities (fire stations), identifying accidents and selecting shortest paths dynamically. To achieve the overall objective of the research the study has utilized various methods and statistical techniques. The AHP and Dijkstra's algorithm are the main methods and techniques to be mentioned here.

Accessibility of Road Networks:-Based on the accessibility evolution technique applied here, roads found near the cross roads and central region found less accessible with accessibility value of less than 5 minutes. While, arterial and sub arterial roads with high speed 60 km/h and 80 km/h and located out of the cross roads and central region are found accessible with accessibility value of greater than 5. By other study Yetenayet Ayaleneh, (2012) found that there is high trip production and attraction towards the central region of the city; the central region is also characterized by high population density and important socioeconomic activities of the city like flight terminals and schools are located in the central regions too. These leads to low accessibility value in the central regions. By similar studies the road density, expressed as length per area, found to be high in the central areas. As settlements in Addis Ababa are mainly established along the road networks; Yetenayet also found that the road length per unit person is found to be low in the central area; proximity to roads in the central region is less than 500m allowing more peoples to access this roads. Whoever, in the outskirts, peoples have to travel more than 1000 meters to reach the existing road infrastructure indicating low congestion of peoples because they cannot reach the roads easily. These result matches the outcome of this paper and since peoples cannot accesses the roads easily in the outskirts of the CBD there is low congestion in this area so there is high accessibility for cars, while in central part of the city peoples and all traffic system access the road easily indicating high congestion which matches with the low accessibility result of this paper.

Site Selection: - For site selection part of this paper; five factor criteria's were selected and AHP technique was used for analyzing these factor criteria.

Using the nearby existing fire stations, ISO standards and the calculated accessibility value of road networks the service areas of each existing fire stations is selected; areas which are under service are also known here. High potential risk areas are also selected using high resolution aerial photograph and top sheets of the city. Next to this high dense residential areas and areas subject to interventions are indentified by similar method. The argument for digitizing and identifying high dense residential area is to represent highly populated area so as to give priority for these areas when weighting. On the other way areas subject to interventions are selected and buffered in the outside buffer since this area are not good for placing new fire stations. Weights are produced using AHP technique with accessibility value >= 5 = 0.31, high risk areas 0.04, high dense residential areas 0.2, nearby stations 0.23 and areas subject to interventions 0.23 on average. Multiplying by the weight value, a multiple ring buffer is created, then finally site scores are calculated and candidate sites are selected.

Perhaps because they do not introduce new methods or address new questions, published case studies applying location models to real-world situations are rare (Current et al., 2012). The eventual goal of this research is to have the formulated methodology applied to solve a problem, and this study is an example of doing just that. However, there are fundamental differences between a theoretical problem and a real-world problem that can complicate the process of finding a solution.

In this case study, the first of those issues was defining demand. Since there were existing fire stations, as there would be in nearly any practical situation, demand could not be defined as simply any location that could possibly need a fire truck. For a realistic answer to the Emergency Manager’s question, demand had to be defined as any location that could possibly need a fire truck and did not have one within the accepted standard distance that was also in the same fire district as the location itself. Other variables could have come into play as well, depending on the circumstances. For example, in this study every demand point had the same weight, but that may not be reasonable if one of the demand points represent a school or a factory while the others represent unoccupied utility sheds or barns

The second issue that had to be addressed was defining potential fire station sites. Since the City had no potential sites in mind, they were represented by a continuous plane, but it is unreasonable to define that plane as everything inside the city boundaries. Some areas are more and less suitable for building, and there is nothing “optimal” about a site that covers all unmet demand but requires millions of dollars of new infrastructure before it is viable. By using building site recommendations from the county's comprehensive plan, reaching an optimal solution that was also viable was simplified. If it had not been available, the introduction of several variables may have been required to produce a practical solution.

For this study to produce a result congruent with existing standards, network analysis was the only choice. Euclidean buffers would have dramatically overestimated response areas given the nature of the road network in the region. That required the road layer to be in good condition with consistent and accurate topology. It was, but if it had not been, the solution would have been questionable from the outset, if it could have even been determined at all. Along that same line is the ambiguity of the term "all-weather road." A consensus definition was found from ISO and the local and state transportation authorities, but finding it was one of the most taxing research tasks of the study. It is not that clear-cut in every jurisdictions, and including or excluding the wrong segments would have drastically affect the accuracy the solution. While these issues do not impact the viability of the methodology, the point is as accurate solution as possible. Decisions affecting people's lives and property might be made relying on studies like this one, so the accuracy and appropriateness of every part of the study needs to be considered, not just the chosen statistical model.

Geo-coding Fastest Path Selection:-The land marks found in the city are expected to be known and given to the city residents. When accident happens the caller is expected to give the name of the nearest land mark. Using the nearest land mark and searching mechanism developed in this study the location of accidents can be found. The shortest paths then selected referring the searched accident location and considering the traffic congestion.

Concerning the presented system, the most important data element is the location of the accident and the exploitation of this information is the main difference between the solely statistical analysis and geographical and geo-statistical analysis. The location reference of an accident can be recorded in several ways, according to the authority that collects the accident data. In Greece, the Traffic Police, stores the location of an accident, based on the postal code, given that the accident occurred in urban environment, or based on the kilometric point, if the accident occurred in regional road. Therefore, the use of geo-coding tool is required. Nevertheless, in other countries, the location reference can be given by the coordinates of the accident, simplifying the procedure. Ultimately, using the geo-coding tool that combines the address locator with the stored data, each one of the accidents is placed to the incident location point. Each accident point contains its attribute data, in order to perform further analysis. In this way, accident data import process, and generally data management, is being systematized, and moreover, the spatial dimension of the accidents, is emphasized, something, which until now was not examined, or it was partial and empirical.

CHAPTER FIVE: - CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

Based on the outcome of this research paper the following conclusion has been reached.

- Addis Ababa city fire service is not to the standard; since 53.5 % of the city is served below standards.
- By adding three fire stations 87.5 % of the city can be served based on the standard; by adding four stations the service area can be upgraded to 100 %.
- AHP is a useful method for selecting new fire stations sites:- Because it makes possible to asses all criteria's simultaneously with no need to carry out several map-overlying operations, modifying value attributes using a constant value and making a final map reclassification resulting from the combination of all criteria layers.
- It is possible to find accidents on a map using simple Geo-coding techniques.
- It is possible to minimize the travel time of the fire truck by using the prototype developed here.

Evaluating the accessibility of road networks is apriority issue for fire station site selection and should be considered as a factor since time is the main determinant factor for any emergency activities. The actual deriving time road networks and the coverage limits of service areas depend on the actual accesses capacity of road networks.

Comparatively speaking, GIS-based MCA provides a more technological, convenient and precise way for fire station site selection than the traditional ways such as Thiessen polygon. It combines spatial and non-spatial data to construct visualized information that can be easily understood and analyzed by decision makers. By using such illustrative maps, decision makers can obtain very accurate solutions for problems. In this study, the optimal site for new fire station allocated in Addis Ababa city approximately matches with the place expected before, which proves that the result from GIS method is, relatively accurate and practical.

Furthermore, a GIS-based MCA together with consistency indexes and consistency ratio make the decision makers be aware of which criteria are really necessary and how the results are sensitive to the weights change. Hence, it can optimize the criteria combination, modify the analytical structure and reduce the deviation, making the results stronger and more convincing.

For the decision makers of fire station site selection, when making GIS-based MCA, reliable data, especially the data for the factor criteria, should be taken seriously. It is essential to convert some tabulated data into geo-referenced data. Besides, in case of unexpected parameters, recheck the results, and match them with the reality is absolutely necessary.

In further research, GIS-based MCA together with necessity tests and sensitivity tests is expected to overcome the drawbacks of too many repeated operations on the MCA models. Instead of running every MCA model respectively on a routine way, a set of synthetic operation software for MCA models is expected to be developed. Then all the result maps come out simultaneously, along with an analytical tool to evaluate the consistency index and consistency ratio. Finally the criteria combinations are revised to get the optimum result. With this development, GIS-based MCA together with consistency index and consistency ratio will absolutely be much more maneuverable and practical. Hence, it will be useful to provide a high-performance application and reference to other site selection such as railway station and shopping mall, acting as an adequate tool for public administration and business market strategies.

5.2 Recommendations

The fire and emergency accident agency should take the results of this work for constructing new fire stations and for improving emergency response time.

For local GIS personnel, the methodology presented here can be duplicated by anyone with the appropriate data and software. Because the technical methods used are pre-packaged in software tools, neither advanced math skills nor programming knowledge are necessary. This leaves the methodology as a viable option for decision support to many agencies without the personnel or funding to implement more traditional location models. For GIS researchers whose goal is to develop methods of solving real-world problems, their case studies should put those methods to a practical test. This study showed the need to identify not just the required data type for inputs, but also the standards of topological accuracy and attribution necessary to produce a reliable solution. Additional case studies like this one could help to refine the existing models and show new paths for further research.

Even though this research has identified new potential sites for locating fire stations and methods to locate accidents and selection of best route dynamically. Further developments are necessary to improve this method because real time technologies like GPS should be used to take into considerations the congestion level of the road networks.

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APPENDIX A. INTERVIEW QUESTIONS

The research is mainly concerned about selecting new fire stations for unmeet demands and selection of best routes for travelling of fire trucks and ambulances.

1. What are the studies conducted to select new fire stations for unmeet demands and optimization of routes?

What factors are considered to slow down the travel time of fire trucks?

What are the dispatching procedures?

Where is the location of past accident in *kirkose* sub city?

1. Where is the location of past accident in *addis ketema* sub city?
2. What was the time needed to reach each accident site?

What was the cause for each accident?

How match property is lost in each accident?

Are there any life or body injuries in each accident?

Interview questions for traffic polices

Which are the peak hours of traffic congestion?

What should do the fire truck drivers should do in the time high traffic congestion?

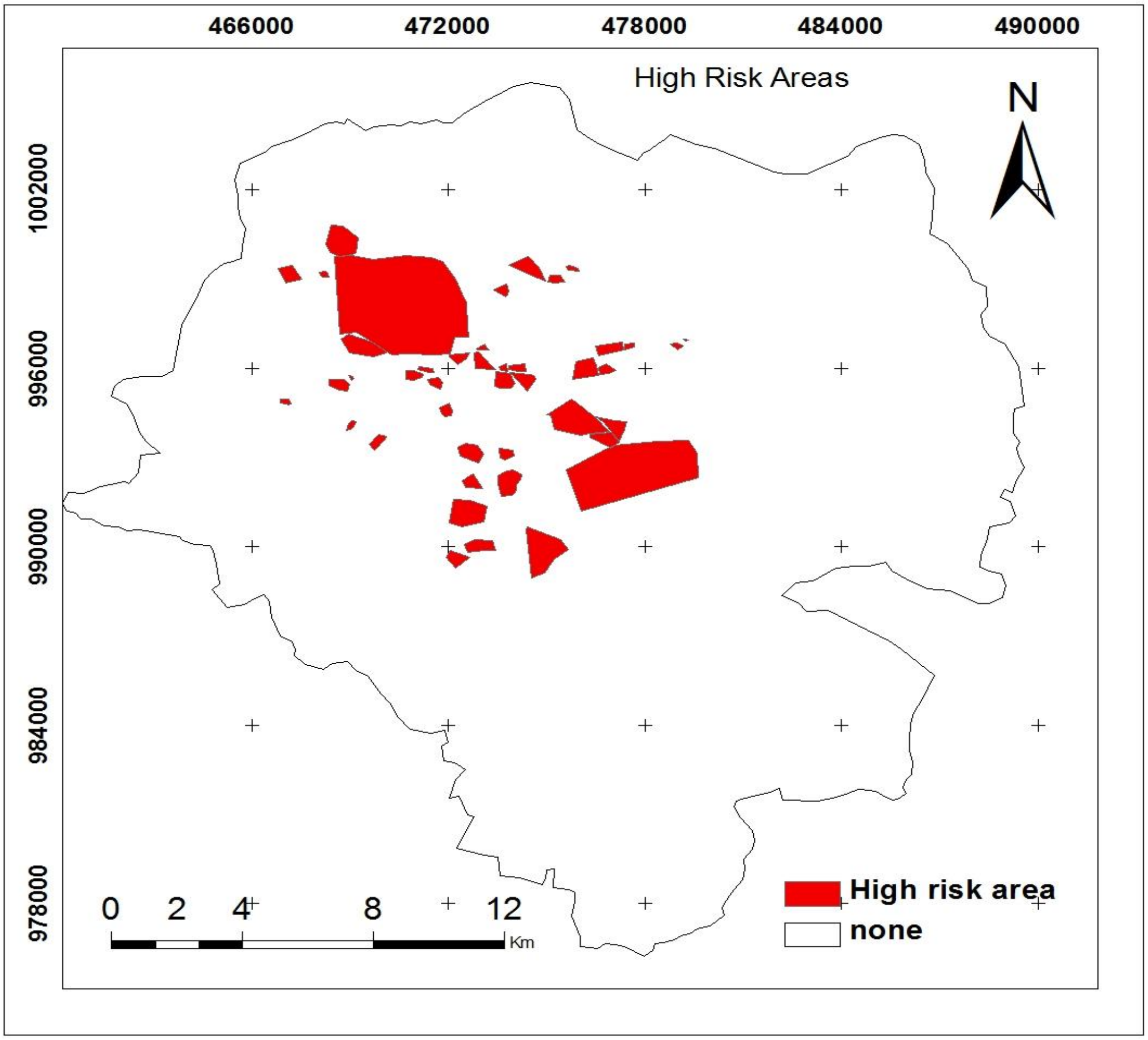
APPENDIX B COORDINATES OF HOSPITALS AND FIRE STATIONS

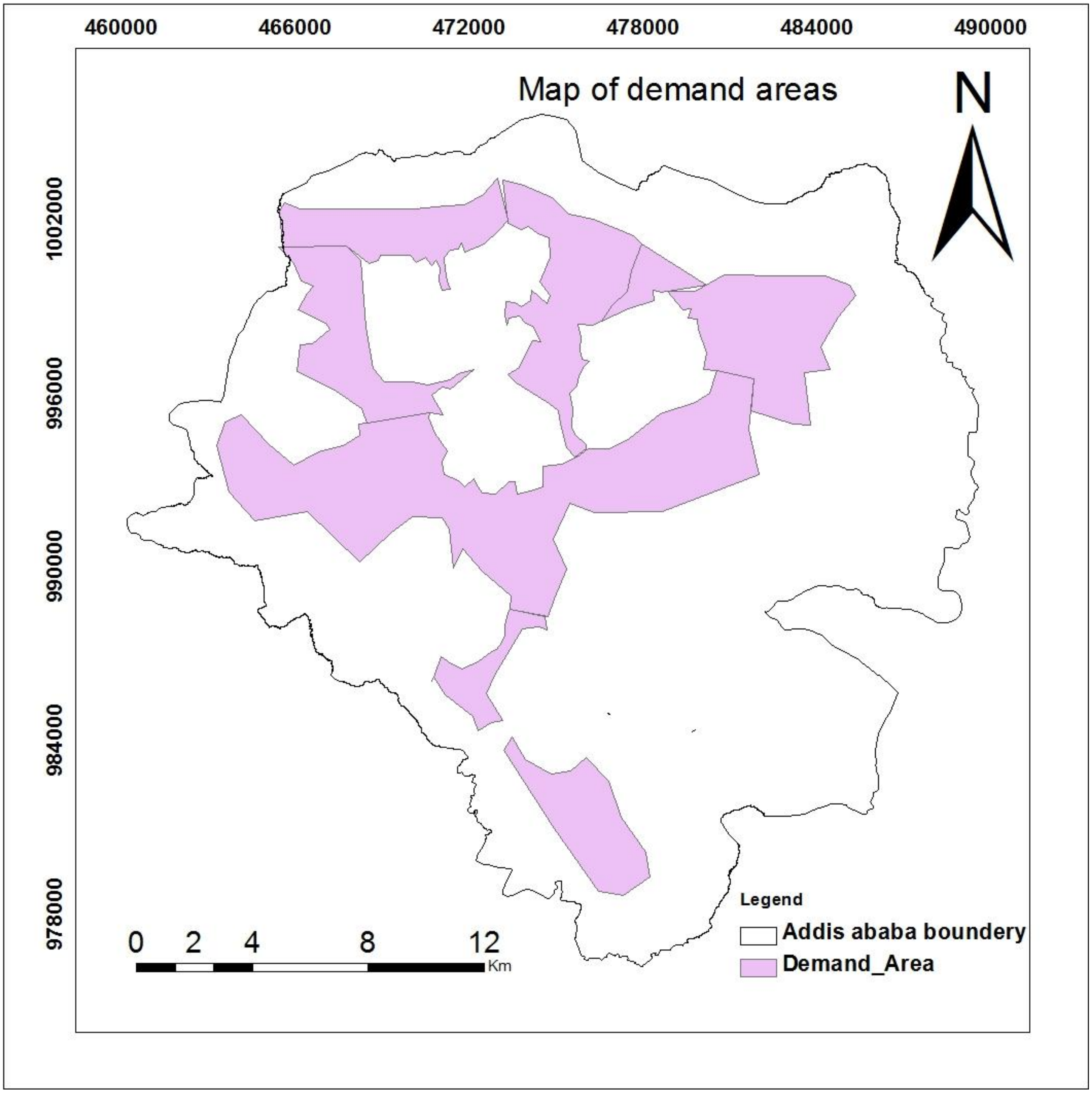
Hospital Name	Coordinate		
	X	Y	Z
Kiduse petrose	474224.617	1001430.75	2529.18
Girume	469171.065	999869.705	2412.702
Paulose	470017.33	99975.539	2422.913
Ras desta	471758.695	999742.123	2469.994
Yekatit	473494.365	999636.871	2208.287
Defense	475759.203	999615.705	2151.471
Tibebu general	4717779.862	999128.87	999128.87
Ethio-tibebe	468906.481	998708.757	2746
Addis general	470543.594	998344.954	2253.714
Yordanose	480513.618	998599.913	2346.752
Menelike II	474997.202	998980.703	2707.143
Tekure anbesa	472438.91	996884.64	2704.431
Balcha	471041.907	996270.805	2509.314
Andenet	477328.42	996926.973	2653.560
Kiduse yared	478915.923	996821.14	2814.380
Addis hiowote	476058.417	996143.805	2205.912
Kiduse gebrial	476587.585	995805.138	2306.229
Bete tsegia	475338.749	995360.637	2504.233
Korian	478704.256	994556.302	2409.333
Biruke	469590.231	993646.133	2575.121
Betezata	472883.411	996228.472	2498.318
T/hamanote	4468831.114	995228.274	2309.112
Kadisco	479360.422	994302.301	2798.128
Zewoditu	471343.642	995764.857	2578.817
Land mark	472190.31	995373.273	2345.554

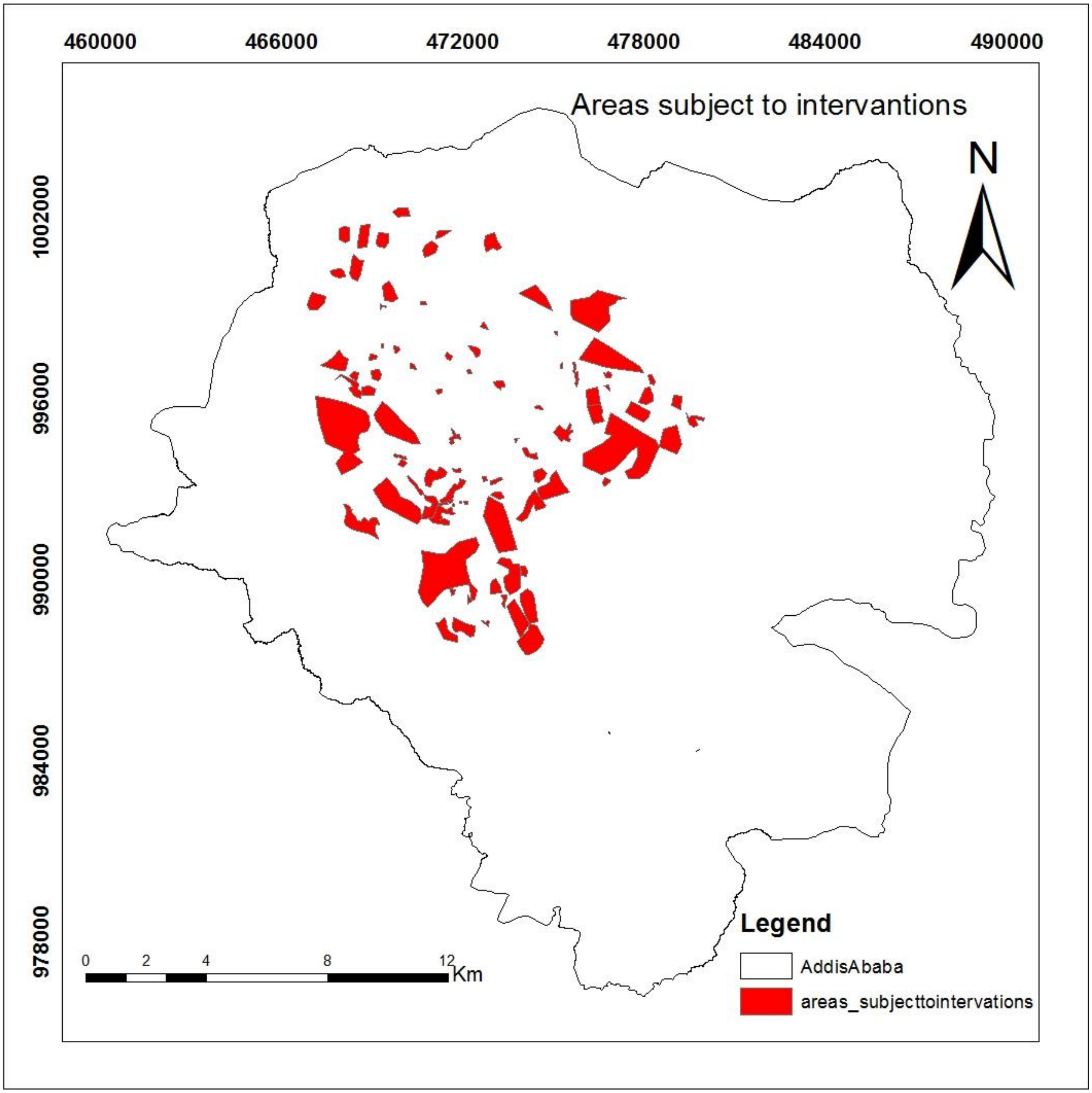
Locations of fire stations

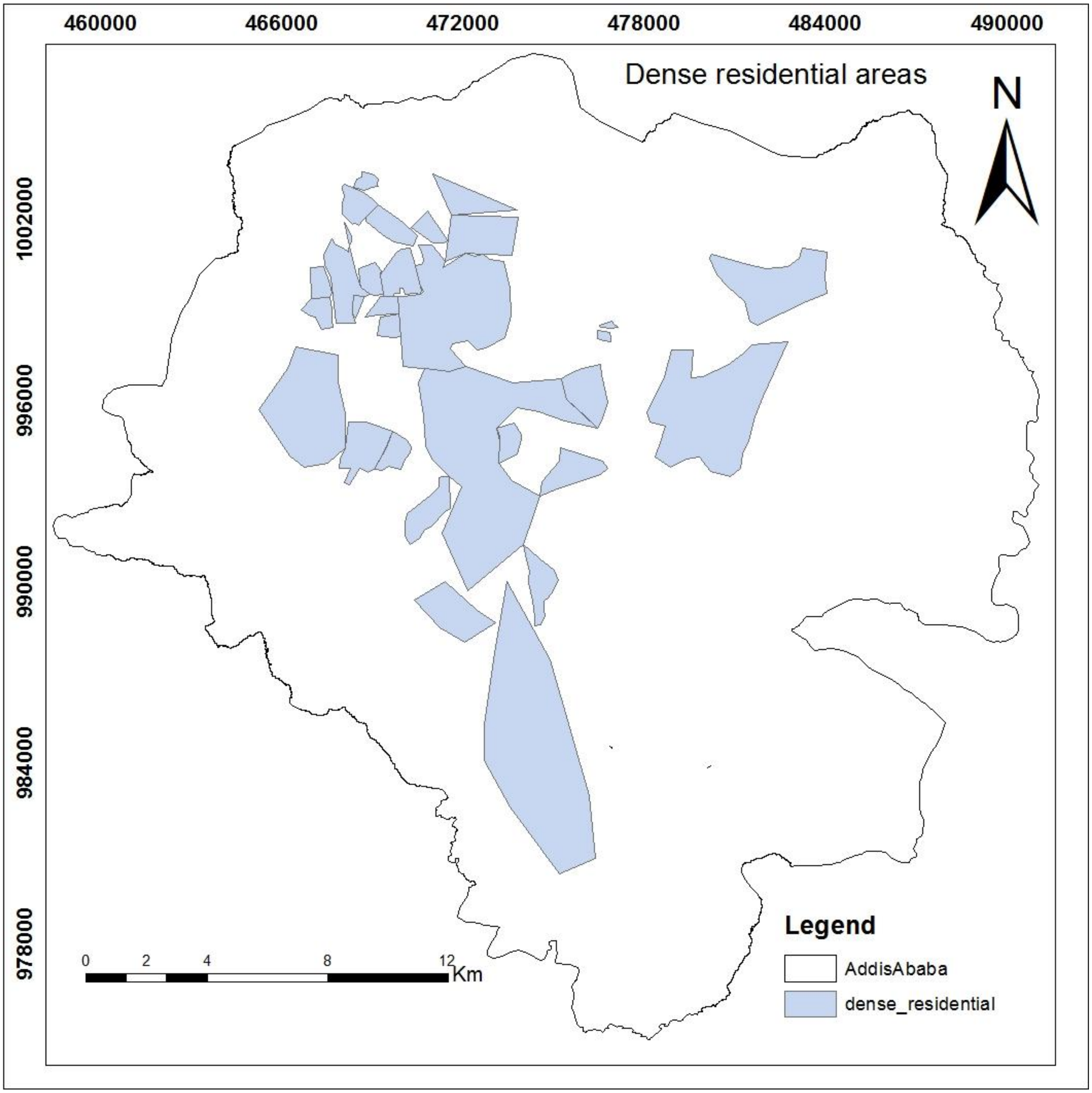
Fire station Sub-city	Coordinate		
	X	Y	Z
Arada (main city)	472678.028	999144.561	2519.028
Addis ketema	469545.355	998446.06	2538.666
Kolfe	465290.846	9994953.553	2474.838
Kirkose	47370.695	995228.72	2309.446
Bole	477779204	996498.723	2259.916
Nefasilk	470701.589	989233.25	2318.591
Akaki	474538.052	986124.39	2151.471

APPENDIX C: - USED MAPS

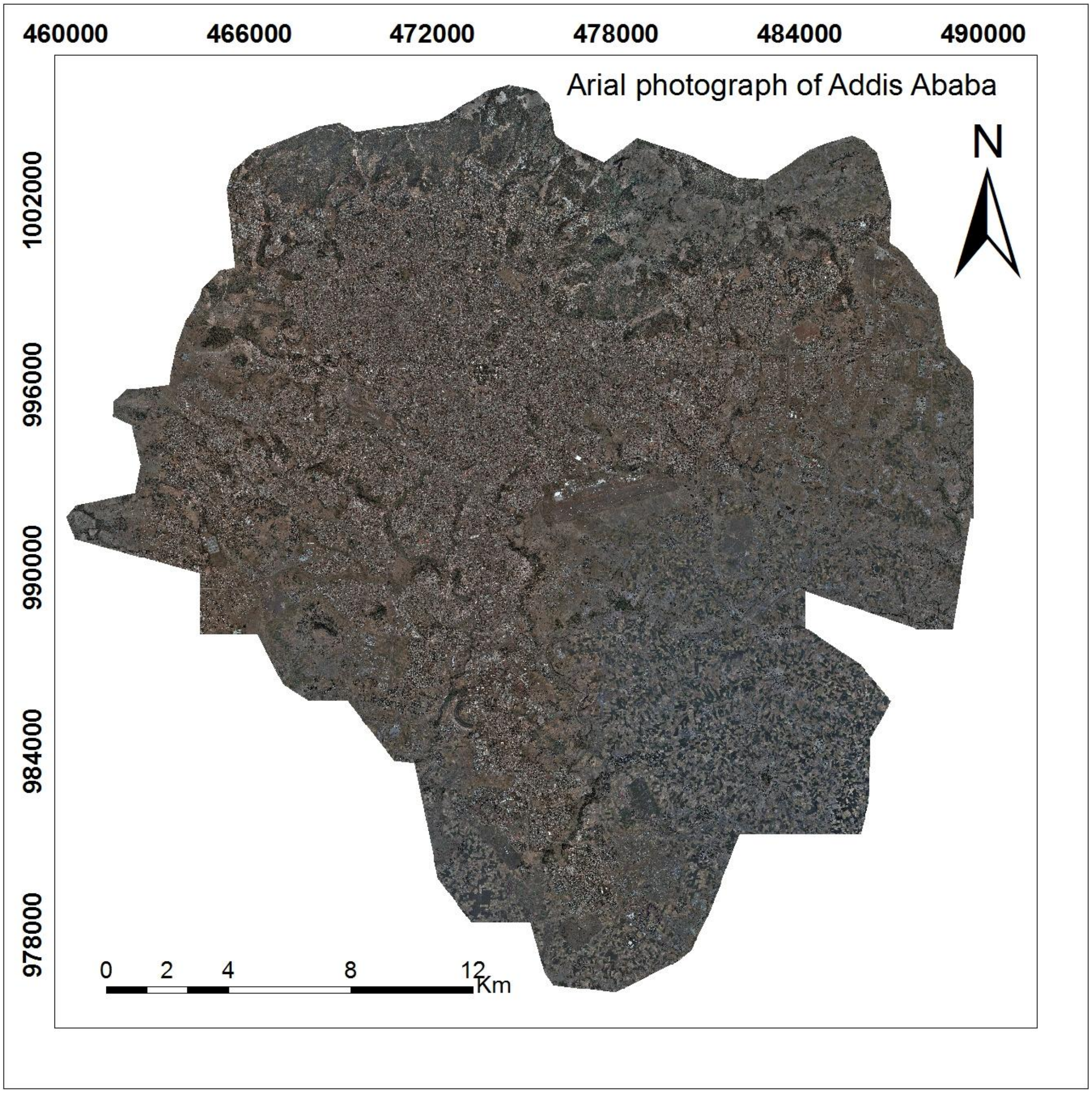



460000
466000
472000
478000
484000
490000
Map of demand areas
N
1002000
996000
990000
984000
978000
0 2 4 8 12
Km
Legend
Addis ababa boundery
Demand_Area


460000
466000
472000
478000
484000
490000
1002000
996000
990000
984000
978000
Areas subject to intervantions
N
0
2
4
8
12
Km
Legend
AddisAbaba
areas_subjecttointervations



460000
466000
472000
478000
484000
490000
Dense residential areas
N
1002000
996000
990000
984000
978000
0
2
4
8
12
Km
Legend
AddisAbaba
dense_residential



460000
466000
472000
478000
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Arial photograph of Addis Ababa
N
1002000
996000
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984000
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2
4
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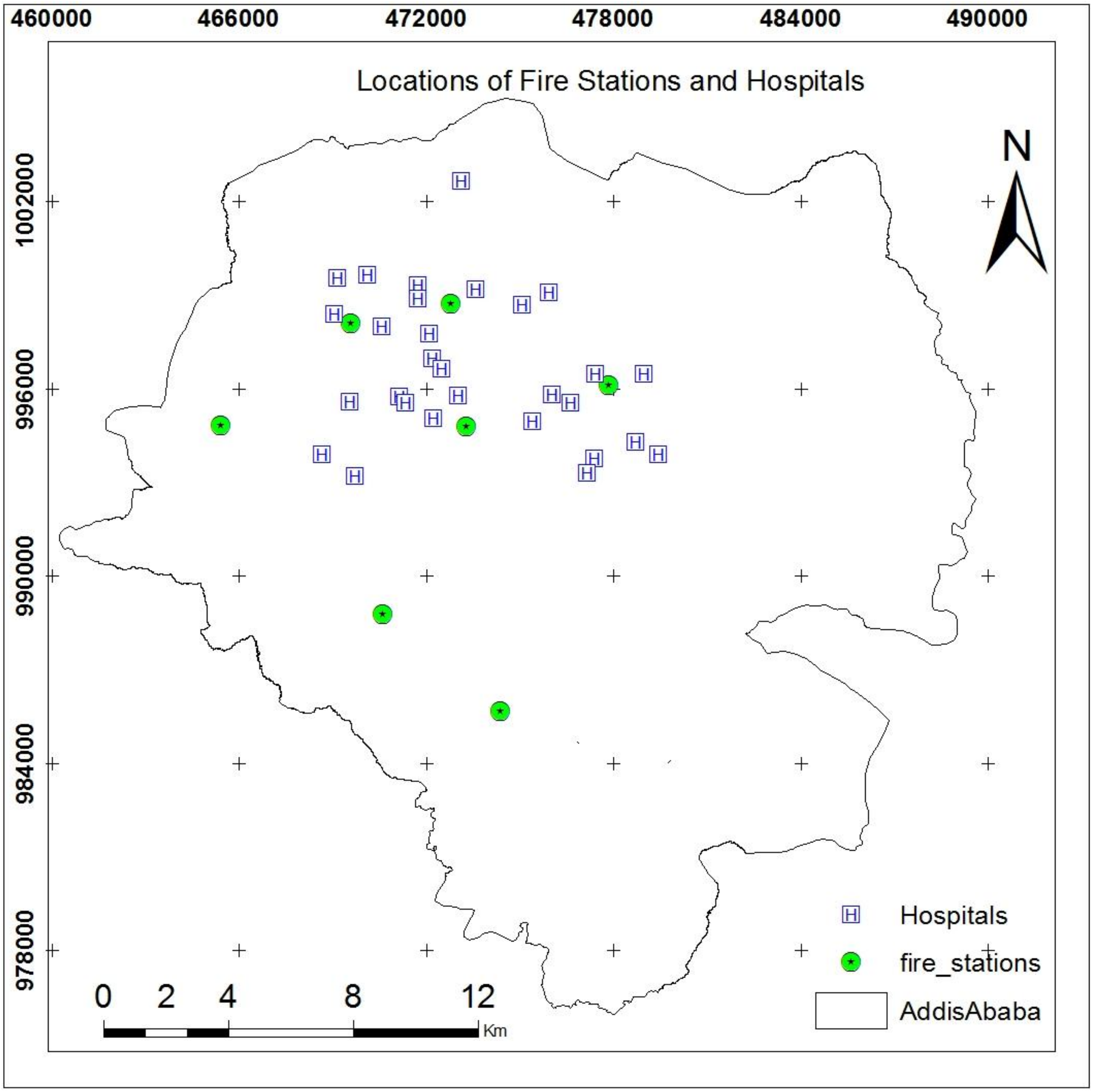
Km


Locations of Fire Stations and Hospitals
460000
466000
472000
478000
484000
490000
1002000
996000
990000
984000
978000
N
0
2
4
8
12
Km
Hospitals
fire_stations
AddisAbaba

Top sheets of Addis Ababa